LEaD: Utilizing Light Movement as Peripheral Visual Guidance for Scooter Navigation

Hung-Yu Tseng* **Rong-Hao Liang†** **Liwei Chan†** **Bing-Yu Chen†**
National Taiwan University
*enlong0705@cmlab.csie.ntu.edu.tw †{rhliang, liweichan, robin}@ntu.edu.tw

ABSTRACT
This work presents *LEaD*, a helmet-based visual guidance system utilizing light movement in scooter drivers' peripheral vision for turn-by-turn navigation. A linear light strip mounted on a helmet navigates for scooter drivers using simple 1D light movement, which can be easily acquired and identified by peripheral vision with the on-going foveal vision task. User studies suggest that this novel system effectively reduces the number of visual distractions for scooter drivers in route-guided experiences.

Author Keywords
Navigation, Peripheral Visualization, Wearable Display

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

INTRODUCTION
Around 200 million motorcycles in use worldwide [1]. Similar to car drivers, scooter drivers often need navigational systems. Visual guidance can be achieved by displaying spatial information to scooter drivers. However, using tertiary displays, such as smartphone displays, glass displays[1], or helmet displays[2], typically direct a driver's gaze away from the road, resulting in hazardous distractive driving [9]. Audible [8] and tactile [2, 12] information can be obtained along with visual information to improve the utility of a guidance system. However, since scooter are often driven in noisy and bumpy environments, scooter drivers may need to wear additional devices, such as earphones [8], gloves [2], or a vest [12], to amplify signals, reducing the practical utility of solutions.

Visual information displayed in a scooter drivers peripheral vision can also be captured and processed simultaneously with the on-going foveal vision task when the information is simple and can be interpreted without cognitive effort in this dual-task scenario [3, 13]. Accordingly, *eye-q* [4] and *AmbiGlasses* [11] used a glass display with LEDs embedded in the frame to deliver static or blinking signals as peripheral visual cues. Although the blinking lights can be understood if the blinking patterns are appropriately encoded in the time-domain [7], interpreting these signals is slower and harder than interpreting animation or images encoded in the spatial-domain. To overcome the limitations of using point light for route guidance, the dimension of peripheral display methods should be extended.

[1]https://www.google.com/glass/
[2]http://www.skullysystems.com

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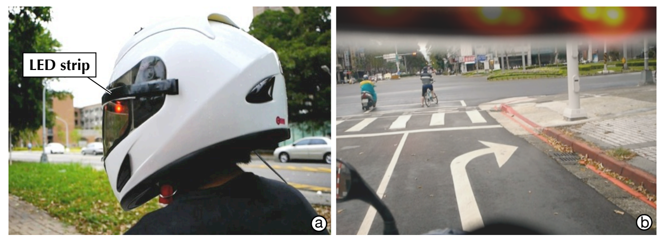


Figure 1. (a) *LEaD* is a lightweight, attachable display module for scooter helmets. (b) The LED strip provides turn-by-turn visual guiding information by light movement in drivers' peripheral vision.

This work proposes *LEaD* (Figure 1), a turn-by-turn visual guidance system utilizing the peripheral vision of scooter drivers, to assist drivers in navigation. The dynamic peripheral-vision display, implemented by attaching a NeoPixel RGB LED strip[3] to the front edge of a scooter helmet, provides rich and simple 1D cues in a driver's peripheral-vision field. Pilot studies are conducted to identify a suitable range of light transition speeds and a usable set of visual signals, and simulation-based user testing results show that this novel system effectively reduces the number of visual distractions for scooter drivers.

This paper is organized as follows. Two pilot studies are conducted to characterize the design space. Hardware design and implementation are then discussed. A simulation-based user study is then performed to assess the system's usability. Finally, findings are discussed and the conclusions are given.

