SecretSign: A Method of Finding a Specific Vehicle Privately and Quickly using Flashing Lights

Yusuke Sakai, Hiromi Morita, Yoshio Ishiguro, Takanori Nishino, and Kazuya Takeda

***Abstract*—In this paper we propose SecretSign, an interactive system which enables users of shared-mobility services to find their allocated vehicle quickly without notifying other people of the identity of the target vehicle. A light attached to the target vehicle turns on and off in conjunction with the user's operation of a remote control device, while the lights on other vehicles blink in 'random' patterns created by study participants. We tested a passive approach, in which the light on the controller blinks in conjunction with the target, however we found users could identify the target faster with manual operation. We collected typical user-generated 'random' patterns in order to better camouflage the distinct patterns likely to be employed by users. We experimentally evaluated SecretSign in a parking lot, and verified that it is also effective in the daytime. Bystanders were rarely able to identify the user's vehicle.**

***Index Terms*—Interactive systems, telecontrol, shared-mobility, personal security, discreet location.**

I. INTRODUCTION

AUTONOMOUS vehicles are steadily improving, and it is expected that autonomous vehicles will begin appearing on roads in large numbers in the near future. For instance, Alphabet is already conducting on-road testing of Waymo One, a self-driving taxi service. Autonomous vehicles will expand the possibilities for shared-mobility, such as ride-sharing and car-sharing, by enabling automated vehicles to efficiently allocate themselves in response to user demand. Although many studies related to shared-mobility have focused on the simulation of ride-sharing using the mobility-on-demand systems [6] or on the environmental benefits of utilizing shared autonomous vehicles [4], few studies have focused on systems that improve the user's experience when accessing shared-mobility vehicles. Consider the case of someone trying to find a vehicle assigned to them by a car-sharing or ride-sharing service in a parking lot, a busy pick-up zone or on the road. Although a Global Positioning System (GPS) can be used to determine the approximate position of the vehicle, it can be difficult to find a specific vehicle from among many others, especially when the vehicles used by a shared-mobility service look similar or the same, as is the case with Waymo One. The user could locate their car by reading the license plates of each vehicle, but this process is not intuitive nor efficient since the user would need to remember a specific license plate number, which can include up to 7 alphanumeric characters in the United States, for example, and check every vehicle in the area until finding the exact match. This process could take a long time and might be difficult for the user if there are many vehicles. It is also extremely important for users to find the correct vehicle in a ride share scenario, since it can be very dangerous if the user enters the wrong vehicle. Therefore, developing an interface that enables users to positively identify their designated vehicle more intuitively, easily and accurately would be very desirable.

According to the National Crime Victimization Survey (NCVS) [2], it is estimated that more than 400,000 crimes (which include rape, sexual assault, robbery, and aggravated or simple assault), and more than two million property crimes (which include motor vehicle theft and property theft) took place in parking lots or parking garages in the United States annually, on average, during the period from 2004 to 2008, which suggests these can be very dangerous places. Currently, drivers can use a remote control key to find their vehicles by making the lights blink and/or the horn sound. Although not all of the crimes included in the NCVS involved assaults on drivers accessing their vehicles, using a remote control key to locate a vehicle in these areas can be dangerous because anyone else in the area can also easily identify the driver's vehicle, allowing an attacker or car thief to intercept them. If only the user knows the location of the target vehicle, it is more difficult for a would-be attacker to intercept them quickly, without tipping off the intended victim by directly following them or by hovering around suspiciously.

This problem can be resolved by enabling users to identify their target vehicle without detection. In a previous study, we proposed a more general version of SecretSign, as a method of finding an off-line target object without revealing the target to other people [14]. In this paper, we introduce improvements to our SecretSign system and conduct a proof of concept study to explore the improved system's functionality and effectiveness. We consequently expand our inquiry as follows:

- introduce user-generated 'random' blinking patterns which are likely to be more similar to the blinking patterns employed by users than truly random patterns;
- evaluate color-based and passive approaches for finding target objects;
- use brighter lights for more visibility and evaluate SecretSign performance under direct sunlight conditions.

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II. RELATED WORK

The Global Positioning System (GPS) is widely used for locating users or objects. GPS equipped vehicles can be located on a map, for example, and Google Maps provides the option of saving and finding the locations of parked vehicles on a map. However, it can still be difficult to visually locate a vehicle in the real world because we need to compare the landmarks on the map with real-world locations as observed by users.

