Gesture Bike: Examining Projection Surfaces and Turn Signal Systems for Urban Cycling

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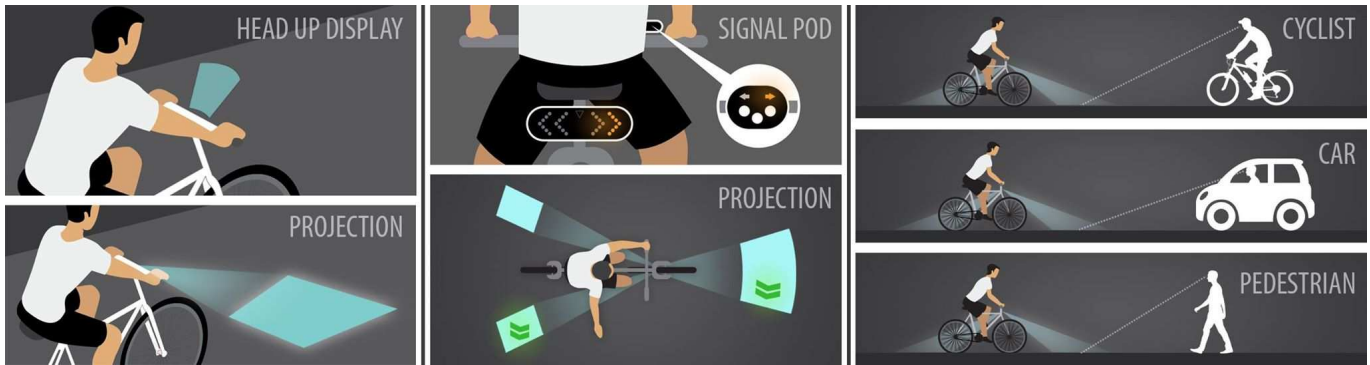
Figure 1. (Left) Comparison between head-up display and projected display (Center) Comparison between gesture input and Signal Pod, a commercial-turn signalling system, (Right) Evaluation using videos recorded from the perspective of participants in traffic

ABSTRACT

Interactive surfaces could be employed in urban environments to make people more aware of moving vehicles, showing drivers' intention and the subsequent position of vehicles. To explore the usage of projections while cycling, we created a system that displays a map for navigation and signals cyclist intention. The first experiment compared the task of map navigation on a display projected on a road surface in front of the bicycle with a head-up display (HUD) consisting of a projection on a windshield. The HUD system was considered safer and easier to use. In our second experiment, we used projected surfaces to implement concepts inspired by Gibson's perception theory of driving that were combined with detection of conventional cycling gestures to signal and visualize turning intention. The comparison of our system with an off-the-shelf turn signal system showed that gesture input was easier to use. A web-based follow-up study based on the recording of the two signalling systems from the perspective of participants in traffic showed that with the gesture-projector system it was easier to understand and predict the cyclist intention.

Author Keywords

Bicycle; Cycling; Turn Signal; Head-up-display; Gibson; Map Navigation; Projector;

ACM Classification Keywords

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

INTRODUCTION

Bicycles enable efficient [37] and sustainable personal transport with more than one billion bicycles produced worldwide in the last fifteen years [1]. Technological systems for use when cycling are a recent growth area. However, a fundamental challenge for these interactive systems is the unsuitability of traditional user interfaces for use while cycling, which can cause safety problems as systems constrain and capture attention [12]. One potential solution to this challenge is to use the environment in the vicinity of the bike as a display and user interface. Relevant and contextual information can be displayed where it is needed, and interaction can harness already known tasks and expectations. In this paper, we study interfaces which combine support for nighttime map navigation with cycling safety aids. We note that projectors are getting more powerful and accessible, potentially allowing for daytime use. The three contributions of this paper are:

(a) Comparing road projection with a head-up display (HUD) for the task of map navigation while cycling (Figure 1, left);

(b) Proposing the concept of displaying information such as minimum stopping distance and rider "safety envelope" through projections on the road (Figure 7)

(c) Comparing a gesture-enabled projection system with an off-the-shelf turn signalling system (Figure 1, center & right)

RELATED WORK

Below we review bicycle conventions and devices for signalling, traffic safety issues, displays and navigation systems

implemented for bicycles, as well as a driving perception theory meant for improving safety.

Signalling Systems for Bicycles

A main factor affecting bicycle safety is motorized traffic [26]. Workshops organized with other road users showed the need for improving cyclist visibility [9]. Nighttime cycling was found to be up to five times more dangerous than during the day [16, 19]. A review summarizes the effectiveness of visibility aids at day and night time [19]. A case study showed that only 25% of night cyclists had front lights, 50% had a rear reflector, and 12% had a reflective vest [15]. There is a growing trend towards designing lighting systems for bikes to display information. For example a research project with a helmet based display [35] has been used to study social exertion activities, and to explore "cyclists' safety, skateboarders' self-expression and riders' communication of heart rate" [34]. Several commercial projects also exist, for example, Zackees Turn Signal Gloves employ LED lights displaying an arrow on the back of the glove [32] that are combined with gestures typically used to express turning intention while cycling. Blaze is an LED and laser light system that projects a bike symbol in front of the bicycle [4]. Xfire uses laser light to project two "lanes" at the sides of the bike, helping drivers in keeping a safe distance to the bike [38]. Inspired by Blaze and Xfire, Gesture Bike combines projections in the front and to the sides of the bike.