PILOT STUDIES
Two pilot studies were conducted to determine peripheral vision and explore the peripheral-vision design space on a scooter helmet. This work recruited a number of scooter and/or bicycle drivers in the age range of $20-34$ as representative group of users for evaluation; this age group has

[3]http://www.adafruit.com/

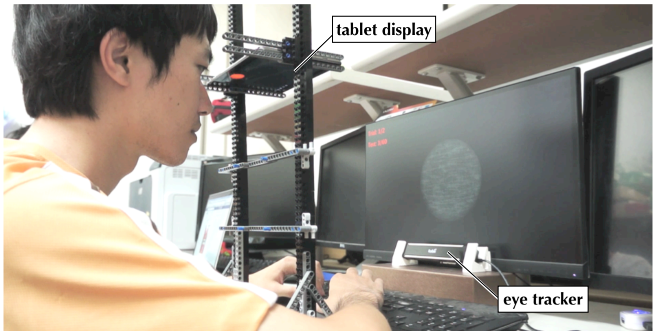


Figure 2. Experimental apparatus in the pilot studies.

the highest injury rate according to a report of fatal and non-fatal motorcyclist injuries[4]. A 7.7-inch Samsung Galaxy[5] tablet provided visual information that can be configured. The tablet display was placed in a tablet holder with its front facing a participant's eyes (Figure 2). Since an eye-tracker can differentiate between foveal and peripheral vision [10], a Tobii REX eye tracker[6] was placed in front of the participant to track gaze positions.

Pilot Study 1: Velocities of Light Movement

The first study investigates how the velocity of light movement affects a user's ability to perceive movement in his/her peripheral vision. Twelve participants (6 males) aged $23 - 33$ (mean age, 24.92) were recruited.

Tasks and Stimuli: After the eye tracker was calibrated, participants were requested to focus on an object on the tablet screen, and the eye tracker monitored their gaze positions. Users were then asked to recognize the lighted points shown on the tablet display in their peripheral-vision field; participants then recorded whether the lighted point was moving left (Left signal) or right (Right signal) by pressing the *F* or *J* keys — each key has a bump, which allowed each subject to focus solely on the tablet's display. Six different signal durations, ranging from 1 second (slowest) to $1/32$ second (fastest), were tested. Signal durations and point types appeared in a random order, and the period between each trial was randomized in the range of $3 - 10$ seconds. Reactions during each trial were recorded, and reaction times were recorded when a user characterized a signal. Each trial was invalid only when users did not gaze at the 15cm-diameter round target on the display for more than 0.2 seconds, the lower bound of typical eye movement time [6]. If a task was invalid, the participant repeated the task. In total, 2 (signals) $\times$ 6 (speeds) $\times$ 10 (trials) $\times$ 12 (participants) = 1440 trials were successful.

Results and Discussions: When signal duration was $\geq 1/4$ second, participants identified light directions with $> 95\%$ accuracy, and their reaction timers were related to light movement speed (Figure 3). Conversely, when signal duration was $< 1/4$ second, the ability of subjects to recognize signal direction decreased, such that the miss (no-answer) rate and reaction time increased. Analytical results indicate that peripheral vision can recognize light movement when a lighted point moves within a range of velocity.

[4]http://www.cdc.gov/features/dsMotorcycleSafety/
[5]http://www.samsung.com/
[6]http://developer.tobii.com/rex-setup/

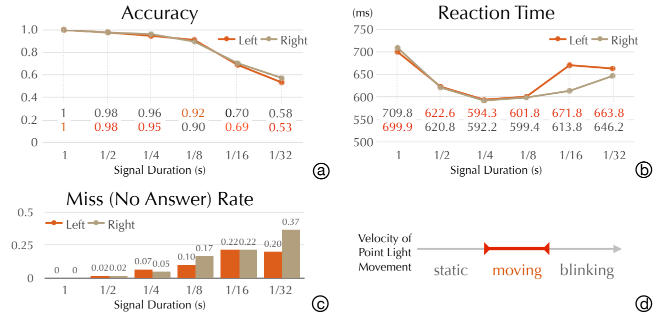


Figure 3. Pilot study 1 results for different light movement velocities. (a) Accuracy. (b) Reaction time (c) Miss (no-answer) rate. (d) Analytical results suggest that peripheral vision can identify to light movement ranging from static to blinking within a range of velocity.

	Initial State	Movement	Left	Right	Split	Merge	Dilate	Erode	Accuracy
Left			239	1					.996
Right			1	239					.996
Split				1	239				.996
Merge			1	3	1	233		2	.971
Dilate			3	2	2	2	217	14	.904
Erode					1	1	6	232	.967

Figure 4. Pilot Study 2 results in confusion matrix on the accuracy of the six types of light movement.