In the context of the Internet of Things (IoT), there is an urgent need for a secure object tracking method, which could be used for many applications, such as finding lost objects [15], finding objects in a room [10], tracking components in a supply chain [3], etc. Sun et al. [15] focused on secure object location using mobile crowdsourcing and Bluetooth tags attached to valuable objects, which enabled users to infer the location of lost objects securely based on the responses of mobile phone users. But quickly and discretely associating a user with a specific object in the real world, e.g., a vehicle in a parking lot, requires a different approach. Nickels et al. [10] developed Find My Stuff (FiMS), which helps users find physical objects in a room using relative position cues, e.g., “the phone is inside the top drawer” or “the wallet is between the couch and the table”, using Radio-Frequency Identification (RFID) tags, devices that allow information to be read via a radio signal [17], and a ZigBee personal area network. Their study showed that users could retrieve objects significantly faster with FiMS than by conducting a normal, manual search. However, FiMS does not allow users to identify specific objects visually when there are many similar objects in the same location.

Augmented reality (AR) technology can also be used as a method of finding objects [1]. Rekimoto proposed an AR system called NaviCam, which added information to real world objects through a camera view [12]. This kind of AR system can enable users to quickly and visually identify a target object using Computer Generated Imagery (CGI) superimposed on the real environment. However, this approach requires a camera for detecting objects and a display or special glasses for superimposing CGI on the user’s field of vision, therefore it requires too much equipment for users who are simply trying to find their allocated vehicle from among many others.

Uber has developed Uber Beacon [7], which enables its customers to find the vehicle of their driver quickly at night, particularly in crowded places. Uber riders can personalize their vehicle by selecting a color from a color wheel on their smartphone, causing the Beacon on the windshield of their driver’s vehicle to glow in the same color, allowing them to identify their reserved vehicle quickly. The Uber driver can also find the right passenger by looking for a raised phone screen glowing in the selected color. However, when multiple users try to find their vehicles at the same time, confusion may occur if riders chose similar colors, and it can be difficult to perceive the colors in bright sunlight. Additionally, users need to look at both their phone screen and the lights on the vehicles; it may be quicker to find the target vehicle if users only needed to look at the lights on the vehicles, without needing to check a device in their hands.

It has been shown that mouse operators can identify their operating cursor on a computer screen from among multiple dummy cursors moving randomly across the screen [18]. Computer users could identify their operating cursor by moving the mouse, but other people observing the computer screen had great difficulty identifying which cursor was being manipulated by a real user. This is because when a person actively moves their body, e.g., by moving a mouse, a motor command is sent to the motor system. It has been suggested that a copy of a motor command, known as the efference copy [16], is created to predict the sensory consequences of actions for comparison with actual outcomes [8]. This efference copy is considered to be related to a “sense of agency”, which refers to the subjective feeling of control over one’s actions as well as their consequences [9]. Farrer et al. evaluated relationships between a subject’s sense of agency and delays in changes on a screen resulting from the user’s actions (pressing a button) in [5]. The results suggested that shorter delays lead to a higher sense of agency. We thought this sense of agency may be what enables someone to find their own moving cursor from among many others, as described in [18], and that it might be possible to apply the same principle to real world objects in order to achieve our research objectives.

On the other hand, Rukzio et al. proposed The Rotating Compass: a public floor display to assist pedestrian navigation [13]. A floor display continuously indicates different directions in clockwise order, and the user’s mobile phone informs the user by vibrating when their desired direction is indicated. This enables multiple users to find the correct direction to their goal at the same time, without any operation by users. It might be possible to apply a similar approach to achieve our research objectives, but further evaluation of the effectiveness of this approach, in comparison to the use of methods involving user operation, is required.

In a previous paper we proposed a general method for discreetly locating a particular object, which we called SecretSign. It allows a user to find an object without notifying others of the identity of the target. A light attached to the target object blinks on and off in conjunction with the user’s activation of a remote control device, while the lights on the other objects turn on and off randomly [14]. While we experimentally verified that SecretSign enabled users to quickly find their target objects, in most cases without revealing the target to other people, several participants in the experiment reported that the pattern in which the light attached to the target object blinked did not always appear to be random, making it possible for careful observers to identify the target. This was because the blinking patterns chosen by the users had distinctive characteristics, even when they tried to make the light appear to flash randomly like the others. In addition, the experiment described in [14] was conducted in a parking lot in the evening, for better visibility of the lights, thus an experiment in sunlight is required to verify the effectiveness of SecretSign in wide range of actual environments.

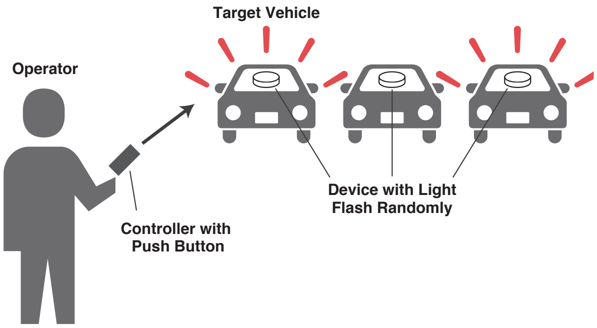


Fig. 1. An overview of SecretSign deployed on vehicles. A device with a flashing light is attached to every vehicle in a group, and an operator holds a controller with a push button. Only the light attached to the target vehicle flashes in response to the user's operation of the push button, while the lights on the other vehicles flash randomly.