Bicycle Gestures

The Vienna Convention on Road Traffic mentions that a driver shall signal the intention of moving laterally by means of either a direction-indicator of the vehicle or using arm gestures [2]. For cyclists, the arms are normally used to indicate the intention of turning. We chose to employ existing gestures for bike ride signalling as most cyclists know their meaning, context of use, and are familiar with them. We detect these gestures using a depth sensor, repurposing and signalling them using corresponding symbols projected on the road. Since the user does not have to learn extra controls, this contributes to ease of use and ease of learning. In gesture controlled interfaces, the simpler the controls, the better [30]. These deictic gestures that involve showing the direction the user will turn by hand, align with Norman's physical analogy [23] and to an average user's mental model [7]. From the perspective of traffic participants, gestures can independently signify the user's intention, while interaction with the system amplifies their effectiveness by making this public interface highly visible to others [28].

Bicycle Proxemics

Research in civil traffic shows that motorized vehicles pass bicycles at a distance of minimum 0.85m, while at 30mph the distance is normally 1.05m [8, 24]. The cycle lane width determines the proximity between the bicycle and the passing vehicle [24]. Passing distances were investigated and correlated with factors related to vehicle type, road (markings, lane width), and bicycle (physical appearance, change in wheel angle, speed) [10]. A longitudinal study suggested that wearing fluorescent colors may increase a cyclist's safety [31].

However, a study on the influence of a cyclist's outfit and the proximity of cars during overtakes concluded that the rider appearance does not contribute to increasing the distance of the vehicles [33]. On the other hand, employing the ground surfaces near the bicycle to signal intention and alert the participants in traffic might contribute to safety. The concept of augmenting the physical space in front of a vehicle with information suggesting optimum driving resembles Gibson and Crooks' perception theory for driving proposed in 1938 which provides a set of concepts "applicable to any type of locomotion", such as minimum stopping zone, terrain, destination, obstacle, collision, path, and the assumption that the driver aims to drive in the middle of a "field of safe travel" [14]. These concepts and the field of safe travel could be computed and visualized, thus increasing safety for vehicles in traffic.

Head-up Displays for Cars

Research on aviation interfaces has shown that important information should be displayed closer to the "normal line of sight (NLOS), which is a line about $20°$ below the horizon extending from the eyes" [36]. Human Machine Interface principles recommend having visual displays for in-vehicle interfaces positioned "as close as practicable to the driver's normal line of sight" and the driver should be able to assimilate relevant information with a few glances [13]. Head-up-displays have been researched in cockpits, but have recently been introduced by many car manufacturers such as Audi, BMW, and Mercedes which developed a head-up display[1] showing speed, navigation, and lane guidance information, "keeping the eyes where they should be, focused on the road ahead". Consumer HUDs for cars have been released by Garmin[2] that project directly onto the windshield information about navigation, speed, and traffic. Jaguar revealed a virtual windscreen concept that shows virtual cones for driver training, virtual cars for racing, and virtual racing lines for optimum track route and braking [17]. As HUDs gain wider adoption in related industries, various aspects of their performance, safety and applicability should be evaluated.

Displays and Navigation Systems for Bicycles

Findings from exploratory bike trips using handlebar-mounted smartphones offered map navigation while cycling [25]. 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" [25]. The Copenhagen City Bike is a bicycle equipped with a touch screen tablet computer mounted below the handlebar, offering GPS map navigation and real-time departure times of trains, buses and the metro [6]. Hammerhead is a T-shaped handlebar-mounted device connected to the smartphone, helping with turn-by-turn bike navigation using LED lights [22]. 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 [29]. Audio instructions were employed to support a "heads-up approach", however

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[1]Mercedes HUD: `https://youtu.be/Wkf_WEek8bc`
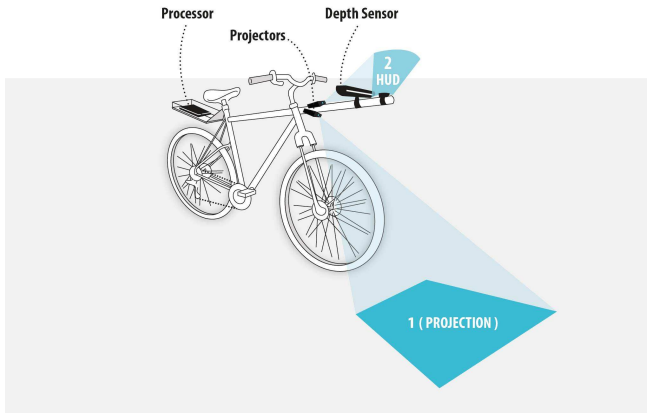[2]Garmin HUD: `https://youtu.be/_B7GIDyN32Y`

Figure 2. Head-up-display and projected display mounted on the bike. Only one of the two displays were used during the experiment. Both are shown for illustration purpose.