Pilot Study 2: Types of Light Movement

The second study investigated how different light movements affected a user's ability to perceive movement in their peripheral-vision. Twelve participants (10 males) aged $20 - 29$ (mean age, 23.54) were recruited.

Tasks and Stimuli: After the eye tracker was calibrated, subjects were requested to record signal type. Six light movements, Left, Right, Merge, Split, Dilate, and Erode were tested (Figure 4). According to the results of Study 1, signal duration was set to $1/4$ second. After a participant sees the point of light on the tablet in his/her peripheral-vision, the participant recorded the light's movement by pressing an icon via a mouse-controlled cursor. Differing from Study 1, as each participant recorded each light movement, no misses occur and reaction time was not important. The light movements were randomized, and the period between each trial was randomized in the range of $3 - 10$ seconds. A trial was invalid if a user did not gaze at the target for > 0.2 seconds, and the trial was retried until it was successful. In total, 1440 successful trials were completed (6 (signals) $\times$ 5 (trials) $\times$ 4 (blocks) $\times$ 12 (participants).

Results and Discussions: All signal types were recognized with over 90% accuracy, suggesting that participants were able to distinguish between types (Figure 4). The Dilate and Erode are prone to be misinterpreted, because the movement is subtle. Merge sometimes was misinterpreted as Left or Right as the initial state was not recognized by the peripheral vision. The signals were generally perceived and inter-

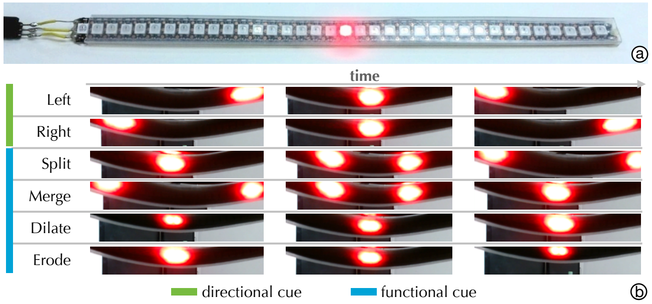
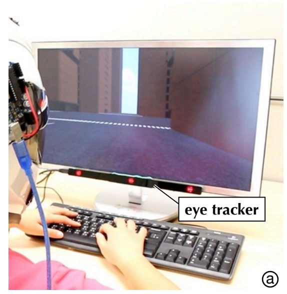


Figure 5. (a) NeoPixel RGB LED strip. (b) Six light movements on the LED light strip inside a helmet.



	Signal Duration (s)	Left	Right	Split	Miss	Accuracy	Mean Reaction Time (ms)
Left	1	397	1	1	1	0.993	954
	1/4	396	1	3		0.990	716
Right	1		398	2		0.995	1100
	1/4	2	390	7	1	0.975	762
Split	1	12	1	386	1	0.965	761
	1/4	8	12	378	2	0.945	687
Overall	Mean distraction count per route: 1.137					0.977	830

Figure 6. (a) Experimental apparatus. (b) User study results in confusion matrix on accuracy with reaction times and visual distraction counts measured while driving.

preted. Using more salient movement and/or unambiguous initial states increased effectiveness.

HARDWARE DESIGN AND IMPLEMENTATION

The dynamic 1D display is implemented by attaching an Adafruit NeoPixel RGB LED strip to the front edge of a scooter helmet. The strip is connected to a micro-controller connected to a computer via an USB connection for power and data transfer. Wireless communication modules and batteries can be used to remove the system's tether in the future. Based on pilot study results, six signals (Figure 4) were presented on the LED strip (Figure 5), and they were categorized as directional or functional. Directional cues were Left and Right, which are essential to route guidance; functional cues were Split, Merge, Dilate and Erode, each of which can carry additional information to indicate, say, a traffic jam ahead, or warnings.

To exploit the peripheral vision of a scooter driver, a display module should not allow a driver to gaze directly at the visual signal. Instead, a visual signal should be sufficiently intense such that the drivers can perceive it without looking directly at it. Hence, to place the LED strip, this work referred the work by Danku *et al.* [5], and placed the LED strip outside the field of view ($> 15°$ angle of pitch). Moreover, the LED strip faced a user's forehead to ensure that light entered a user's peripheral vision. All signals were in red for maximum saliency, and signal duration was less than $1/4$ second. Each signal was only presented once to minimize distractions.

