Mindful Navigation: Design Consideration of Mixed-Reality Based Indoor Navigation Assistance System

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May 6, 2010

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Executive Summary

This proposal is primarily motivated by the observation that people can easily become mindless in their decision-making and become disengaged from their surroundings when their actions depend on information and guidance from an assistive technology. Researchers have shown how automated navigation assistance systems lead users to be disengaged from the space through which they are traveling, resulting in poor recollection of the environment and poorer situational decision-making. This disengagement and mindlessness can potentially increase the risk of accidents and lower the quality of user experience. Our hypothesis is that if we become mindfully attentive to the environment and surroundings while carrying out navigation tasks, we will have better memory of the space, improved cognitive reconstruction of environment, and better understanding of the immediate situation, all of which might lead to better decision making and more effective navigation.

In this proposal, I will present a new approach to analyzing the problem of navigation assistance, which considers both the physical and psychological constraints of users focused on navigation. I will address the physical constraint that eyes should remain "on the road" by providing new visual interface that offers a mixed reality presentation of guidance information. We will address the psychological constraint that minds should remain engaged with the environment by applying framework of mindfulness/mindlessness theory (Langer 1989) in the design of the system. The theory explains how mindsets affect engagement levels and decision-making in daily activities.

The proposed research will have contributions in developing novel navigation assistant systems (Guiding Light) for pedestrians utilizing mini-projectors to support a mixed-reality way of providing navigation guidance and help us understanding how this mixed-reality way can affect our engagement level in surrounding environment. In the process of developing the system will lead us to explore new interfaces and information design ideas considering people's mindset by applying the theory of mindlessness and mindfulness. The theory explains how our mindset can affect information processing in our mind as well as handling new stimulus coming into our sensory system, which provides ideas about how we might apply this theory in designing user interfaces. Our additional technical contribution is in developing a new hybrid in-door positioning system that will increase the accuracy of 802.11 RSSI fingerprint method by adding magnetic field fingerprints to enhance the precision of detecting location.

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1. Introduction

Navigation assistant systems are widely employed[1,2], and the question of how these systems affect our understanding of our environments or the quality of our navigational judgment (Blanc et. al. 2006) has become increasingly relevant. Researchers have shown how navigation systems lead users to be disengaged from the space through which they are traveling (Lorimer & Lund 2003, Burnett & Lee 2005, Leshed et. al. 2008), resulting in poor recollection of the environment and poorer situational decision-making. A series of experiments conducted at NASA evaluating aviation assistant systems (Skitka et. al. 2000) showed that aviators made more decision-making errors when they were using assistant systems because of inadequate sensory engagement. This also resulted in poorer abilities to recover in unexpected situations. This research confirms anecdotal evidence from news stories that blame GPS systems for a variety of accidents:[3]

Driver Blames GPS For Driving On Railroad Tracks, Getting Hit By Train (The New York Times, February 2008)

"If he was paying attention to the road it might not have happened," said Assistant Dep. Chief Steve Conner of the Metropolitan Transportation Authority Policet might not have happened," said Assistant Dep. Chief Steve Conner of the Mepoorer abilities to recover in unexpected situations. This research confirms f experiment conducted at NASA S told him to take an immediate right, so he did, turning his car onto the railroad tracks, instead of staying on the road.

Bus driver says he was using GPS before crash (The Seattle Times, April 2008)

A charter-bus driver who crashed into a low pedestrian bridge in the Washington Park Arboretum on Wednesday, sending more than 20 members of the Garfield High School softball team to the hospital, said he was following a GPS system and did not see signs warning of the bridge's heighteriment conducted at NASA e was following a GPS system and did not see signs or flashing yellow lights indicating the low bridge height. He did not show any sign of alcohol or drug use and was not asked to take a sobriety test, police said.

Sat-nav dunks dozy drivers in deep water (Times online Aprile 2006)

Since a road closure, dozens of drivers have blithely followed directions from their satellite navigation systems, not realizing that the recommended route goes through the forde said. bridge's heighteriment conducted at NASA illor who lives by the ford, said: who lives by the ford, sf drivers have blithely followed directions from their satellite navigation systems, not realizing th

Disengagement inhibits people's decision-making processes and decreases their ability to construct cognitive maps (Burnett & Lee 2005). This appears to be true for

[1] "Just under 2.5 million (GPS car navigation assistant) devices shipped in Q2 2006, beating the previous quarterly record of 2.3 million." http://blogs.zdnet.com/ITFacts/?p=11523

[2] "Sales of GPS-enabled GSM/WCDMA handsets grew to an estimated 150 million units in 2009, up from 78 million devices in 2008 … GPS-enabled handsets sales are estimated to reach about 960 million, or 60 percent of total handset shipments in 2014."
http://www.reportlinker.com/p0183439/GPS-and-Mobile-Handsets-4th-Edition.html

[3] "Whom Do You Believe, G.P.S. or Your Own Eyes?" (NY Times Feb 2008) "Bus driver says he was using GPS before crash" (The Seattle Times, April 2008), "SatNav danger revealed: Navigation device blamed for causing 300,000 crashes." (The Mirror, July 2008), "Drivers on edge over cliff route" (BBC News, April 2006), "Sat-nav dunks dozy drivers in deep water" (Times online Aprile 2006), "Driver Blames GPS For Driving On Railroad Tracks, Getting Hit By Train" (The New York Times, February 2008).

both vehicle and pedestrian navigation. Our own preliminary pilot study shows that when pedestrians are guided in a manner similar to that provided by in-car GPS systems, the pedestrians have greater difficulty recalling the paths through which they have walked. When subjects were asked to navigate previously traveled routes they failed to correctly recall the route (this experiment will be described in more detail in a later section). We have also observed divisions in visual attention our subjects often focused on their handheld navigation systems while conducting tasks rather than devoting attention to the surrounding environment. This resulted in one of our subjects almost getting hit by a passing vehicle during the study. Similar observations were reported in other research of handheld navigation systems. (Aslan et. al 2006)

To explore these problems, I propose building an navigation assistance system that helps people to be better engaged in their environment and task domain. In particular, I propose to focus on indoor navigation, an area which is increasingly necessary as the size and complexity of buildings increases, as in modern hospitals, airports and shopping malls. The indoor environment is a particularly rich domain for developing detailed evaluation because there are better opportunities for controlled testing of different approaches to navigational assistance.

We are primarily motivated by the observation that people can easily become mindless in their decision-making and become disengaged from their surroundings when their actions depend on information and guidance from an assistive technology. This disengagement and mindlessness can potentially increase the risk of accidents and lower the quality of user experience. Our hypothesis is that if we become mindfully attentive to the environment and surroundings while carrying out navigation tasks, we will have better memory of the space, improved cognitive reconstruction of environment, and better understanding of the immediate situation, all of which might lead to better decision making and more effective navigation. Our designs will focus on tools that help users to engage with the space through which they are traveling.

In this proposal, I will present a new approach to analyzing the problem of navigation assistance, which considers both the physical and psychological constraints of users focused on navigation. I will address the physical constraint that eyes should remain "on the road" by providing new visual interface that offers a mixed reality presentation of guidance information. We will address the psychological constraint that minds should remain engaged with the environment by applying the framework of mindfulness/mindlessness theory (Langer 1989) in the design of the system. The theory explains how mindsets affect engagement levels and decision-making in daily activities.