Figure 3. Map navigation using a bike-mounted head-up display. The navigated route is shown in pink. Landmarks are highlighted.

one user was very distracted and in danger of a collision. They found that for map navigation, adapting digital media to the cycling activity was essential. Another way to improve the safety while cycling is considering the routes and informing cyclists about their characteristics [27]. GPS map navigation is considered a skilled activity where users should support their navigation with the system and not follow instructions blindly [5]. Design choices are drawn from recent GPS navigation guidelines suggesting active drivers are "interpreting, ignoring, and re-using instructions while also combining them with related information from the environment and their own route knowledge" [5].

In our previous work, Smart Flashlight, we proposed replacing bicycle headlights with information projected on the road [11]. We showed that map navigation was possible by projecting a map in front of the bike and compared it with map navigation on a bike-mounted smartphone, finding out that with projection cyclists could be more attentive to the route and that it was perceived easier and safer to use. In this follow-up study, we first investigated whether a head-up display would be preferred over a projected display (Experiment 1). Additionally, we were interested in employing the projection surfaces in making the bike and cyclist intention more visible on the road (Experiment 2).

EXPERIMENT 1: HUD VS. ROAD PROJECTION

The goal of the experiment was to compare map navigation on a bike-mounted head-up display (HUD) with a projected display in front of the bike (Figure 2). The experiment was a within-subjects comparative study evaluating the two conditions over two different routes using a balanced distribution of route-display combinations. Each subject received either an HUD or projector equipped bike, and was tasked with following a highlighted route on a map with the assistance of a GPS location marker. (Figure 3 shows the route colored in pink). After each condition, subjects completed a NASA Task Load Index (TLX) and a System Usability Scale (SUS) questionnaire. After completing both conditions, the subjects filled out a questionnaire comparing the two devices and were interviewed about their ratings.

Apparatus and Interfaces

The hardware of our prototype consisted of a mountain bike equipped with two Brookstone pocket projectors mounted on an aluminum reinforced styrofoam extension of the frame (Figure 2). The projected graphical interface consisted of an OpenGL application displaying a high contrast map with the route thickened, colored in pink, and the current position displayed as a blue dot. two different HUD materials were tested: $2mm$ thick half-transparent low density polyethylene (LDPE) and transparent plexiglass sheets mounted at a distance of $52cm$ from the handlebar (see Figure 2). We cut the sheet as $28cm$ high trapezoids with the small base of $20cm$ and the large base of $28cm$. The sheet was then slightly bent in the form of a windshield and mounted at a $24°$ angle from the vertical (see Figure 2). The projector was at a distance of $32cm$ from the HUD, placed on a $16cm$ high styrofoam block glued on top of the aluminum reinforced extension of the frame in front of the handlebar, resulting in an image of $23 \times 16cm$ (see Figure 3) with a projection area of $365cm^2$. The ground projection system used a single projector mounted in front of the handlebar and under the aluminum frame. The front projection area was at a distance of $104cm$ from the end of the front wheel, and measured $13776cm^2$. We asked two pilot study participants to cycle two routes, one with an HUD, the other with the display projected on the road. Map visibility was better with LPDE, but one could not see through it as in the case of a head-up display of a car, so we replaced it with the plexiglass. The HUD was also made removable so that it would not affect the view of the projected road display.

Experiment Results

We recruited 12 participants (5 females); university students and interaction design professionals aged between 21 and 50 (mean 28.0, s.d. 7.9) with an average cycling proficiency of 3.3 (s.d. 0.8) on a scale ranging from 1 (no experience) to 4 (advanced). The within-subjects comparative study evaluated the two display conditions over two different routes.
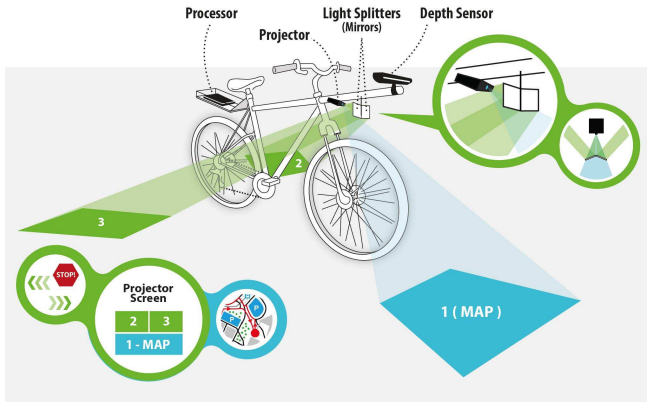
Figure 4. Illustration of how the projection was split using mirrors