SIMULATION-BASED USER STUDY

To assess the capability of users to see and interpret the visual cues while driving, this work conducted a simulation-based user study to identify the *upper bound* of a user's performance using the proposed method.

Participants and Apparatus: Twenty paid participants (10 males) aged $21-29$ (mean age, 23.75) were recruited. Fifteen were experienced scooter drivers, and the other five road bicycles daily. Each participant wore the the helmet with the LED strip in front of a 24-inch LCD display, with a Tobii REX eye tracker that tracked gaze positions (Figure 6(a)). Participants sat in an open environment (with environmental noise), wore the helmet, and drove a scooter on a simulator implemented using Unity[7]. The city consisted of an 8×8 grid of Manhattan street blocks. In this simulated city, all buildings are the same to prevent participants from memorizing the routes visually. Participants drove 25 mph in the simulation.

[7]https://unity3d.com/

Tasks and Stimuli: After the eye-tracker was calibrated, participants were instructed to focus on the road ahead as if they were actually driving. Participants placed both hands on the keyboard, in the same position as they would if they were driving a scooter. Once a participant noticed a signal, they pressed the F or J keyseach key has a bumpor pressed the *space* key for Split signals. Even when the user did not respond to a signal, the scooter turned as scripted because the focus of this study was to measure accuracy and reaction time after a user perceived a signal. The three signals that yielded the highest performance in Study 2 were used in this test: Left, Right, and Split. Each signal was presented in two durations: fast ($1/4$ second) and slow (1 second). Four 5-minute scripted routes were provided. The sequences of movement types and speeds were randomized, and the sequence of the routes was counterbalanced. Learning effects were avoided by implementing a practice session. Fatigue effects were avoided by allowing participants to rest after each trial. The numbers of correct responses and misses (no response) were recorded, as were reaction times. Based on eye-tracking data, number of time a driver was distracted was recorded; distraction was defined as looking somewhere other than at the target for > 0.2 seconds, which is the lower bound of typical eye movement time. In total, data from 20 (participants) $\times$ 3 (signals) $\times$ 2 (speed) $\times$ 5 (trials) $\times$ 4 (routes) = 2400 trials were collected. After each test, the participant was interviewed.

Results: The average accuracy for all light signals was 97.71%, and only 0.16% were missed, suggesting that participants were able to see and identify the light movements (Figure 6(b)). The average reaction time of 830 milliseconds shows that subjects were responsive to light movement. Light movement speed also had an effect on reaction time. Unpaired t-test results show that all three fast light movements had significantly faster response times than the three slow light movements (all $p < 0.01$), suggesting that lights that move rapidly should be used in urgent cases. The mean distraction count per each 5-minute route of 1.137 also confirms that peripheral visualization did not introduce visual distractions. Analytical results demonstrate that the proposed system was effective.

Figure 7. Radar-like light animation with an absolute direction cue. (a) The point light first locates at direction of the desired route's entry, and (b) then moves and dilates when approaching to the entry.

User Feedback: One participant mentioned that *"Since it was too close to look at the moving light directly, I concentrated on the main driving task"*; and another reported that *"The LED strip actively pushed the signal into my sight, and I felt comfortable using my peripheral vision to see the signals."* One participant said she was startled by the light when it first appeared, but soon felt better as she became used to the system. Providing a progress bar was recommended by one driver, who reported that highway drivers need extra time to prepare before making turns, and another suggested that the distance to a crossroad can be color-coded. According to one driver, directional cues presented were only suitable for typical crossroads, like those in Manhattan, and felt that a radar-like absolute direction cue can be useful for road guidance in complex road networks (Figure 7). These opinions and recommendations, which appear useful, require further examination because complex signals may also increase the cognitive effort needed for their interpretation.

CONCLUSION AND FUTURE WORK

This work presented the *LEaD* guidance system that utilizes light movement in the scooter drivers peripheral vision for turn-by-turn navigation. Pilot study results identified a suitable range for light transition speeds and a set of visual signals. The simulation study results further suggest that light movement in the peripheral vision can effectively direct drivers without introducing visual distractions. We believe these results extend the dimension of peripheral visualization research.

Although the simulation study was useful for understanding human factors, the simulation excluded some factors associated with real-world driving, such as environmental noise, bumps, and other motorcyclists. Future research can include several of these real-world factors when assessing the efficacy of the proposed navigational system.

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