Our proposed system consists of two parts: a novel infrastructure for indoor-positioning and a novel handheld interface for navigation assistance. The proposed indoor-positioning system is a hybrid system combining the 802.11 relative signal strength indicators (RSSI) fingerprint positioning technique (Liu, Darabi, Banerjee, and Liu 2007) with building-specific magnetic field fingerprints to provide highly accurate and low-cost real-time positioning. This will require the development of a new sensor for measuring magnetic fields and detecting position, which will be installed in a handheld device.

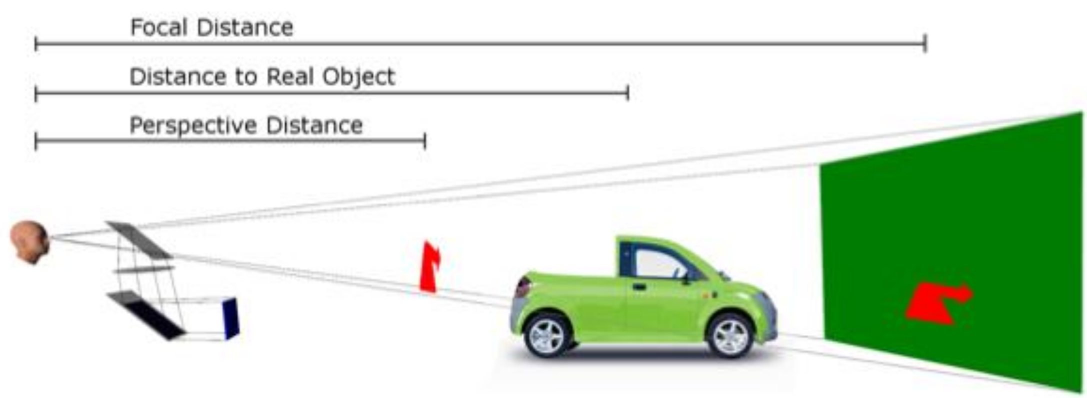
The proposed novel handheld interface ("Guiding Light") uses a mini projector embedded in the device to project navigational information on the world. It uses the previously described array of sensors to detect its location within a building as well as the movement and orientation of the handheld device. This allows us to present different information when the projector is held at different angles or distances from the projected surface. The core metaphor involved in this interface is that of a flashlight, which reveals objects and information about the space it illuminates. This interface enables users to retrieve relevant spatial information by pointing the device at the particular spaces the users are interested in – for example, directly on the path on which the users are walking.

The following sections will analyze the problems of current navigational assistance systems in order to provide background and rationale for of our design strategy. Then, we will provide detailed description of the proposed indoor location system and handheld interface in the Proposed system section. Finally, we will state our hypotheses and describe our evaluation methodology.

2. Background

2.1. Physical design constraints, attention division, and distraction

Efforts to reduce distractions to our visual and cognitive attention have led to a variety of solutions around alternative representational modalities such as audio and tactile interfaces. David and Schmandt's "Voice assisted automobile system" (David & Schmandt 1989) was one of the first systems that assisted users real-time while traveling. It was designed to let drivers maintain visual and cognitive attention on the street by providing automatic directions audibly. Today, widely used in-car GPS navigation systems employ this voice guiding strategy along with a screen-based maps that are automatically updated with users' location. This combination is designed to reduce secondary work and cognitive loads while driving. (Carsten et al. 2001) However, drivers still need to translate auditory information into visual cues, which could cause an additional cognitive burden. Complex instructions might be better represented using simple visual cues, eliminating the need for this translation. Recently, Kim and Dey (2009) explored using augmented-reality (AR) systems to provide visual cues directly on the windshield. This approach can be problematic due to focal mismatching between the AR display and real-world object that could introduce visual confusion (Tonnis, Plavsić & Klinker, 2009).



A number of attempts have been made to develop real-time navigation assistant systems for pedestrians. In contrast to in-car navigation systems that are installed in vehicles, pedestrians must carry the system while moving. The dashboard in a vehicle makes a nice place for the system to be mounted, but researchers have faced significantly more difficulty in designing interfaces for pedestrians. The most technically sophisticated systems use head mounted display (HMD) employing augmented-reality (Steven Feiner et al 1997). This provides a nice way to display directional information while the user's eyes are on the path, but it creates additional problems by obstructing field our vision (Jansen et al. 2008; Hassan et al. 2007), creating difficulties in focus shifting (Willemsen, Colton, Creem-regehr, and Thompson, 2009) and burdening users with a cumbersome HMD. Alternative modalities using audio (Holland et. al 2002, Turunen et. al 2007) and tactile interfaces (Erp et al. 2005, Jones & Sarter 2007) allow our eyes to focus on the street, but provide the burden of translating auditory and tactile information into visual representations. Erp developed a system to indicate direction tactilely by vibrating one of several actuators arranged around our neck or waist in a particular direction. However, we still need awareness of the layout of the surroundings and identify the right pathway in order to translate this into action. This awareness requires additional effort using our other senses, i.e. vision, to acquire this preliminary knowledge. A simple directional indicator may be

insufficient for navigation tasks in complex pathway layouts, especially indoors.

The most popular way to provide directions for pedestrians is currently to display maps on handheld devices such as PDAs and smart phones. Phone-sized handheld devices provide convenience without the burden of having to constantly wear a device such as a HMD or actuator belt. Although maps or AR on the small screen could provide a just-in-time reference for guidance, the nature of this task – holding up a handheld device to see the small screen (Gartner & Hiller 2007) – could divide our visual and cognitive attention (Bungum & Henry 2005). This makes it difficult for a moving user to use it as real-time assistant system.

We propose to address the problem of attention division by providing information directly on the surface of the path using small projectors on handheld devices. We hypothesize that *a personal navigation system that projects guidance directly on the path surface can reduce visual and cognitive attention division.* We are proposing a system to enhance our understanding of navigation behavior and cognitive processes, and to identify any limitations of our approach that might direct us toward better interface designs.

Previous work in the area of augmented reality using handheld projectors was explored by Raskar (Raskar et al. 2003). This work introduced the concept of AR on objects, which reveals information on the surface of the object by augmenting it with information through projection. It focused on engineering aspects such as how an enhanced projector can determine and respond to the geometry of the display surface, and can be used in an ad-hoc cluster to create a self-configuring display. More recent work known as Sixth-Sense (Mistry & Pattie 2009) also utilizes wearable mini projectors on chests to provide information augmented on the surfaces of held objects (or a wall in the front). Sixth-Sense adds a hand gesture interface to provide rich interaction with the investigated everyday objects and the information augmented. Our proposed work adds the aspect of how the augmented information can leverage the engagement and attention level of users when information is projected directly in the task domain.

2.2 Overreliance and automation bias resulting from mindlessness

"Even when information is being fed back to them (Nav-assit users), such as road signs that suggest they're on the wrong route, they won't believe it." (By Tanith Carey, The Mirror 2008)

Automated procedural and decision aids may in some cases have the paradoxical effect of increasing errors rather than eliminating them. Results of research investigating the use of automated systems have indicated the presence *automation bias,* a term describing errors made when decision makers rely on automated cues as a heuristic replacement for vigilant information seeking and processing (Mosier & Skitka, 1999). Although psychological effects of automated navigation guidance systems such as overreliance and automation bias have not been widely applied in the design of the systems, we believe that using these results to inform designs will reduce poor decision-making and disengagement.