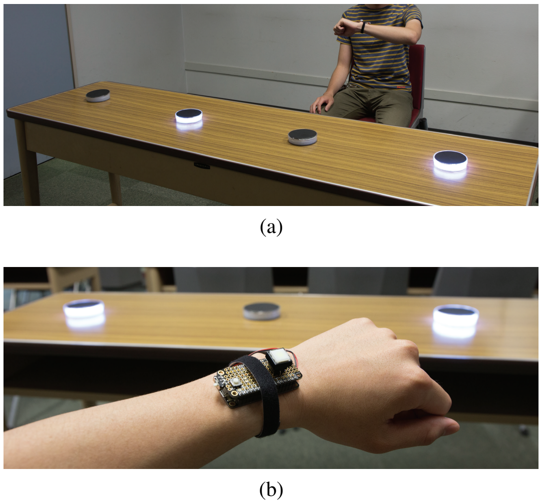
III. OVERVIEW OF SECRETSIGN

In order to enable the users of vehicles (who we call operators) to find their own target vehicle, but not other people in the area (who we call observers), we propose the use of flashing lights as a clue, rather than the movement of the object, as was done in [18]. An overview of SecretSign as deployed on vehicles is shown in Fig. 1. We developed a device that has a bright flashing light, and attached one of these devices to each vehicle in a group. When the system is activated, only the light attached to the target vehicle flashes in response to operation of the remote controller in the possession of the operator, while the lights attached to the other vehicles flash randomly. Finding a vehicle using this process is relatively quick and intuitive compared to reading the license plate of each vehicle, because the user does not need to remember specific license plate information or check each vehicle. The SecretSign user simply operates a push button, like those on a conventional key fob, and then locates the corresponding flashing light, without any need to remember or read plate numbers. Since only the controller used by the operator and the flashing light on the target vehicle work in tandem with one another, the operator can discreetly and intuitively identify the target vehicle.

To solve the problem identified in [14], that the 'random' patterns selected by users to locate their target vehicle had distinctive, non-random characteristics, in this study we explored using the 'random' blinking patterns generated by other users with the flashing lights on the non-target vehicles, instead of using truly random patterns. We expected that these user-generated, 'random' blinking patterns on the non-target vehicles would make it more difficult for observers to identify the target vehicle of the operator.

IV. COMPARISON OF EFFECTIVENESS BETWEEN ACTIVE AND PASSIVE MODES

It would be possible to ensure that observers have no chance to identify the operator's target object based on distinctive blinking patterns by eliminating manual operation by the operator, e.g., via the pressing of a key or a button. This could be achieved, for instance, if a light on the controller flashed randomly in conjunction with the light on the target device, while the other peripheral devices also blinked on and off randomly.


(a)

(b)

Fig. 2. Experimental setup for comparing the effectiveness of SecretSign's active and passive modes: (a) Overview of the arrangement of the devices on the table in relation to the position of the operator, (b) Overview of the controller worn on the left wrist of the operator.

Thus, when the target device blinks in response to the user's operation of a button on the controller, the system can be said to be operating in "active mode", and when the light on the controller blinks randomly in conjunction with the target device, the system can be said to be operating in "passive mode". When using the active mode, users would have a higher sense of agency [5] (pressing a push button activates the light) than when using the passive mode. We hypothesized that the operators would identify the target object faster when using the active mode than when using the passive mode, and evaluated this by comparing the difference in the time needed for operators to find the target object when using each mode.

A. *Method*

Our experimental setup is shown in Fig. 2. The operator wore the controller on his wrist and sat on a chair in front of a table on which four devices with blinking lights were arranged in a line. There were no observers during this experiment.

The experiment was conducted under two different conditions, active mode and passive mode. We performed two sets of five trials under each of the two conditions (active and passive) for each of the five participants, thus a total of 100 trials were conducted. The order in which active versus passive conditions were used in each trial was random. We recruited five students (five males, aged $20 \leq \text{age} \leq 25$) who had normal vision as participants for this preliminary experiment.

Each trial was conducted as follows:

1) The trial started when the operator turned on the controller. A stopwatch was also started simultaneously to record how long it took the operator to find the target object.
2) The operator tried to identify the target device by pressing the controller button when in active mode, or

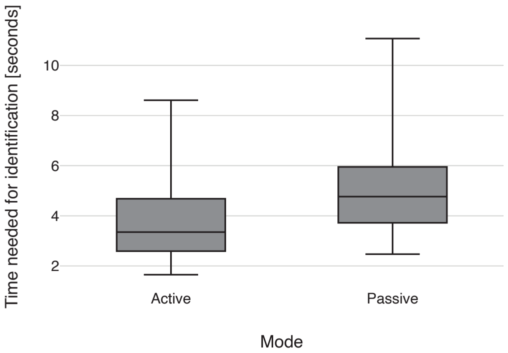


Fig. 3. A box plot of the time needed for operators to identify the target, in both active and passive modes. The horizontal line within each box represents the median time needed to identify the targets.

by looking at the flashing light on the controller button when in passive mode.

