Smart Flashlight: Map Navigation Using a Bike-mounted Projector

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ABSTRACT
While mobile phones affect our behavior and tend to separate us from our physical environment, our environment could instead become a responsive part of the information domain. For navigation using a map while cycling in an urban environment, we studied two alternative solutions: smartphone display and projection on the road. This paper firstly demonstrates by proof-of-concept a GPS-based map navigation using a bike-mounted projector. Secondly, it implements a prototype using both a projector and a smartphone mounted on a bike, comparing them for use in a navigation system for nighttime cycling. Thirdly, it examines how visuo-spatial factors influence navigation. Our findings will be useful for designing navigation systems for bikes and even for cars, helping cyclists and drivers be more attentive to their environment while navigating, providing useful information while moving.

Author Keywords
Bike; GPS; Navigation; Smartphone; Pico-projector; Visuo-spatial; Field of View

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Most mobile device interfaces today use a "stop-to-interact" paradigm [4]. This enables design for general-purpose interaction but makes several assumptions about the mode of operation, such as using both hands and holding the display still. This poses a challenge when designing interfaces for interaction in motion. This paper examines the design and use of projectors and smartphones mounted on bicycles.

A common smartphone application is digital map-based navigation of urban settings. This task requires switching focus between the device and the terrain. Handheld devices thus impose limitations on our behavior and separate us from the physical environment, which could be part of the information domain if we could project onto it when and where needed,

Figure 1. Driving a bike equipped with the Smart Flashlight.

allowing the user to move without requiring stopping to look at a handheld screen.

Here, we study nighttime map navigation using GPS, as we compare a mounted smartphone's display versus a projection onto the road. We note that projectors are getting more powerful and accessible, potentially allowing for daytime use. The key contributions of this paper are:

(a) Demonstrating by proof-of-concept that navigation of an urban setting using a projected map is possible;

(b) Designing an experiment focused on subjective feedback that compares navigation while cycling between a map projected on the road with one displayed on a mounted smartphone;

(c) Discussing visuo-spatial factors that influence interface design for interaction in motion

RELATED WORK
Designing for interaction in motion is necessary since mobile devices are worn and used at almost all times. Instead of having the user stop to interact with the mobile device, the system design could be adapted to support perception of digital information while maintaining spatial awareness during motion. Some examples of activities that could make use of interaction in motion are walking, running, cycling, swimming, or driving a car [4]. A similar system to the one demonstrated here used a bike-mounted projector as an augmented headlight to display speedometer data[1]. Findings from exploratory bike trips using handlebar-mounted smartphones reported that map navigation is possible while cycling

[1] `http://youtu.be/Nfk1-XMASrk`

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[6]. It was reported that by not offering turn-by-turn navigation, the bike rider could be more aware of the environment, but most cyclists had to stop to read the map anyway, "since they found it too small" [6]. In a stationary indoor study involving memorizing locations on a map, smartphone displays were compared with handheld projectors. For that task and context, spatial memory improved 41% when using projectors [3]. Our focus is not to compare display sizes. Rather, we compare the use of smartphones and projectors for navigation outdoors while in motion. Previous work by Rowland et al. on designing interactive experiences for cyclists employed mobile phones mounted on the bicycle's handlebars or worn on the cyclist's lower arm [7]. They found that for map navigation, adapting digital media to the cycling activity was essential. They used audio instructions to support a "heads-up approach", however the user still had to stop to interact. We note that safety remains a challenge, as interaction with a device in traffic will generally be less safe than passive, stationary use [8].

Automotive ergonomics state humans are comfortable with eye movements of 15 degrees above or below the line of sight, and can easily tilt their heads 30 degrees upward or downward [5]. These field of view parameters are relevant when designing systems presenting visual digital information while moving. Research on car driver attention and behavior revealed how map system configuration (audio, visual, or audio-visual) inside a car influences eye glance frequency [2].

Informed by work in the area of interaction in motion, the design of interactive experiences for cyclists, and findings from the study of car drivers' visual capacity, we verify if map navigation is possible using a bike-mounted projector and compare it with a smartphone display for the use of GPS-based navigation during nighttime cycling. We then discuss factors influencing interaction in motion.

EXPERIMENT

We conducted an experiment comparing two conditions, each using GPS navigation while cycling: mobile phone display versus projection on the pavement in front of the bike. GPS map navigation is considered a skilled activity where users should support their navigation with the system and not follow instructions blindly [1]. Design choices are drawn from recent GPS navigation guidelines suggesting active drivers are "interpreting, ignoring, re-using instructions while also combining them with related information from the environment and their own route knowledge" [1]. Experiment leaders indicated start and finish for the four routes. Subjects cycled for over 20 minutes and had 20 minutes to complete a questionnaire. Recruits were required to be able to ride a bike. Novelty effect was addressed by choosing university students as subjects, having more routes, and providing subjects time to get them acquainted with the technology. These findings, together with the goal of designing for interaction in motion, led us to not have audio or turn-by-turn instructions in our study. Instead, subjects were instructed to identify their need to turn solely from visual information, given as a route and their location on it. We wanted subjects to be more aware of their surroundings in order to use their visuo-spatial capabilities, allowing a heads-up approach instead of following instructions blindly.