When a specific instruction is given by a trusted authority, most people become submissive and instinctively obey only instruction without thinking. (Langer 1989) This results in an effect called "overreliance", in which users become dependent on a potentially faulty authority for instruction. ("Automation and human performance", Moiser and Skitka 1996) Instead of paying attention to the task environment to autonomously solve problems, people selectively choose or ignore stimulus that falls outside the given instructions.

Skitka et. al (1999) conducted an experiment at NASA to learn how an automated guidance system affects the user's performance and errors. The experiment was to measure the performance by asking the subjects to navigate paths in appropriate speed and altitude that were given in the flight manual prior to the aviation task. Deviations from the paths, speed and altitude were considered to measure the flying performances of the subjects. The result shows that when the correct respond rate (speed and altitude adjustments on a path) was higher among those who used the automated assistance (83%) as compared to volunteers relying solely on instruments (72%). On the other hand, despite the presence of a 100% reliable alternative (gauges), much higher error rates were observed when some of the prompts were not presented. Computer-aided subjects showed a respond rate of 59%, while the response rate among volunteers relying solely on instruments was 97%. The later study of Burdick et al (1999) applied a psychological treatment to address the problem, and showed that subjects who perceived themselves as accountable were significantly less likely to fall victim to automation bias in a simulated cockpit environment. This result suggests that performance can be improved and errors reduced by changing the operator's mindset. Making users believe that they are more accountable, however, could burden them with responsibility, causing them to avoid using the system.

We propose a different approach by applying Ellen Langer's (1989) theory of mindlessness and mindfulness. Her theory suggests that overreliance and automation can be framed as symptoms of *mindlessness*. Langer suggests that whether people engage in tasks mindfully or mindlessly affects their cognitive performance, decision-making, health, creativity and learning, and level of engagement.

The characteristics of mindlessness are: automatic behavior, attention to structure rather than conscious attention to content (Langer, Blank, Chanowitz 1978), and acting from a single perspective. The roots of the mindlessness are repetition, over-learning (Langer, Weinnman 1981), and premature cognitive commitment (Chanowitz, Langer 1981).

Mindlessness can be seen in a variety of different processes. For instance, we might selectively pick cues that fit our preexisting thought process from incoming stimuli, and filter or ignore others when making decisions, resulting in poorer decision making. Mindlessness can be the result of excessive repetition, which causes a rigid relationship between signal and response.

Mindlessness can be avoided by actively noticing differences in an impression or a piece of information, creating opportunities for decision-making, and actively participating in decision-making, all of which increase one's engagement and awareness of context they are in. Mindfulness is characterized by flexibility in handling information, which positively affects our decision-making, response time in changed context, memory, and creativity (Langer & Moldoveanu, 2000).

2.2.1 Preliminary pilot study applying theory in navigation guidance

One way to avoid mindlessness is to create opportunity for decision-making. We applied this principle in the design of an experiment to see if artificially created opportunities for decision making would result in navigational behavior that engaged people in the environment. As a preliminary study, we tested this with two groups in two different conditions: a Mindless Walking Condition, and a Mindful Walking Condition.

Our hypothesis was that giving navigators more freedom of choice would make them more mindful, and telling people exactly where to go at every turn would make them more mindless. If they had become more mindful, our expectations were that subjects would develop a better sense of direction within the space that they had navigated, and would remember more details and would feel more positive about the space through which they had navigated.

2.2.2. Experiment setup

Participants take a tour of MIT Stata Center which is notorious for its confusing interior. The structure of the building is unconventional and highly asymmetrical. Because it is hard to navigate intuitively in the building, if one pays less attention to the surroundings, one can easily get lost. Participants walked to 6 different locations on different levels in the Stata Center.

"Mindless Walking" condition: Participants were introduced to basic navigational commands. For example: "Turn left up the stairs"; "Continue straight"; "Take right/left path". Also, before walking to each new destination, the guide pointed as accurately as possible in the direction of the destination (regardless of walls/ceilings that are in the way). Further, the guide pointed out that there is an alternate route to get to the destination ("you could also walk through the second floor instead of the first floor")

"Mindful Walking" condition: Participants were given general directions via pointing (similar to the previous condition). Then, they were given two options for routes when arriving at each target location and asked to choose one of the two routes. Because the subjects may select different routes from previous group, we constructed the mindless group's route to match the mindful group's route.

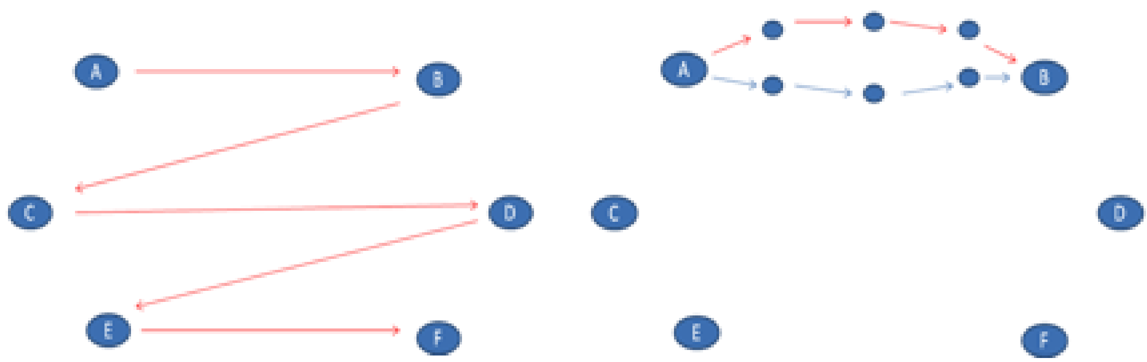


Figure 1. Experiment's tour plan in graphics. Each letter indicates the next target location. The distance between consecutive target locations is approximately 50 meters.

Task: We asked subjects to walk to three of the destinations they had previously visited, but in a new sequence. For example, if the six destinations are called A,B,C,D,E and F, we had them walk from A to E, then from E to C, then from C to F. The test was in the same pattern for all subjects i.e., every subject walked from A to E, then E to C, then from C to F. They were told; "You have 3 minutes to walk from [A to E]. If you cannot find [E] within 3 minutes, you can either keep trying, or we will direct you to [E]. After 5 minutes, we will direct you to [E] regardless of whether you have given up yet. Do you understand?"

We measured; 1) Whether the subject successfully found each destination; 2) How long it took the subject to find each destination; 3) Whether the subjects give up; 4) Which paths the subject chose.

The result: Our preliminary result shows that, on an average, the mindful walking group finished all their tasks successfully, while the mindless walking group only achieved 1.3 tasks successfully. The average time for the mindful group's completion per task was 2 minutes and the mindless group's was 3.5+ minutes.