3) When the operators identified the target object, they wrote down the time on the stopwatch.

We then calculated the median time needed for operators to find the target object when using each mode.

B. Results

The operators identified the target objects correctly in all of the trials. A box plot of the time operators needed to identify the target is shown in Fig. 3. We used a Mann-Whitney U test to determine if there was a significant difference in identification time needed when using active versus passive mode. The median times needed for operators to identify the target in active and passive modes were 3.35 seconds and 4.77 seconds, respectively. Distributions in the two groups differed significantly (Mann-Whitney $U = 664$, $n_{\text{active}} = n_{\text{passive}} = 50$, $P < 0.05$ two-tailed), where n_{active} and n_{passive} are the number of experimental trials in active and passive modes, respectively.

C. Discussion

Both active and passive modes were effective for identification of the target objects because the operators identified the target correctly in all of the trials. The time needed for operators to identify the target was significantly shorter when using active mode; therefore, we decided to use SecretSign in active mode instead of passive mode.

V. ON-SCREEN EXPERIMENT

In this section, we experimentally investigate how the number of similar objects that are present effects detection accuracy or time needed for target identification when SecretSign is used in active mode, for both operators and observers. In addition, we discuss an upper limit on the number of objects which can be present in a group, and compare timing-based and color-based approaches. In order to better understand user and observer behavior, and to explore other possible uses of the SecretSign concept in general, for the experiment described in this section we designed an ideal environment in which circles are projected on a screen.

A. Implementing SecretSign on a Screen

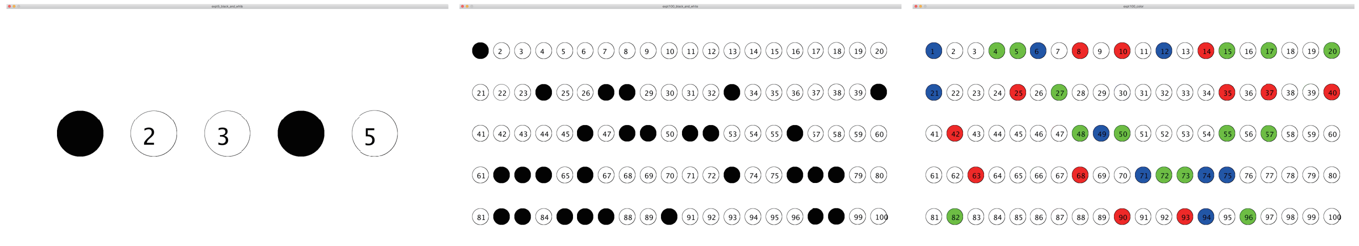
In order to determine the upper limit on the number of objects from among which a target object could be detected when using SecretSign, we simulated the SecretSign system on a screen. Multiple circles, each with a unique ID number, were projected on a screen using a projector, as shown in Fig. 4. These circles change their color back and forth from white to black in conjunction with the operator's pressing of a key on a keyboard, which corresponds to turning the light on the SecretSign device on and off as described in Section IV. This experiment enables us to analyze whether the operator is able to identify the target on a screen by observing the change in the color of the target object when there are many objects which are changing color randomly. It also allows us to determine if observers are able to detect the target object.

Uber has developed Uber Beacon to help its customers find their vehicle quickly, using a beacon on the vehicle which glows in a color selected by the customer, as described in Section II. If the SecretSign operator could control not only the timing of the blinking but also the color, the operator might be able to identify the target faster due to greater variation in the appearance of the target object in response to their operation (e.g., the timing of the blinking and the color of the beacon). We therefore added the feature of allowing the operator to change the color of the target circle on the screen, as shown in Fig. 4(a).

The core logic of these timing-based and color-based approaches is based on the user's "sense of agency", as described in Section II, which is the subjective feeling of control over one's action (operating the keys on the operator's keyboard) as well as the consequences of those actions (changes in the colors of circles on a screen).

B. Method

Neither the operators nor the observers were told which circle was the target. Under the condition that the operator could only control the timing of the blinking (which we called 'without color'), we had the target circle change from white to black when the Z key on the keyboard was being pressed, while the other circles on the screen changed back and forth from white to black randomly. Similarly, under the condition that the operator could control the timing of the blinking and the color of the circle (which we called 'with color'), the color of the target circle changed to white when the operator was not pressing any key, and when the operator was pressing the R, G or B keys, the color of the target changed to red, green or blue, respectively. We asked both the operators and the observers to identify the ID number of the target circle. Observers were told to look at the monitor and not at the operator's keyboard. We conducted the experiment with various different numbers of circles, so that either 5, 10, 50, 100, 500 or 1,000 circles were shown on the screen. We chose a maximum value of 1,000 for this experiment because we wanted to determine the upper limit on the number of objects from among which SecretSign users could successfully find a target object. Under the condition 'without color', eight trials each were conducted using 5, 10, 50, 100, 500 or 1,000 circles. Under the condition



(a) (b) (c)

Fig. 4. Examples of the circle arrays: (a) when the number of circles is 5, (b) when the number of circles is 100, (c) when the number of circles is 100 and colors (red, green and blue) are also used.