Figure 5. Turn signalling through gestures and projection (top) and Signal Pod, an off-the-shelf system which uses buttons and LEDs (bottom)

Subjective Measures

Paired t-tests for each of the NASA TLX questions revealed a significant effect of device type on performance (t = -1.8, df = 11, p <0.04) with the projector ranking lower than the HUD (3.0 points difference in means). The other task load questions showed no significant effect. Regarding the sources of workload, mental demand was ranked the highest (mean 3.3, s.d. 0.9), followed by performance (mean 3.1, s.d. 1.1), effort (mean 2.75, s.d. 1.0), frustration (mean 2.5, s.d. 2.1), and temporal demand (mean 1.9, s.d. 1.7). The average SUS score for the HUD was 68.3 (s.d. 7.8) and for the projector was 69.5 (s.d. 7.6). When asked to compare the two displays, the participants considered that with the head-up display they could be more attentive to the route (58.3%), have better road and traffic visibility (HUD 50%, same 8%), have better aid in navigation (HUD 58.3%, same 8%), it was safer to use (66.7%), and it was easier to use (66.7%). On the other hand, when asked which system was more fun to use, 66.7% opted for the road display.

Participant Comments

From a cyclist's perspective, participants noted that the HUD was more visible since it was less susceptible to surface variations than the projector: "The image changed when you went over different surfaces." However, one user observed that the the light reflected in the windshield affected the visibility of the HUD. "Sometimes there was a reflection of traffic lights on the screen." The angle of the line of sight to each display was an important factor when participants rated their attention to the route. Several users noted that with the projector, they had to shift focus between the projector and the road, while one taller (196cm) participant noted:"[The projector] is better because you are not looking down so much." Participants also took issue with the brightness of the projector, noting that it was distracting: "The projector would distract me more. It was very bright and caught my attention more". Users requested a turn-by-turn navigation feature that alerts participants before a turn is coming up. As one user suggested, this could be implemented via augmented reality displayed on the HUD. Another participant proposed a system which considers selective attention: "If new information is
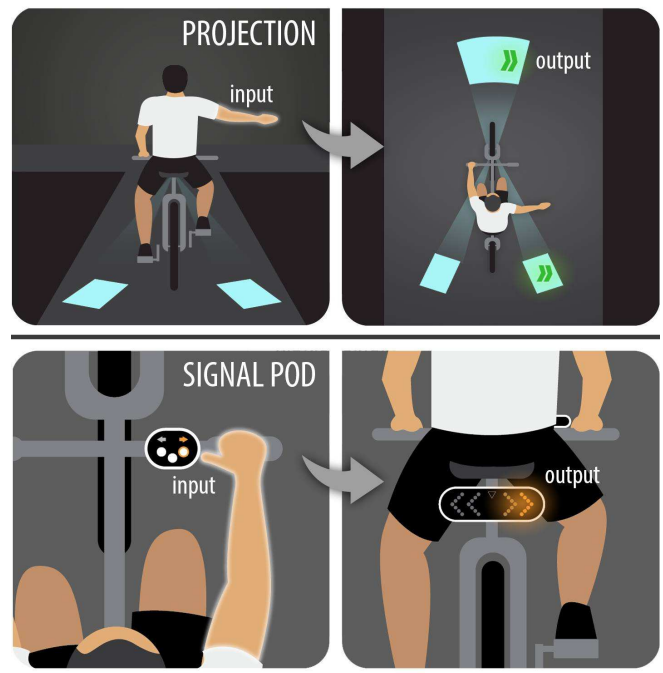
coming, it beeps to me. It's good to have the map on all the time, but I want to know when to look at it."

EXPERIMENT 2: BIKE PROJECTOR SIGNALLING

We built a system for a bicycle that recognizes a cyclist's turning gestures and projects the cyclist's intention on the road (Figure 5). This prototype was evaluated in two ways:

(a) using cyclist participants who compared this system with an off-the-shelf turn signalling system, and

(b) using an online survey containing video recordings from the perspective of participants in traffic (pedestrians, car drivers, cyclists) presenting a cyclist using the gesture-projector and the commercial system.

The task was to navigate two routes displayed on the road and to signal turning intention; one route using gestures, the other one using a commercial off-the-shelf signal turning system called Signal Pod (see Figure 5). The latter system was composed of two devices; one mounted on the handlebars that had three buttons, out of which only the left and right button were required in the task, while the other device was a group of LED lights arranged as left and right arrows (Figure 5, bottom right image). Pressing the buttons would send a wireless signal triggering the arrows to blink and an audio signal (one beep for left, two beeps for right). Pressing them again would stop the blinking and beeping. The arrows projected around the bike had the same color and style as Signal Pod's arrows.