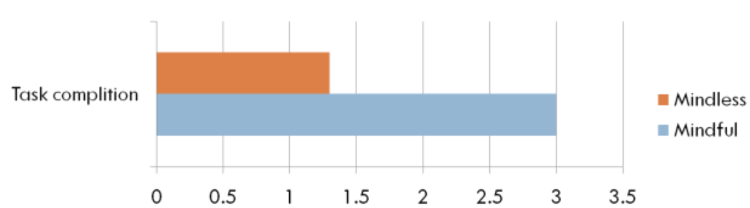


Figure 2. The graph indicates the performance between the two groups. The length is the average task successful completion.

We also had an interesting observation: Subjects in the mindful group were curious about the surroundings, and asked more questions frequently about the environment to the guide. The members of the mindless group were more focused on the directions that the guide was providing. In the task phase, subjects reacted more sensitively to the landmarks and shapes of the surroundings, trying to find new paths to the target location. However, the Mindless group followed the route that was provided by the guide. This resulted in the subjects requiring significant detours, and when lost, they gave up finding the target place easily.

2.2.3 Implication of illusion of control effects in design of navigation assistant systems.

From the experiment, we can derive some ideas for user interface design. The major difference between the groups is the provision for decision-making. However, the other conditions, i.e. travel time in the tour phase, and exposure to the space – were identical, and we believe that the experience of the journey was not so different between groups. Also, the effects of decision-making on the task of selecting a route (in this case, the tour with the guide) were insignificant. In other words, the choice that was given is a variable that is insignificant to the result (the choice do not greatly impact on the qualities, lengths and efforts to travel) – which has similar effects to the users having an illusion of control. (Langer 1983) Although, some opportunities for decision-making in insignificant variables are provided in the context of conducting the task, people are likely to be engaged in and become mindful in the process. As a result, it changes the mindset of the user: we can call this **Perceived control in User Interface**.

Although there are limitations to how directly this experiment can be applied to all navigation systems, one plausible implementation scenario is the following: When the user of a “mindfully designed” navigation assistant system enters his destination, the system computes a piecewise overall route plan and considers the distance between each segment. The segments are calculated in order to find enough time for interaction with the user. For example, before entering the next segment, the system provides opportunity for the users to make choices, altering routes explicitly.

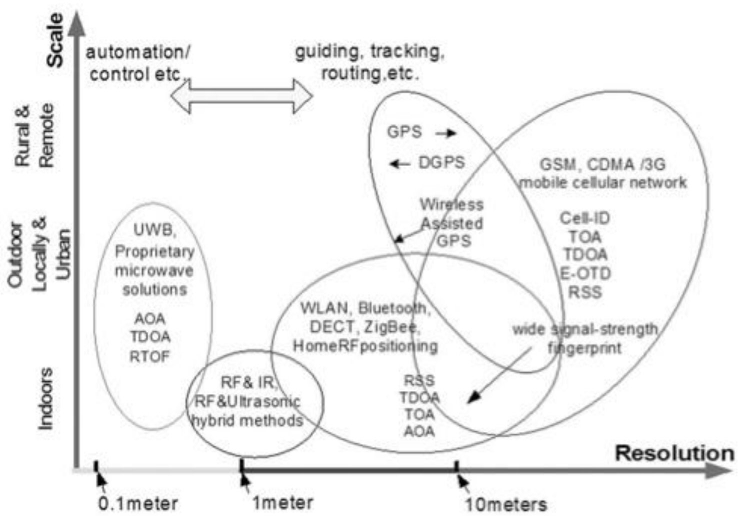
We can predict that the user experience of “mindful navigation” will be somewhat similar to that observed in the experiment: a change of mindset (less mindless than users of conventional car navigation systems). In addition, as the user becomes more mindful, we may expect faster response times (especially in changed context), better strategies for dealing with problems, higher engagement in the process, greater satisfaction in decision-making, and positive feelings toward the assistant system.

3. Proposed System:
Indoor real-time navigation assistant system for pedestrians

Indoor navigation provides a controlled environment for testing the design of a navigation system, independent of constraints like weather. The position of landmarks and complexity of routes can be easily controlled in indoor navigational experiments. Working indoors also gives us control of lighting conditions which is important because of the low brightness of current generation of hand-held projectors. In addition to the advantages provided by a controlled environment, indoor navigation assistance system is desirable on its own as the internal structure of buildings becomes larger and more complex and traditional positioning systems like GPS are usually unavailable.

3.1 Positioning System

Although positioning systems have been explored in robotics for real-time indoor navigation systems (Souza and Kak 2002, Thrun 2002), some technical issues remain to be addressed such as: i) orientation tracking ii) higher positioning precision iii) faster location detection and iv) personal portability.



3.1.1 IR beacon based positioning

Our previous method for utilizing Infra-red (IR) beacons provides decent accuracy as well as a good method for satisfying the four previously mentioned requirements, as well as quick deployment, (Long, Kooper & Abowd 1996) in small-scale area. However, some difficulties remain, such as the need for line of sight between transmitter and receiver, high cost and effort required to provide infrastructure for installing beacons (we estimate beacons to be installed in every square meter for real-time navigation system), and the need for a continuous power supply to the beacons.

3.1.2 802.11 RSSI based triangulation & fingerprint based positioning

A popular method for indoor positioning systems uses the Relative Signal Strength Indication (RSSI) from the 802.11 specification (Liu, Darabi, Banerjee, and Liu 2007). Wireless network access points (AP) are becoming ubiquitous and many phones are now equipped with WiFi. Theoretically, it would be necessary to have three APs in a building to provide detection of location (within a single floor), but the accuracy of positioning is not good enough (3-5 meters accuracy (Liu, Darabi, Banerjee, and Liu 2007)) to provide real-time tracking system due to low density of APs[4].

3.1.3 Proposed magnetic field aided positioning system

We propose to use the Earth's magnetic field to aid in positioning detection. Our initial study utilizing the magnetic field provides new ideas for how the field can be used to detect location. Building structures and interiors in indoor environments distort magnetic fields, shifting magnetic field readings by more than 45 degrees in some cases. We measured the distortions in MIT's building E15 and MIT's Dewey Library, in 7 different corridors, and found that the distortions create unique signatures in different locations. We have collected 100 feature vectors (deviation of angles from true direction for every 3.6 degrees around a 5 cm circumference) every 1.4 square meters, 80cm from the ground, to access the distortion. The sets of feature vectors are unique across the locations. In addition, our limited initial investigation on the variability of the field to check if the field changes over time or is affected by use of electronics indicated that the fields remained stable over time.