'with color', eight trials each were conducted using 5, 10, 50, or 100 circles, and six trials each were conducted using 500 or 1,000 circles. We reduced the number of trials when using 500 and 1,000 circles to six because we discovered during the experiment that it was too difficult for some participants to find the target circle among a very large number of circles. We recruited 10 students and staff (7 males, 3 females, 20 $\leq$ age $\leq$ 45) who had normal color vision as participants for this experiment. During each trial, one participant was the operator while the others served as observers, with the participants changing roles after each trial.

Each trial was conducted as follows:

1) When the session started, the target circle was randomly selected by the system, and a stopwatch was started to record the time needed by the operator and each observer to find the target circle.
2) The operator tried to identify the target circle by pressing and releasing keys on the keyboard, while the observers tried to find the target circle only by watching the changes on the screen.
3) When the operator and each of the observers found the target circle, they wrote down the time on the stopwatch and the ID number of the circle.
4) After the operator found the target circle, he or she kept operating the keyboard in the same manner as before.
5) Each trial lasted 60 seconds. If the operator or observers did not find the target circle, they noted that they did not find it.

We used the Processing application [11] to construct the tasks used in this experiment.

C. Results

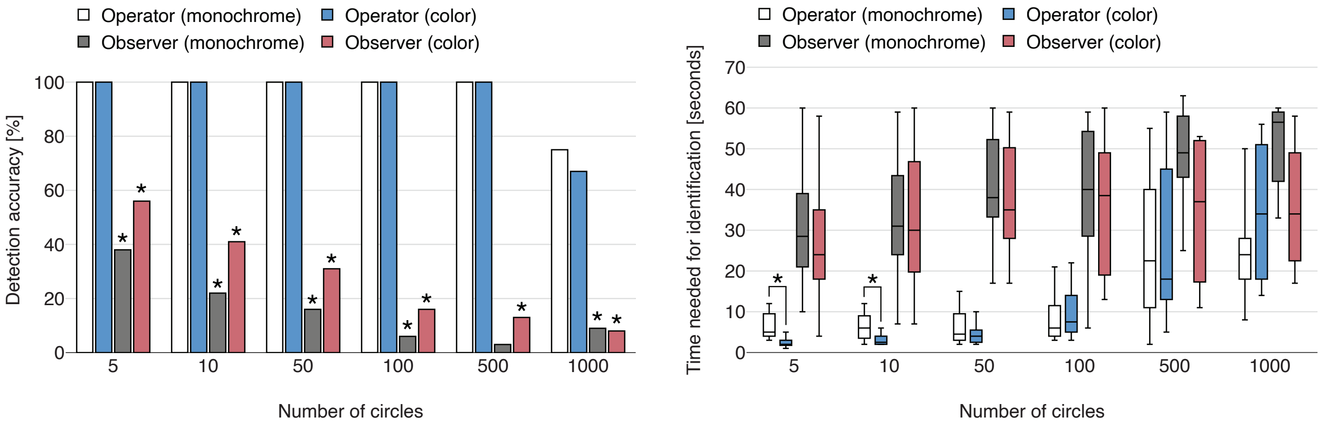
The relationship between the number of circles on the screen and detection accuracy for the operators and observers is shown in Fig. 5(a). The relationship between the number of circles and the time it took for the operator and observers to find the target is shown in Fig. 5(b) with box plots. In order to plot "Time needed for identification" by the operator and observer, only trials in which the operator or observers correctly identified the ID number of the target circle were used.

We conducted a binomial test to determine if the detection accuracy of the observers was significantly higher than chance under each of the two conditions (monochrome and color) and for each number of circles (5 through 1000). Bars with a $*$ above them in Fig. 5(a) indicate that detection accuracy was significantly higher than chance ($P < 0.05$ one-tailed). In addition, we used a Mann-Whitney U test to determine if there was a significant difference in the median time needed for identification by the operators under monochrome versus color condition. The median time for identification by the operators differed significantly ($P < 0.05$ two-tailed) under the monochrome versus color condition when the number of circles was 5 and 10, as indicated in Fig. 5(b) by the $*$ above the box plots.