Apparatus and Interfaces

Standard hand signalling used with bicycles was employed as an input to our system that detected this gesture and projected the cyclist's intention on the road in the direction of
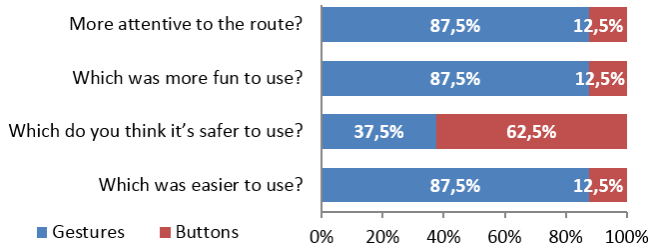
Figure 6. Experiment results (n=8) ranking gestures and buttons as input while navigating routes on a map projected in front of the bicycle

Figure 7. Field of safe travel, minimum stopping zone [14], and safety envelope illustrated in the context of our Gesture Bike design

turning. This concept was implemented by splitting the projection space as shown in Figure 4. The bottom of the illustration shows how we split the projection into three parts – the two at the top (2 and 3) are reflected using two mirrors oriented at an angle so that they are displayed on the sides of the rear bike wheel. The remaining larger image (1) projects a map directly in front of the bike and is used for navigation. The front projected area remained the same area and location as in the first experiment, while each side projection measured $3072cm^2$ to create a total projection area of $1.6848m^2$. The detected gestures would trigger the display of symbols shown on the two displays at the rear but also in front on the sides of the map.

The gesture recognition hardware consisted of an Xtion depth sensor mounted in front of the bike, connected to a MacBook laptop fixed to the back of the bike (see Figure 4). The software was based on the OpenNI library[3]. We created a framework that supports adding multiple gestures. In our experiments we focused on the left and right gestures. The projector was a Brookstone HDMI projector. We iteratively improved the prototype and conducted two experiments with this system. For the pilot study, the static map displayed in front of the bike was improved in contrast, and did not rotate or show the current position. The route required for navigation was shown in red 4. For the experiment, the map showed the current position on the map using a blue dot. Based on a set of unique gesture inputs, the system was able to recognize and trigger the display of left and right turning arrows, stop signs, pass-me arrows, awareness markers, and hazard signs. Symbols were projected both in the front on the sides of the map, and also on each side of the rear of the bike. Only the turn signals were evaluated for the experiment. The majority of the visuals have been implemented as animations (blinking or scrolling) to improve visibility and attention of participants in traffic.

Pilot Study

We conducted a pilot study to confirm the prototype was usable for navigation, to get early feedback, improve the system, and design the final experiment. We recruited 5 university students (1 female) aged between 19 and 28 (mean 23.8, s.d. 4.0) to evaluate the gesture signalling system. The task was to perform map navigation and signal turning intention. After initial training, the route was completed, and a SUS questionnaire was filled out. An average SUS score of
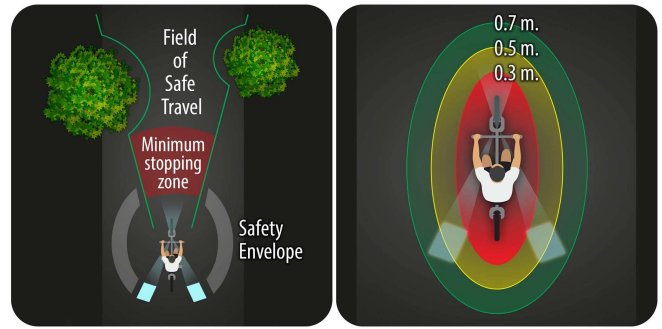
[3] https://github.com/OpenNI/OpenNI

77 (s.d. 5.4) was obtained. Pilot study participants thought it felt both safe and natural to use the system, since they used these kinds of gestures regularly whilst cycling. However, they considered using the bike made them look down on the ground more than normal and that they sometimes had to "hold" the gestures for too long to make the system recognize them. An experienced cyclist considered that most gestures did feel natural to use in spite of it not being part of his regular biking routine. Another subject commented that this kind of system may be useful in teaching people to use gestures when biking. However, he did not feel that all gestures felt equally natural to use, in particular the stop gesture struck him as less comfortable.

Following the pilot study, we improved the system with the following features for the final experiment: i) we added the current position of the cyclist on the map (added a GPS module) ii) moved the position of the sensor higher and further from the handlebar in order to improve the user skeleton tracking iii) tested and improved reliability of Signal Pod by measuring the voltage and replacing batteries with higher amperage iv) improved robustness of the system and slightly increased the projection size v) replaced the routes with more similar ones that had the same number of turns vi) added visualizations, such as the "safety envelope" based on Gibson's driving perception theory [14].