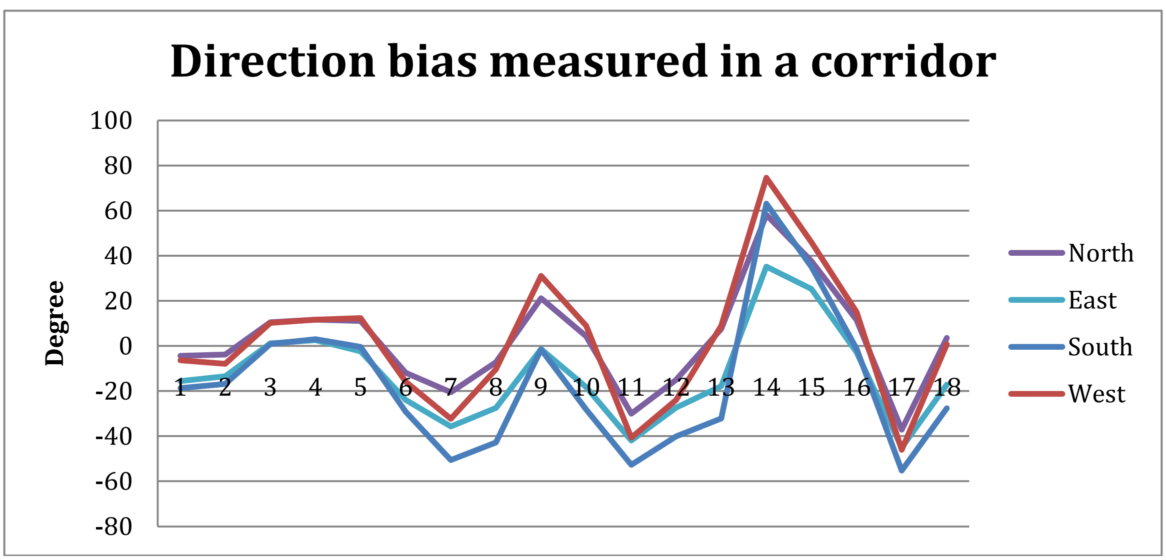


Figure 3. Direction biases caused by magnetic field distortion. The graph shows the direction bias measured on a corridor of 74 feet length. Each number of x axes indicates 4 feet, and y axes indicates the degrees of deviation from true north, east, west and south.

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[4] The primary use of AP is to provide network in the area, so it is not cost efficient to deploy more APs when the coverage wireless network is adequate.

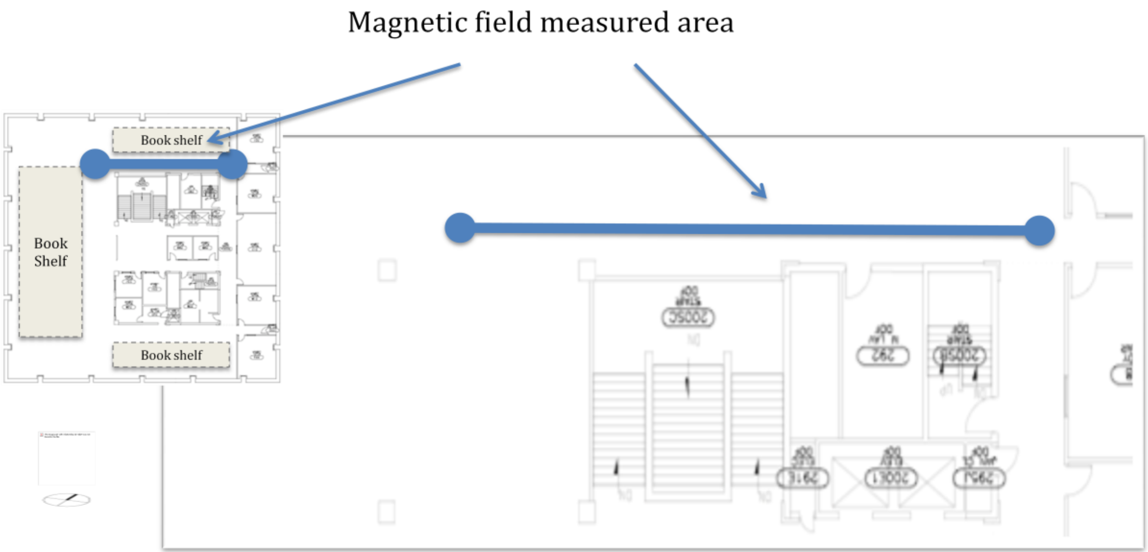

Figure 4. Map of magnetic field measured area. This map shows a part of Dewey Library on the second floor. The length of the corridor measured is 74 feet.

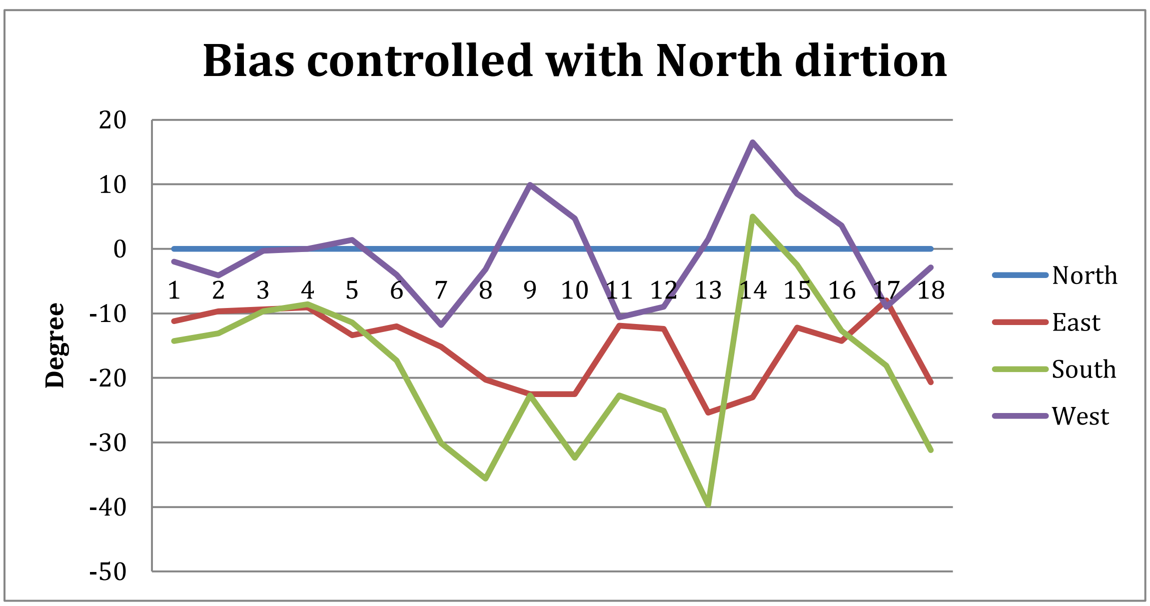

Figure 5. Direction bias controlled with north direction. The graph shows the proportion ratio difference between north direction and other three directions (east, south, and west).

3.1.4 Proposed hybrid system (Wi-Fi + Magnetic field fingerprint + Vision)

We believe that if we use 802.11 RSSI fingerprint technology to localize the target area with 8 meters accuracy, the accuracy of location can be further improved by adding the magnetic fingerprint map. As a method for mapping fingerprints of 802.11 RSSI is similar to measuring magnetic fields, the process of measuring both can be done in parallel with ease. This hybrid positioning system would use environmental constraints to its advantage; while RF based positioning functions better in wide-open areas, magnetic field based detection functions better in spaces where in-door interior structure is complex.

We will expand our hybrid system with vision-based localization as this area is actively being explored. Our use of vision will be dedicated to detecting figures on walls that provide both location and information of the investigated objects. Vision is expensive in terms of computation and storage, but it could provide positioning accuracy of a few centimeters.