D. Discussion

As shown in Fig. 5(a), as the number of circles increased from 5 to 500, the detection accuracy of the operator remained at 100%, while the detection accuracy of the observers decreased. When there were 1,000 circles, the detection accuracy of both the operator and the observers was low. This indicates that the operator could identify the target object from among up to around 500 objects while the observers could not. In addition, as Fig. 5(b) illustrates, the operator could identify the target in less than 10 seconds when the number of circles was 100 or less, which was much faster than the observers. However, the mean time needed by the operators to find the target increased sharply under both the 'without color' and 'with color' conditions when the number of circles increased from 100 to 500. Therefore, we consider the upper limit on the number of objects which can be quickly and accurately discriminated among by an operator, when using circles projected on a screen, to be around 100.

The operators identified the target circle significantly faster under the "color" condition versus the "monochrome" condition when the number of circles was 5 and 10. This implies that the operators could identify the targets faster using a color-based approach than a timing-based one when viewing circles on a screen. However, when the number of circles was 500 or less, the detection accuracy of the observers was higher when the timing and color of the changes could be chosen by the operator, as denoted by "Observer (color)" in Fig. 5(a). In comparison, it was more difficult for observers to identify the target when only the timing of the change from black to white could be controlled by the operator, as denoted by "Observer (monochrome)" in Fig. 5(a). This indicates that it is easier



(a)

(b)

Fig. 5. Results of on-screen experiment. (a) Relationship between the number of circles and detection accuracy, for both operators and observers, with and without colors. The $*$ above a bar represents detection accuracy that was significantly higher than chance ($P < 0.05$ one-tailed). (b) Box plots show the time needed for target identification, for both operators and observers, with and without colors. The horizontal line within each box represents the median time needed to identify the targets. The $*$ above a box plot indicates that the median time required for identification by the operators differed significantly between the monochrome and color conditions ($P < 0.05$ two-tailed).

for observers to find the target circle when a variety of colors could be chosen by the operator. Therefore, we decided to use only the timing of the blinking lights as our clue for operators when seeking a target using SecretSign, instead of also using colors.

The following are comments made by observers regarding how they identified the target circles:

1) The patterns used by the operators when changing the color of the target circle had distinctive characteristics;
2) The sound of the operators pushing the keys of the keyboard was noted in relation to the changes on the screen;
3) Completely by intuition.

The first comment implies that operators tend to change the color of the target circle in distinctive, non-random patterns. In addition, the results showed that the detection accuracy for the observers was significantly higher than its chance in most of the conditions, which implies that the observers could identify the target with confidence by observing the operators' distinctive patterns in some trials. Therefore, we consider it might be possible to make it harder for observers to identify the target by using blinking patterns that are more similar to those generated by actual users. The second comment suggests the use of a device that does not emit a sound when the button is pressed.

VI. ACQUISITION OF USER-GENERATED RANDOM PATTERNS

Some of the participants in the on-screen experiment described in Section V commented that they could identify the operator's target circle because the blinking pattern of the target sometimes had distinctive characteristics. We thought it might be more difficult for observers to identify the targets of SecretSign users when the system is in active mode if the lights on all of the non-target peripheral devices flashed in user-generated patterns instead of in truly random patterns. We therefore acquired actual user-generated 'random' patterns employed by operators when trying to find target circles during the experiment described in Section V.

We will now describe our method of acquiring these user-generated 'random' patterns and discuss the details.

A. Method

We modified the application used in the experiment described in Section V in order to acquire the user-generated 'random' patterns used by operators when trying to find a target circle under the 'without color' condition. The sequence of key-pressed and key-released duration times were acquired by recording the elapsed time for each key operation from the beginning of each trial. We set the number of circles at 500, with only the timing of the change of the circle from white to black being controlled by the operator. In this experiment, the other circles stayed black for a period selected randomly, from about 0.1 to 1 seconds, and then the circle remained white for about 0.1 to 4 seconds. This random pattern is based on our observation that users tended to push the button for a short period of time and then allow longer periods of time to pass when they were not pushing it.

We recruited six students and staff (six males, $21 \leq$ age ≤ 45) who had normal vision as participants for this experiment, with three participants taking part in each trial. The participants for this experiment were different from the ones in our evaluation experiment, described in Section VIII because the objective of this experiment was simply to collect typical user-generated random patterns in order to better hide or camouflage distinct, non-random patterns which were likely to be used by operators. During each trial, one participant was the operator and the two others were observers. We conducted three trials with each participant as the operator, resulting in 18 trials in total. The circles were displayed on a TV screen.

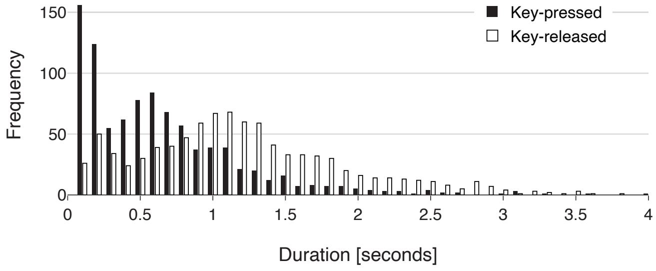


Fig. 6. Histograms of time duration for the key-pressed (black bars) and key-released (white bars) conditions for all participants. Each bar represents the total number of 'key-pressed' or 'key-released' events which occurred during each time period.