Figure 2. Images selected from experimental video recordings: projector (left) and mobile display (right).

Apparatus and Interfaces

The map and navigation application OsmAnd [2] was running on the 4.7" display of an LG Optimus 4X 4D (Android 4.0) smartphone with a screen resolution of 720x1280 pixels. The pico-projector was a Brookstone HDMI Pocket Projector with a resolution of 854x480 pixels, connected to the smartphone via an MHL adapter. The projected display had the shape of a trapezoid, with an area of $0.72m^2$, shown one meter in front of the bike. To mount this equipment on the bike, a commercial mobile phone holder was used, while for the projector we designed our own holder and had it 3D printed. Cycling routes were created using the Viking application[3]. Runkeeper, an application for tracking sport activities, collected information on the route travelled (distance, time, and speed). Subjects were asked to wear a helmet with an attached GoPro video camera to record the journey.

Task and Data

Each subject received a bike equipped with a mobile phone and a small projector mounted to the handlebars, and the helmet. They were instructed to follow routes on a map displayed on the mobile phone screen or the light projected on the pavement (Figure 2). In the projector case, we covered the phone display. Using the map and current GPS location, depicted by a blue arrow, the subject followed a route displayed in pink. Based on this visual information, the subject had to identify when and where to make turns. The subject stayed at the center of the map, which rotated so that "up" on the map always represented the direction of movement. After completing the routes, each subject was asked to complete a questionnaire. The study was completed at night in the city center of a medium-sized city. Total length of routes with recorded data exceeded 90 km. For quantitative analysis we collected the travelled route, distance, time, and speed. We counted the head tilt frequency by analyzing the videos filmed with a head-mounted camera. Subjects then completed a questionnaire comparing usability of the two devices and their subjective assessment of the perceived task workload using a modified NASA Task Load Index. We chose to focus on subjective

[2] `http://osmand.net/`

[3] `http://sourceforge.net/projects/viking/`

feedback because this work was an initial test to check if map navigation is feasible while cycling.

Pilot Study

A within-groups pilot study was performed to ensure the general usefulness and feasibility of the prototype. The aim was both to confirm that the projected light was appropriate for navigation, and to design the final experiment. Six persons (four females and two males) aged between 24 and 50 years (M=34.5, SD=8.89) tested our prototype. We chose several routes throughout the city, with distances varying between one to three kilometers. Initially, each subject was given two arbitrary routes from the set of all available routes. Thereafter, they completed a questionnaire and we subsequently conducted an interview, taking into account their questionnaire answers. We used the collected data for an informal assessment of our prototype to incrementally adjust the system and the experiment. We concluded that because subjects might not be familiar with navigation while cycling, letting them first ride with the projector-based system would introduce two new aspects at once, and thus would be more difficult than beginning with the mobile phone. This observation contributed to the decision in the final design to have four shorter routes (less than a kilometer) instead of two longer routes. This way, the subjects would have more time to learn, to get familiar with the prototype, and also take more time to form an opinion and make a better assessment.

Experiment Results

The final experiment was a 2 x 4 (device: mobile phone, projector; trial: 1-4) within-subjects design using four different routes with a balanced distribution of the number of trials across route-device combinations, and a strict alternation of mobile (M) and projector (P) across the different routes (M-P-M-P or P-M-P-M). The number of subjects was 16, out of which were 7 females and 9 males of ages between 21 and 33 (M=25.8, SD=2.98). subjects completed four routes and a questionnaire whose results are presented below. Each questionnaire section is reflected in the following sections.

Mobile or Projector

The aim of this section was to compare preference and usability of the two displays. The subject could choose between the mobile and projector as answers to questions about which was easier to use, safer, helpful, fun, kept road and traffic more visible, and which kept attention on the route (Figure 3). For 69% of subjects, the projector-based system was easier to use, and 75% found it safer to use. Regarding support for navigation, 69% of subjects stated the projector helped them more than the mobile phone. Similarly, route attentiveness was perceived as being higher with the projector-based system for 63% of subjects. In 69% of all cases subjects reported, road and traffic visibility was reported as higher with the projector-based system.

Task Workload

The goal of this section was to assess the perceived task workload. The subject rated the mental, physical, and temporal demand, as well as frustration level and their perceived map checking frequency, on a seven-point Likert scale where one

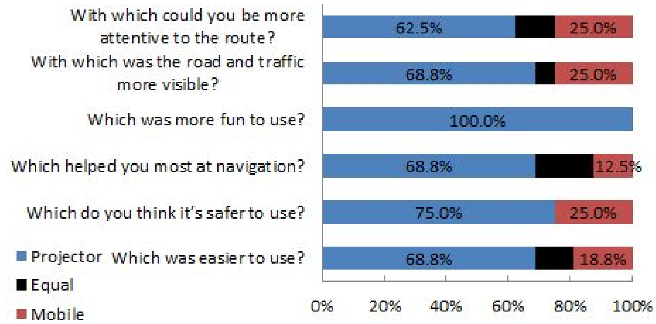

Figure 3. Users' system preferences among the six criteria for projector (blue) and mobile display (red): attention, road visibility, traffic visibility, navigational aid, safety, and ease of use.

meant "Very Low" or "Very Little" and seven meant "Very High" or "Very Much". Additional comments in clear text were encouraged to justify or clarify the ratings and are presented in the next subsection. The reported task loads and relative map check frequency were compared across devices. Paired t-tests for each of the questions revealed a significant effect of device type on mental load ($t = -3.27$, $df = 15$, $p < 0.01$). On the other hand, the type of device had no significant effect on neither the other task load aspects nor the map checking frequency.