Positioning System	i) Direction	ii) Accuracy of positioning	iii) Computation & Latency	iv) Portability & Infrastructure
IR beacons based	Fair (require more infra structure)	Great (1-2 meters)	Great	Poor
802.11 RF based	Poor (no direction provided)	Fair (3-5 meters)	Fair	Good
Magnetic based	Good (compass)	Good (2 meters)	Good	Good
Vision	Fair (Large corpus of image features required)	Great (less than meter)	Poor	Poor

3.1.5 Summary
Our goal of developing a positioning system is to address the four requirements (i,ii,iii,iv) for real-time navigation assistant systems. In order to achieve this goal, we require additional investigation into using magnetic fields for a robust, high quality and low cost positioning system. Therefore, we will investigate system performance in different types of location such as corridors, stairs, intersections of corridors, and atria to find the cost of mapping and positioning in terms of time and effort, accuracy, sensitivity of the influence of noise (weather, surrounding materials), number of APs, layout of APs and building structure, resolution, latency and ease of use.

3.2 Guiding Light: navigation assistant system
We propose a handheld pedestrian navigation assistant system, "Guiding Light" that utilizes a handheld projector to present way-finding information directly on the environment. We intend to test the system using indoor spaces, providing users with directions to different indoor locations.

3.2.1 Initial prototype of Guiding Light
Our initial development of Guiding Light provides some ideas for how devices can be used for navigation tasks. The space around a traveler becomes an open canvas for projections. Since we cannot predict where a user will start to project information on a space, designers of the system should consider all possibilities of what information should be projected according to the projection area. The system must also consider the user's point of interest, such as, whether he or she is projecting on an object, i.e. a map on a wall to get augmented information, or projecting on an empty space to get directional information. In addition, the

designer of the system should decide when to automatically turn projection off so that the system temporarily stops projecting meaningless or unnecessary information on the space. These constraints and designs can be differently applied in different contexts, such as office-buildings, shopping malls, and libraries.

3.2.2 System design considerations

From insights derived from our initial prototype, we suggest core design considerations that need to be taken into account for different spaces when designing a system based on handheld projectors: i) projection direction from user, ii) projection distance from user, iii) projection area such as floor, walls on left, right, front, and back, iv) projection target – point of interest vs. path. As the design of the system will be based on the floor plan, in order for the system to draw a layout of the space surrounding a user (based on location and direction of the projector), it will be necessary to develop a geographic information system (GIS) for indoor environments. This would provide path information with respect to orientation and location, as well as information about the surrounding environment.

i) ***Projected direction from user***: Projected direction is the most important fundamental contextual information to decide how the guiding information should be presented in order to guide the user to move in the right direction. A designer needs to consider a strategy for displaying different types of information. Electronic compasses can be used to detect the direction.

ii) ***Projection distance from user***: Our observed normal projection area from the user was approximately 1.7 meters. When a user approaches towards the end of a straight path (or an intersection), users may want to project further ahead to investigate anticipated future directions. Therefore, we must consider strategies for how and what information should be presented depending on projected distance. Detecting the projecting distance requires both proximity and tilt sensors not only to measure the distance of projected area, but also to discriminate projection surfaces, wall vs. floor. Tilt sensors are used to support the proximity sensors by measuring the projection angle from the user' hand.

iii) ***Projection area***: Indoor spaces consist of basic elements such as floors, walls, ceiling, doors (entrances) and stairs, which form the function of the space we are in. In our initial prototype of Guiding Light, guiding information was primarily displayed on the floor, and supplementary information such as a map is displayed on the walls. To expand the navigation directions to cover the entire building structure, designers must consider different types of projection areas. For example, what information should be provided for an entrance that would contrast it with guiding information on corridor floors? How could we use ceilings for navigation (navigation based on star constellations)? What information on office doors could be useful for visitors?

iv) ***Projection target*** – point of interest vs. path (local vs. global): As projection can be placed on any type of surface. The targeted area can be a surface which is part of the navigation space, or an object, i.e. map or poster stands, which can be interesting pieces of information on the path. Although the guiding information projected on surrounding surfaces should be designed for coherently pointing to the destination, augmented information on an object can be independent from path information. Therefore, it is important for the system to discriminate between global and local information spaces. This problem is challenging because the system may need to read the intention of the user. Our initial proposed approach is to provide visual tags to inform both the human and the system to indicate the availability of local information.

3.2.3 Other technical considerations

The current system is implemented with a handheld mini projector retrofitted with sensors (proximity sensor, IR camera, 3D e-compass, 3D accelerometer, tilt and gyro sensors) that support position and orientation of the device as shown in the Figure 3.2.3. As we use computer vision for both positioning and recognizing visual tags and images, substantial computation power is required, which exceeds the capability of the fastest mobile phone (Google s Nexus One phone running on Qualcomm QSD 8250 1 GHz, 2010). Therefore, we will consider using ultra mobile pc's (UMPC over 1.33 GHz, with GPU built in) to handle vision processing. As the scope of this thesis does not include developing new technology for computer vision, we will modify and utilize OpenCV and existing algorithms for handling vision processes.

3.3 Mindset consideration in design of navigation strategies and guiding information

As discussed in the previous chapter, we will apply mindfulness theory in navigation guidance design to reduce the automation bias and overreliance such that users can be more engaged in the process of navigation. We will consider two design ideas, ***perceived control*** and ***less constrained instructions (or reduced specificity)***, implemented in the navigational guidance information design. Perceived control will be applied to the navigation system to allow users to actively choose different paths in the course of navigation (as explained in the previous section). Less constrained instruction will be applied by avoiding specific instructions, for instance, by changing visual guidance of arrow to dashed lines or a string of dots such that it does not imply direction as strongly. The principal goals in the two design ideas are reducing feelings of following a hard instruction and increasing users' sense of intervention in the process of path selection and navigation. Although these design considerations may be simple, we expect to have greater impact on users as we presented our results from the previous section. As we continue developing the system, we will refine the design to provide guidance based on the theory of mindfulness.

3.4 Summary

Our proposed system consists of three components support in-door navigation assistant systems: the positioning system, the handheld device that provides user interface, and the GIS system for indoor spaces. We propose a novel hybrid positioning system aided by magnetic field, 802.11 RSSI fingerprint, and computer vision. We also propose a novel interface for navigation assistant systems that allows users to interact more with the environment. Our proposed system will serve as platform for evaluating our hypothesis that providing navigation assistant systems through which the system users could be more engaged in the space they are navigating improves performance.

4. Research Method

Our motivation of this research comes from the observation that people can easily become mindless in decision-making and become disengaged from their surroundings in situations where people's actions for achieving goals depend on information and guidance from an assistive technology, especially in navigational tasks. This disengagement and mindlessness can potentially increase the risk of accidents and lower the quality of user experience.

We posed the problem into two frames: a) physical constraints of the user interface in navigation which creates division of visual and cognitive attention, and b) psychological effects of automation bias and overreliance resulting from mindlessness. To address the problems, we proposed to develop Guiding Light as our platform to test if engagement level of the system users increases when we consider i) projecting guiding information directly on the surface of navigating spaces, and ii) applying mindfulness / mindlessness theory to the design of the navigation system.

The primary question of this research is "How does the new design of the system affect a user's engagement level in the task domain of navigation?" This question can be divided into sub-questions to measure different aspects of engagement.