Safety Envelope

Projections around vehicles could be used to improve visibility and safety of participants in traffic. The following visualizations are inspired by Gibson's driving perception theory [14]. The minimum stopping zone is displayed in front of the vehicle showing the distance needed to bring the vehicle to a halt. This depends on the speed of the vehicle. The visualization for the minimum stopping zone was implemented by placing two bars inside the front road projection (to the sides of the map) that would increase in height depending on the speed of travel (Figure 7 left). The other visualization is the "safety envelope" projected on the ground near the sides of the vehicle that becomes larger according to the speed of the vehicle. Figure 7, right shows the ideal safety envelope surrounding the whole bike and the position of the rear projections from our implementation. Safe distances between bicycles and motorized traffic during overtaking should be larger than 0.85m [8]. The two rear displays were used to show the

"safety envelope" that was visualized as bars scrolling from front to back, growing outwards depending on speed. Both visualizations were increasing outwards in front and to the sides of the bike, proportionally to speed. The minimum stopping zone is visible to the cyclist and participants in traffic, while the safety envelope is intended to be seen by others.

Experiment Results

The experiment was a within-subjects comparative study evaluating the two input conditions over two different routes. After each condition, a NASA TLX and a SUS questionnaire were completed. Finally, a questionnaire for comparing the two input methods was completed, followed by an interview. The participants were 8 university students and interaction designers (2 females) aged between 25 and 33 (mean 28.7, s.d. 3.0) with an average cycling proficiency of 2.8 (s.d. 0.5) on a scale ranging from 1 (no experience) to 4 (advanced).

Subjective Measures

Paired t-tests for each of the NASA TLX questions revealed a significant effect of device type on performance ($t = 1.8$, $df = 7$, $p < 0.01$) with buttons ranking lower than gestures (3.1 points difference in medians). The other task load questions showed no significant effect. The sources of workload were mental demand (mean 3.1, s.d. 1.1), effort (mean 2.8, s.d. 1.4), followed by performance (mean 2.7, s.d. 1.4), physical demand (mean 2.2, s.d. 1.9), frustration (mean 2.1, s.d. 2.0), and temporal demand (mean 1.7, s.d. 1.8). The average SUS score for gesture input was 73.7 (s.d 6.4) and for the Signal Pod buttons input was 67.8 (s.d. 6.1). The average perceived percentage of recognized input was 92% for gestures and 75% for the buttons of Signal Pod. When asked to compare the two inputs, the participants considered that with gesture input they found they could be more attentive to the route (87.5%), have better road and traffic visibility (75%), and was easier to use (87.5%) (Figure 6). Regarding safety, participants were in favour of the buttons input (62%) .

Participant Comments

We noticed that the safety depends on several factors: *keeping balance*, *visibility*, and *attention*. The gesture system requires users to take their hand off the handlebar to signal intention, causing concern about their ability to balance: "I think buttons are safer because you don't need to take your hand off the handlebar. With gestures, you can lose your balance." The button system also caused similar complaints about balance, with one user suggesting that the buttons should be in reach without letting go of the handlebar and placed close to the fingers like with motorcycles.

Participants commented on traffic visibility noting that gestures can be easily distinguished from a distance, while one participant had the opposite opinion, noting that "buttons are safer because drivers can see the lights better than the indicators on the road." Another safety concern was raised by a participant regarding false positives. He reported waving to onlookers and triggering the turn signal gesture. He suggested having the option of enabling and disabling gesture recognition. Although triggering gestures is an analog action, users preferred its visual feedback, which they trusted to reflect the
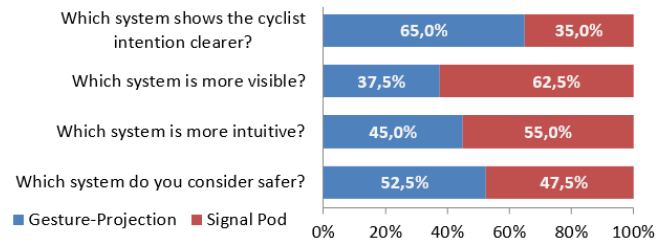

Figure 8. Online survey rankings (n=40) comparing preference between gesture-projection and commercial off-the-shelf turn signals. Gesture-projection is ranked higher than Signal Pod when it comes to showing biker intention. However, Signal Pod is more visible.

current state of the system: "For gestures, I really know that it went on. So it's safer that way."

Participants complained about the button signalling system, mentioning that they had to turn their attention away from the road and look at the handlebar when pressing buttons. Many agreed that for button signalling the location should be on the left and right handlebars. They were disturbed by the fact that the left and right buttons were so close to each other and too small. The two-step activation and deactivation procedure of the button system took more time to control and thus reduced route attention. The feedback provided by both systems had a strong effect across all ratings. Multiple participants noted that traffic noise reduced the effectiveness of button beeps as a feedback system. Most users found gestures intuitive and natural, which contributed to the high ratings: "You don't have to do anything special, it comes naturally and it augments the reality." Lower button ratings could also be attributed to additional effort required, as one user noted: "With gestures, because you do it normally, it's fine, but with buttons I need to put in more effort to push it."