User Feedback

Most of the subjects appreciated the large projector display for navigation because it increased the map's clarity, making street names visible. One subject mentioned that it aided in planning the route—the projector freed them to observe and be aware of their surroundings. The projected map was natural to look at, helping them to see the way ahead, letting them feel secure about when to turn. In contrast, some reported missing turns with the phone display, as it was easy to forget about the small device. The safety concerns of looking down into a small mobile screen caused some stress, whereas looking at the projection was much less distracting, allowing peripheral vision to remain on the road. But this was not universal: some subjects preferred the mobile instead, as they could keep the map in memory and focus fully on traffic, with one writing how the greater effort to glance at the mobile encouraged better memory.

Projector Visibility

The goal of this section was to assess if the map was visible enough for navigation and to find out what conditions affected its visibility. All subjects (100%) considered the projected map was visible enough for navigation. The main factors affecting visibility were light sources (from street lights or cars) and ground irregularities (leaves, cobblestones, or other patterns) also causing vibrations.

DISCUSSION

While display size and position are important factors for interaction in motion, the former was not the focus of our research. Similar to the research of Kaufmann and Ahlström [3], our study focused on comparing map navigation using a smartphone versus a portable projector. However, in our study, we evaluated two alternative display types for map navigation during cycling and factors other than display size affecting this task. One such visuo-spatial factor was eye-to-digital information distance (EI), which can be understood as the radius of a circle whose center is the cyclist's face and ends at the phone view or the projected view (Figure 5). In our study, the map was either visible at an arm's length from the eyes of the cyclist or on the ground in front of the them. Besides EI, another factor is normal-view-to-digital information distance (NVI). There is thus a distance between the normal view and the information displayed by the mobile and by the projection. For the cyclist, the normal view is ahead, towards the road. The normal view is characterized by the field of view (FOV) and the line of sight directed ahead (A) (Figure 5). If digital information is presented outside of the FOV, the cyclist's head is required to move towards that information. In our study, the information was the map, requiring a head tilt to enable seeing the projection view (B) or the phone view (C) (Figure 5).

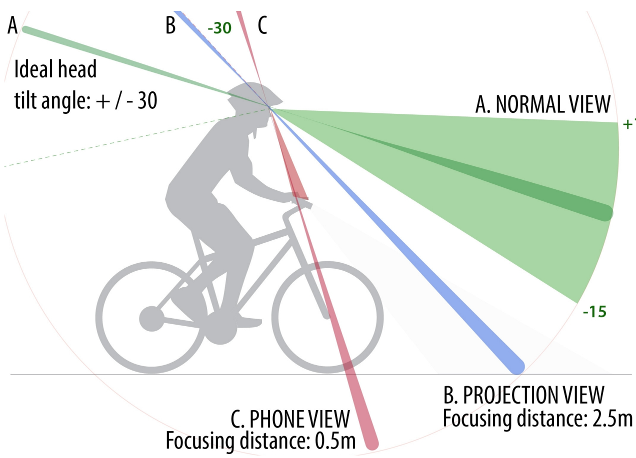

Figure 4. Line of sight and field of view in: A) normal view, B) projection view, and C) phone view.

The mobile's EI is less than the projector's, so the eye focuses faster on the projection. This is because the projection is closer to the normal view and in the FOV, as suggested by one subject. The NVI for the mobile is larger than it is for the projector, resulting in a larger angle during the head tilt. This difference in information placement, together with display size, could be the reason why the mental demand is perceived higher for the mobile phone than for the projector display. For the projected map, we noticed that head tilts had shorter duration and smaller angles, probably because the projected map is closer to the field of view. The experiment provided statistically non-significant data on head tilt frequency differences between devices. However, the data for both devices was remarkably close to the eye glance frequency found by researchers studying car driver attention and behavior for different GPS configurations [2].

CONCLUSION AND FUTURE WORK

This paper presented a mobile system, Smart Flashlight, designed to evaluate bicycle map navigation using a mobile phone versus using a projector. The mobile phone display could be used for navigation during the day, while the projector could serve as both flashlight and map during the night. This interaction method for navigation could be applied to other settings, such as hiking, swimming, or driving. To reliably measure and test objective factors such as completion time and head tilt frequency, we suggest i) controlling subject's cycling proficiency, ii) controlling subject's map navigation skills, and iii) controlling the GPS performance.

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