- Would people pay more attention to surrounding spaces while navigating?

- Would people develop a better sense of direction within the space that they have navigated?
- Would people remember more details?
  - How would this knowledge affect decision-making?
- Would people feel more positively about the space through which they had navigated?

We are also interested in usability questions:

- How easy is it for users to accomplish basic tasks the first time they encounter the design?
- Once users have learned the design, how quickly can they perform tasks?
- When users return to the design after a period of not using it, how easily can they re-establish proficiency?
- How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
- How pleasant is it to use the design?

In order to answer the questions, we will evaluate the system by comparing two (physical and psychological) design conditions with conventional pedestrian navigation assistant systems using map and picture of landmark on a small screen handheld device, which will provide 2x2 matrix of condition comparison groups.

	Screen display based navigation system	Projection and AR based Guiding Light
Information Design based on the theory of Mindfulness		
Information Design based on conventional way-finding system		

Subject recruitment will be carefully considered to provide equal distribution of gender, age as well as occupation as these factors can influence the result. People with vision disabilities will not be considered since our system design is insufficient for supporting people with visual impairment. In addition, subjects who are not familiar with the interior of building E14 and E15 will be considered, as the experiment will be conducted in these buildings.

We will have a number of subjects using the system in each condition going through two task setting phases, navigation task with the device and navigation task without the device. Before getting into the first phase, independent measures will be recorded such as Sense of Direction Scale (Pazzaglia & Debeni, 2000) to assess self-rated sense of direction, and general questions related to their occupation and lifestyle to learn about their prior experience and skills in in-door and out-door navigation followed by basic training of how to use the device.

Phase one is designed to measure usability of the device by asking subjects to use the device to find a number of designated destinations. To reduce the unpleasantness and burden of being in an experiment, we will pose the first phase as a tour in the Media Lab. Also hiding the purpose of the experiment will be an important factor not to induce subjects to intentionally memorize landmarks and details of environment that would affect the result of second phase.

Measurement: During this phase, several measurements will be conducted including: the number of successful completions of finding multiple destinations, time of travel, usage of device (direction, acceleration, and number of touches on buttons and screen of the device), head-orientation (to access the frequency of looking at the device vs. environment), number of errors (missed turns or wrong turns), confusions (number of stops made in order to re-orient themselves). At the completion of all the tasks in the first phase, a quick self-report survey will be conducted to access the usability and satisfaction of the device. In addition, we will ask the subjects to draw layouts of the paths in as much detail as possible to assess the knowledge they gain from the navigation.

Phase two is designed to assess subjects' engagement and disengagement level in the task domain of navigation. Our prediction is that subjects who are mindfully engaged in the process of navigation will have a better sense of directions and remember more details of the environment that will render them better in handling navigation tasks in an environment they have been through. Each subject will be asked to find one of the destinations where the subject has been before. Then, the subject will be asked to find a path to a number of different locations (the locations are the destinations introduced in the first phase), to which the direct path has not been introduced. The design of the task requires decision-making on path selection, flexibility in handling acquired information, and sense of direction. This design is a replication of our preliminary experiment conducted in the Stata Center at MIT.

Measurement: Our dependent measure will include the number of successful task completions, task completion time, coverage area (area the subject visited in the course of conducting the tasks), and the distance and path selection strategy between destinations (finding new path vs. tracing back from the path learned in phase one). In addition, similar measurements applied in the phase one, such as errors and confusion will be measured. As the subjects don't carry any type of assisting device for navigation, the subjects will be recorded in video to be used in the evaluation process. Following completion of all the tasks in phase one and phase two, selective questions of the NASA Task Load Index (TLX) will be used to measure mental demand, effort and frustration level to assess perceived workload (Hart & Staveland, 1988, Hart 2006)

4.1. Discussion

The suggested experiment only provides the basic framework to test our hypothesis. Although we believe that the skeleton of the experiment design will provide an understanding of the effects of the two different approaches of designing navigation systems, we may like to learn more about social implications of using handheld projectors in public spaces, privacy and interaction between multiple handheld users in co-located situation. Also, as part of the goal for developing novel interfaces for indoor navigation, we will provide a framework with guidelines for designing such systems as well as constraints and limitations.

5. Expected Contributions

Our work will have a clear contribution to developing novel navigational assistance systems for pedestrians utilizing mini-projectors and mixed-reality techniques. We will develop the idea of the system design by tackling problems of disengagement in both physical and psychological domains, which will lead us to explore new interfaces and information design ideas considering people's mindset by applying the theory of mindlessness and mindfulness. The theory explains how our mindset can affect information processing in our mind as well as handling new stimulus coming into our sensory system, which provides ideas about how we might apply this theory in designing user interfaces. We believe that the principles of design applied in our proposal can be extended to outdoor applications not only for pedestrians but also interface design for vehicle navigation assistance employing mixed reality technology and mindfulness theory.

An additional technical contribution is in developing a new hybrid in-door positioning system that could potentially increase the accuracy of 802.11 RSSI fingerprint method by adding magnetic field fingerprints to enhance the precision of detecting location.

6. Schedule

March – May 2010:
- Initial development of positioning system & Guiding Light

May – July 2010:
- Measuring magnetic field of E14 and E15

July – August 2010:
- Test the positioning system

August – October 2010:
- Full development of Guiding Light

October – December 2010:
- Design of experiment and conduct pilot study

December – February 2011:
- Conducting experiment

February – April 2011:
- Data analysis and Dissertation defense

April - May 2011:
- Writing thesis

May 2011:
- Submission of thesis

References

Blanco, M., Biever, W.J., Gallagher, J.P., & Dingus T.A. (2006). The impact of secondary task cognitive processing demand on driving performance. *Accident Analysis & Preven- tion*, 38(5).

Aporta, C., & Higgs, E. (2005). Satellite culture - global posi- tioning systems, Inuit wayfinding, and the need for a new ac- count of technology. *Current Anthropology*, 46(5).

Lorimer, H., & Lund, K. (2003) Performing facts: finding a way over Scotland's mountains. *The Soc. Review* 51(s2).

Burnett. G.E., & Lee, K. (2005). The effect of vehicle naviga- tion systems on the formation of cognitive maps. In *Traffic and Transport Psychology: Theory and Application*, Edited by G. Underwood.

Leshed, G., Velden,T., Rieger, O., Kot, B., Sengers, P. (2008) In-car gps navigation: engagement with and disengagement from the environment, In Proceeding of CHI2008

Pranav Mistry, Pattie Maes, Liyan Chang, "*WUW Wear Ur World Wearable Gestural Interface*", Ext. Abstract CHI2009 Boston, ACM Press (2009) 4111-4116

RASKAR, R., VAN BAAR, J., BEARDSLEY, P., WILLWACHER, T., RAO,S., AND FORLINES, C. 2003. *iLamps: Geometrically Aware and Self configuring Projector*s. ACM Trans. Graph. (SIGGRAPH) 22, 3, 809 818.

Skitka, L., Moseir, K (1999) Accountability and automation bias, International Journal of Human- Computer Studies archive Volume 52 , Issue 4 (April 2000)

Davis J.R. and C. Schmandt. utomation bias, International Journal of Hiving Instructions". *Vehicle Navigation and Information Systems*, 1989.