Online Survey

We created a survey to help us compare the two signalling systems using videos recorded from the perspective of participants in traffic (cyclists, car drivers, and pedestrians). Two videos were recorded from all three perspectives: one presenting a cyclist using the gesture-projector system, the other with a cyclist using Signal Pod. Each video contained the following scenes:

Cyclist perspective: seeing cyclist from the back (turning left, turning right, and stopping), seeing cyclist coming from the front and turning right

Car driver perspective: seeing cyclist from the back (turning right, left, and stopping), seeing cyclist coming from the front and turning left

Pedestrian perspective: cyclist passing by and turning left, cyclist coming from the front and turning right.

The survey was created using the LimeSurvey platform and shared with online cyclist and student groups from Europe and North America. Forty persons (seven females) aged between 21 and 60 (mean 32.8, s.d 9.8) completed our survey. We balanced the order of watching the videos, so that half watched the gesture-projector video first, and the other half

watched the Signal Pod video first. After watching the first video, participants answered questions regarding their ability to identify visual cues, understand, and predict the cyclist's intention and actions, followed by rating the corresponding mental effort required, both having a 4-point scale (very easy, fairly easy, somewhat difficult, very difficult). These questions were derived from the Mission Awareness Rating Scale (MARS) [21], which assesses subjective measures that are "suitable for soliciting self-reports of a driver's confidence in their situation awareness abilities" [3]. The final questions compared the two systems in regard to safety, ease of use, and visibility.

Participants rated the following on a scale of "very easy", "fairly easy", "somewhat difficult", and "very difficult". The corresponding ratings are listed in this respective order. In comparing their **ability** to identify visual cues (Projector: 37.5%, 45%, 17.5%; Signal Pod: 15%, 30%, 42.5%, 12.5%), to understand (Projector: 57.5%, 40%, 2.5%; Signal Pod: 35%, 40%, 20%, 5%), to predict future actions (Projector: 57.5%, 35%, 7.5%; Signal Pod: 15%, 42.5%, 30%, 12.5%), and awareness of the cyclist's intention (Projector: 65%, 32.5%, 2.5%; Signal Pod: 42.5%, 37.5%, 15%, 5%). When comparing the **mental effort** required, the participants rated the projector as being somewhat difficult for the following abilities: ability to identify visual cues (17.5%), ability to understand the cyclist's intention (7.5%), ability to predict the cyclist's actions (15%). For the mental effort required for these capabilities, the Signal Pod was rated "very easy" and "fairly easy". However, regarding situation awareness ("How difficult - in terms of mental effort required – was it for you to be aware of the situations presented in the video?"), there was a significant difference between the projector (17.5% rated "somewhat difficult") and Signal Pod (37.5%).

Figure 9 depicts the final survey questions showing that 65% of participants considered that the gesture-projector system showed the intention of the cyclist clearer and 52.5% rated it safer. However, the survey participants rated Signal Pod more visible (62.5%) and more intuitive (55%). Overall 37.5% preferred Signal Pod, 25% the gesture-projector system, and 37.5% chose "other" which allowed them to suggest another system, such as "project on the cyclist's back", "reflective neon gear and hand signals", "combination", more advanced Signal Pod ("LED placed further apart", "lights on both sides"), hand signs with LED and reflective details on gloves.

DISCUSSION

This paper presented a mobile system, Gesture Bike, designed to evaluate bicycle map navigation and turn signalling using a projector. The projector display could serve as both flashlight and map during the night. The road acts both as a transportation medium and an information carrier. It does not constrain and capture attention, imposing limitations on behavior and separating us from the physical environment. Instead, relevant and contextual information is displayed where it is needed and harnesses already known tasks and expectations.
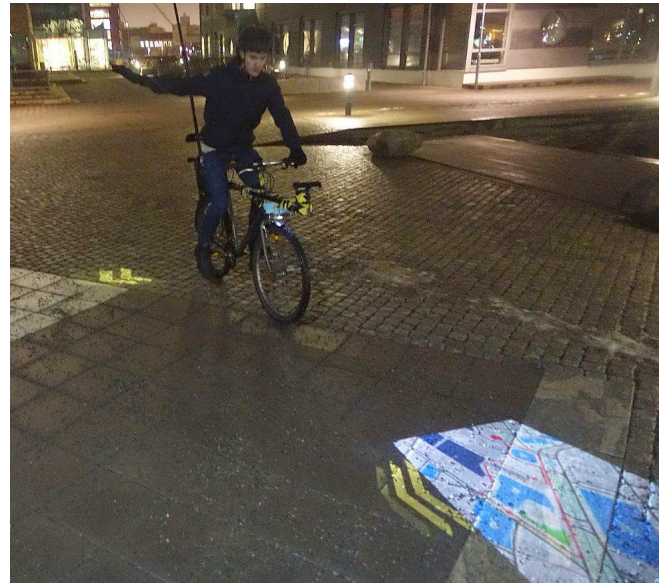

Figure 9. Cyclist navigates a map and signals the intention to turn right. The map is in the front, while arrows are shown in front and at the back.