Each trial was conducted as follows:

1) When the session started, the target circle was randomly chosen by the system.
2) The operator tried to identify the ID of the target circle as quickly as they could by pressing the keyboard, while trying not to reveal the target to the observers. The observers tried to find the target circle by watching the changes on the screen.
3) When the operator found the target circle, he pressed the escape key to finish the trial.
4) When the trial finished, the experimenter wrote down whether or not the observers identified the target circle correctly.

B. Acquired Data

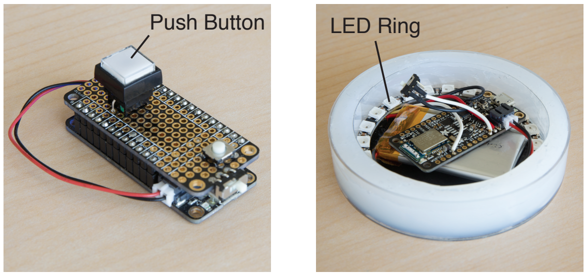
The average duration of each of the 18 trials was 60.4 seconds ($SD = 67.4$). The histograms of time duration for the key-pressed and key-released conditions are shown in Fig. 6. 'Key-pressed' represents the periods when the operator was pressing the key, and 'key-released' represents the periods when the operator was not pressing the key. The mean duration of the key-pressed and key-released states were 0.66 second and 1.26 seconds, respectively. The histograms of both the key-pressed and key-released states have two peaks. The shortest time interval on the key-pressed histogram shows a sharp peak due to high frequency, meaning operators tended to press the key for a very short period of time (0.1 to 0.2 of a second).

VII. DEVICE IMPLEMENTATION FOR FIELD EXPERIMENT

In this section, we describe in detail the implementation of both the hardware and the software of the devices used in our SecretSign system during our field experiment.

A. Hardware

Fig. 7 shows the devices used by the SecretSign system. Fig. 7(a) is a controller that can be carried in a pocket or worn on the wrist. Fig. 7(b) is the peripheral device that is attached to each vehicle in a group of vehicles. Fig. 8 shows the hardware setup of our system. The controller consists of an Adafruit Feather nRF52 Bluefruit LE, a push button and a battery. The peripheral devices consist of an Adafruit Feather nRF52 Bluefruit LE, a circular LED light and a battery. The central controller and the peripheral devices communicate via Bluetooth Low Energy (BLE).



(a) (b)

Fig. 7. Devices used by the SecretSign system: (a) A controller which is used by the operator, (b) A peripheral device, one of which is attached to each vehicle in a group of vehicles.

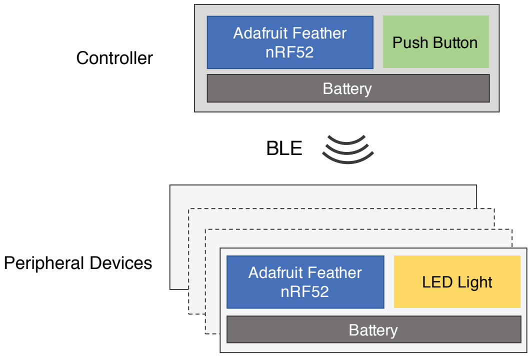


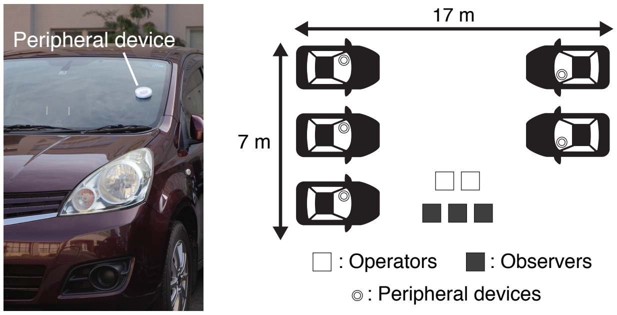
Fig. 8. Overview of the hardware setup. A controller is used by the operator (see Fig. 7(a)). The peripheral devices are the devices attached to a collection of vehicles (see Fig. 7(b)). The controller scans the IDs of all of the peripheral devices to find the target peripheral device.

B. Software

We used Arduino to develop the software for the controller and the peripheral devices.

1) Controller: When the controller is connected to the peripheral devices via Bluetooth, the controller scans the IDs of all of the peripheral devices to find the target peripheral device. The controller then sends all of the peripheral devices the ID of the target peripheral device when the push button is pressed, using a loop function which is executed repeatedly. When the state of the push button changes from pressed to released, the controller sends a stop command to all of the peripheral devices.