Carsten, O.M.J. *and* Nilsson, L. (2001) *Safety Assessment of Driver Assistance Systems.* European Journal of Transport and Infrastructure Research, 1 (3). pp. 225-243. ISSN 1567-7141

Burdick, MD, Skitka LJ, Mosier, KL (1996) The ameliorating effects of accountability on automation bias, Human Interaction with Complex Systems, 1996.

Crum, Langer (2007) Mind-Set *Matters: Exercise and the Placebo* Effect, Psychological Science, 2007 - Blackwell Synergy

Langer, E. (1989) Mindfulness Reading, MA: Addison-Wesley Co.

Langer, E. (1983) The psychology of chance. Journal for the theory of social behavior, 7, 185-207.

Langer, E. (1975) The illusion of control. Journal of Personality and Social Psychology.

Langer, E., Permuter, L., Chanowitz, B., and Rubin, R. (1988). Two new applications for mindlessness theory: aging and alcoholism. Journal of Aging Studies, 2, 289-299.

Langer, E. (1994). The illusion of calculated decisions. In R. Schank and E. Langer (eds.), Beliefs, Attitudes and Decision-making. Hillsdale, NJ: Erlbaum Press.

*Langer, E. J. and Brown, J. P. (*1995). Control from the actor. (ted decisions. In R. Schank and EBehavioral Science, 1992, 24

Langer, E. and Abelson, R (1974). A patient by any other name⋯: clinician group differences in labeling bias. Journal of Consulting and Clinical Psychology, 42, 4-9

Langer (1987) The prevention of Mindlessness

Skitka, L., Moseir, K (1999) Accountability and automation bias, International Journal of Human- Computer Studies archive Volume 52 , Issue 4 (April 2000)

Langer, E. J., & Moldoveanu, M. (2000). The construct of mindfulness. Journal of Social Issues, 56, 1–9.

Frank Steinicke∗, Gerd Bruder†, Klaus Hinrichs, Markus Lappe (2009) Judgment of Natural Perspective Projections in Head-Mounted Display Environments, VRST2009, November 18 – 20, 2009

JANSEN, S. E. M., TOET, A., AND DELLEMAN, N. J. 2008. Effects of horizontal field-of-view restriction on maneuvering performance through complex structured environments. Proceedings of the 5th symposium on Applied Perception in graphics and Visualization, 189–189.

HASSAN, S., HICKS, J., HAO, L., AND TURANO, K. 2007. What is the minimum field of view required for efficient navigation? Vision Research 47, 16, 2115–2123.

WILLEMSEN, P., COLTON, M. B., CREEM-REGEHR, S., AND THOMPSON, W. B. 2009. The effects of head-mounted display mechanical properties and field-of-view on distance judgments in virtual environments. ACM Transactions on Applied Percep- tion 2, 6.

Willemsen et al. 2009; Kuhl et al. 2006; Kuhl et al. 2008; Thompson et al. 2004; Knapp and Loomis 2004

P. Milgram and A. F. Kishino, Taxonomy of Mixed Reality Visual Displays IEICE Transactions on Information and Systems, E77-D(12), pp. 1321-1329, 1994.

R. Azuma, A Survey of Augmented Reality Presence: Teleoperators and Virtual Environments, pp. 355–385, August 1997

Chandler, P. & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. British Journal of Educational Psychology, 62: 233-246.

The influence of personal navigation devices on drivers' visual attention on the road ahead and driving performance by *Memarovic, Nemanja,* M.S., UNIVERSITY OF NEW HAMPSHIRE, 2009

J. Kim and A. K. Dey. Simulated augmented rality windshield display as a cognitive mapping aid for elder driver navigation. In CHI 2009, pages 133–142. ACM, Aprill 4-9 2009.

To¨nnis, M., Plavsˇic´, M., & Klinker, G. (2009). Survey and Classifi- cation of Head-Up Display Presentation Principles. In Proceed- ings of the International Ergonomics Association (IEA).

G.N. De Souza and A.C. Kak, Vision for mobile robot navigation: A survey, *IEEE Transactions* *on Pattern Analysis and Machine Intelligence.* 24 (2) (2002), pp. 237–267

S. Thrun. Robotic mapping: A survey. In G. Lakemeyer and B. Nebel, editors, *Exploring Artificial Intelligence in the New Millenium*. Morgan Kaufmann, 2002.

Long, Sue, Rob Kooper, Gregory D. Abowd and Christopher G. Atkeson (1996). Rapid prototyping of mobile context-aware applications: The Cyberguide case study. In the *Proceedings of the 2nd ACM International Conference on Mobile Computing and Networking (MobiCom '96)*, pp. 97-107, White Plains, NY, ACM. November 10-12, 1996

Liu, H., H. Darabi, P. Banerjee, and J. Liu, 10-12, 1996bile Computing and Networking (MobiCom '96)le context-aware applications: The Cyberguide case study. In— Part C: Applications and Reviews, Vol. 37, No. 6, November 2007.

Sandra G. Hart. NASA-Task Load Index (NASA-TLX); 20 Years Later. In 50th Annual Meeting of the Human Factors and Ergonomics Society, pages 904–908, October 2006.

Aslan I, Schwalm M, Baus J, Krüger A, Schwartz T (2006) Acquisition of spatial knowledge in location aware mobile pedestrian navigation systems. In: Proc. MobileHCI 2006, ACM Press, New York, pp. 105–108

Holland, S., Morse, D., Gedenryd, H. (2002). AudioGPS: Spatial Audio Navigation with a Minimal Attention Interface. Personal and Ubiquitous Computing, 6(4), 253-259.

Jones, M., Bradley, G., Jones, S., and Holmes, G., Navi- gation-by-Music for Pedestrians: an Initial Prototype and Evaluation. In Proceedings of the International Sympo- sium on Intelligent Environments 2006: 95-101, 2006.

Turunen, M. Hakulinen, J., and Kainulainen, A., Melto, A., and Hurtig, T. Design of a Rich Multimodal Interface for Mobile Spoken Route Guidance. Proceedings of Interspeech 2007 - Eurospeech: 2193--2196, 2007.

Van Erp, J.B.F., Van Veen, H.A.H.C., Jansen, C., and Dobbins, T., (2005) Waypoint navigation with a vibrotactile waist belt. ACM Transactions on Applied Perception (TAP), vol. 2, issue 2, pp: 106-117, 2005

K. Tsukada and M. Yasumura, "Activebelt: Belt-type wearable tactile display for directional navigation," in Lecture Notes in Computer Sci- ence. Springer-Verlag GmbH, Oct 2004, vol. 3205, pp. 384 – 399.

L. Jones and N. Sarter, "Tactile displays: Guidance for their design and application," Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. in press, 2007.

Bungum, T. J., Day, C., & Henry, L. J. (2005). The association of distraction and caution displayed by pedestrians at a lighted crosswalk. Journal of Community Health , 30, 269-279

G Gartner, W Hiller (2007) Impact of Restricted Display Size on Spatial Knowledge Acquisition in the Context of Pedestrian Navigation, Location Based Services and TeleCartography II Vol. 2, Chapter 10, Spriner 2007

APPENDIX:

Rating Scale and Definition

RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?