Bicycle Displays

Electric bicycles are becoming more popular with over 100 million vehicles purchased in China only [18]. Having an electrical power source on bicycles would allow electronic devices like sensors and display systems to improve the cyclist's safety and experience. Many city authorities offer bikes for rent and are now beginning to be equipped with displays. In Copenhagen, for example, a tablet computer is mounted under the handlebars allowing for map navigation [6]. Our findings can inform such bicycle designs in improving safety and ease of use.

In this paper, for the task of map navigation, the head-up display was considered safer, easier to use, and more helpful in navigation than a projected display in front of the bike. This is in line with research that suggests that information should be as close as possible to the normal line of sight [36]. However, our previous work comparing mobile phones mounted on handlebars with road projection showed the more distant road display was considered safer and easier to use [11]. This could be explained by the fact that the position of the phone display was lower than the projection, requiring looking down. So a larger head movement angle required during locomotion might be perceived as more distracting and more difficult than having information further away on the road. The HUD's placement of information is comparable with the road projection from the perspective of the normal line of sight, but is positioned closer. This could explain why the HUD was considered safer and easier to use.

Regarding size and placement of the HUD, the cyclist height should be taken into account, so it should be adjustable, as noticed by one participant. The transparency, contrast, and colors used in the HUD could be the agenda of future research, as well as the visualization of information relevant to support situation awareness in traffic [3]. The normal line of sight and the angle to information are important aspects which should

be considered when designing interfaces and displays for bicycles.

Improving vehicle safety using projected surfaces
Many battery-powered locomotion devices are coming to market, such as electric skateboards, uni-cycles, self balancing scooters and dual wheels. As projectors are getting cheaper and widely available, augmenting the physical space around vehicles has the potential of improving safety and the interaction between participants in traffic.

The experiment results comparing our gesture-projector system with the button-LED system showed that gesturing was easier to use. From the perspective of participants in traffic (pedestrians, drivers, and cyclists), our online survey presenting videos of the two systems suggests that the projector system showed the cyclist's intention clearer, but the LED system is more visible. However, the visibility of the mobile projector could be improved in the future. The context of traffic demands high awareness of the situation for which our study shows that the gesture-projector system yields better results than Signal Pod in the ability to identify visual cues, understand, predict, and be aware of the cyclist's intention. On the other hand, mental effort was rated higher for the gesture-projector for all abilities except situation awareness. In regard to safety, the experiment participants were equally divided, while the survey participants were slightly in favour of the projector. One advantage of the projector system is the potential of transforming the physical environment around the vehicle and creating a safety envelope (see Figure 7) that could make the participants in traffic more aware of the presence of the vehicle on the road. The visualization of the minimum stopping zone could take into account physical factors such as tire type, braking strength, road surface, and weather conditions. Furthermore, Gibson and Crooks' concepts of field of safe travel could be visualized and improve the safety of drivers and cyclists. The field of safe travel could be displayed on a head-up display, while the minimum stopping zone which depends on the vehicle speed could be communicated to other drivers through a projected surface in front of the vehicle.

Designing to repurpose and support familiar tasks
Creating systems which allow direct interaction while moving is a difficult challenge [20], and can add extra attentional load and reduce safety [12]. By repurposing bicycle headlights through projecting information and employing this familiar context of cyclists, the flashlight is thus transformed into a display, a digital output system that could be used to inform and improve safety. Similary, employing conventional gestures for controlling projected signals allows cyclists to interact with the system without extra mental load. There is a need to design displays that present information on the go, non-intrusively, and hands-free. Currently, we use small computing devices that we call mobile and that we carry in our pockets at all times, but which isolate us from our surroundings. Instead of just placing computing devices on and around our bodies, we could integrate information into our environment and take advantage of familiar tasks and our context.

CONCLUSION AND FUTURE WORK
Our first experiment showed that a bike-mounted head-up display was considered easier and safer to use than a projection in front of the bicycle. Our second experiment proposed the implementation of the minimum stopping distance and safety envelope through projections on the road and compared a gesture-enabled projection system with an off-the-shelf turn signalling system. The gesture-projection system was considered easier to use and allowed the users to be more attentive to the route. Future work could include a system that combines a head-up display with a safety envelope. We hope that this work will give rise to a new class of headlights for vehicles that would support people in their tasks by projecting information where they need it. Our findings will be useful for designing future vehicles and could help participants in traffic to be more attentive to their environment while navigating, providing useful information while moving.

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