2) Peripheral: Once a peripheral device is connected to the controller via Bluetooth, its LED light starts blinking on and off 'randomly' using the user-generated patterns acquired as described in Section VI. After every five iterations of blinking on and off in a selected 'random' pattern, a new 'random' sequence consisting of five sets of key-pressed and key-released intervals is selected randomly. The peripheral device then blinks its light on and off based on the supplied duration sequence. When a peripheral device receives an ID from the central device which matches its own ID, it lights up only when the controller button is pressed, and when the button on the controller is released the target peripheral device



(a) (b)

Fig. 9. An overview of the setup used for the parking lot experiment. (a) A peripheral device is attached to the front windshield of each vehicle. (b) The arrangement of the five vehicles and five participants during the two-operator trials.

receives a stop command and it turns off its light. If the push button on the controller is not operated for about two seconds, the light on the target peripheral device begins blinking on and off 'randomly'.

VIII. Field Experiment

Using a method similar to that in [14], we deployed a SecretSign system with user-generated 'random' blinking patterns to five vehicles in a parking lot, in order to evaluate the system's effectiveness for allowing a user to identify an allocated vehicle without revealing the identity of the target vehicle to bystanders. In addition, we tested whether SecretSign is effective under bright daylight conditions and whether SecretSign can be used simultaneously by multiple operators, each trying to find their own target vehicle.

A. Method

An overview of the setup used for the parking lot field experiment is shown in Fig. 9. We attached a peripheral device to the front windshield of each vehicle as shown in Fig. 9(a). The five participants stood in front of the five parked vehicles as shown in Fig. 9(b). The five vehicles were all different in terms of model and color, due to difficulties we encountered in obtaining five identical vehicles. In order to simulate a situation in which the target is hidden among a group identical vehicles, as alluded to above, the target vehicle of the operator was chosen randomly and the operator was not given any preliminary information about the target before each trial. We conducted the experiment under two conditions; with one operator, and with two operators using the system at the same time. We recruited 11 students and staffs (8 males, 3 females, $21 \leq \text{age} \leq 45$) who had normal vision as participants for this experiment. Under the one-operator condition, one person participated as the operator and four participated as observers, with the participants changing roles from trial to trial. Under the two-operator condition, two participants served as operators while three others participated as observers, with the participants changing roles from trial to trial. We conducted 20 trials under the one-operator condition, and 17 trials under the two-operator condition. The experiment took place in a parking lot at Nagoya University under the daytime sun.

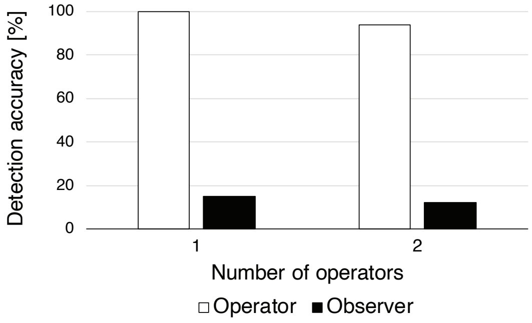


Fig. 10. Relationship between the number of operators and detection accuracy for both the operators and the observers.

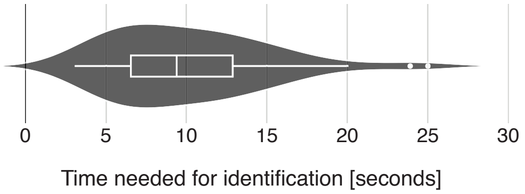


Fig. 11. A violin plot of the time needed by operators to identify their target vehicle under both experimental conditions (one operator and two operators). The vertical width of the violin plot represents the distribution of time needed by the operators to identify their target vehicle. A box plot is drawn within the violin plot in white lines. The vertical line within the box represents the median value, and the white dots represent outliers.

Each trial was conducted as follows:

1) The operator(s) turned their remote controller(s) on. Once the peripheral devices were connected to the controller, the devices started blinking in user-generated 'random' patterns.
2) When all of the peripheral devices were blinking, the experimenter started the stopwatch to measure the time needed for the operator(s) to find their target vehicle. At the same time, the experimenter gave the observers a cue to begin trying to identify the target vehicle(s).
3) Operators tried to identify their target vehicle by detecting which light turned on and off in conjunction with the operation of the button on their remote control. At the same time, the observers also tried to identify the target vehicle(s).
4) When an operator found their target vehicle, they raised their hand as a cue to the experimenter, who then stopped the stopwatch and wrote down the time needed by the operator to find their target vehicle.
5) The experimenter then asked the observers if they had identified the target. If they successfully identified the target vehicle, they were asked to explain how they did so.

In order to evaluate the effectiveness of SecretSign, we used the time needed by the operators to identify the target vehicle, the detection accuracy of the operators and the observers, and the comments of the participants.

B. Results

Fig. 10 shows detection accuracy of the operators and observers. Mean detection accuracy of the operators and observers were 100% and 15.0% under the one operator condition, respectively, and 94.0% and 13.2% under the two operators condition, respectively. The overall mean accuracy rates under both of the two conditions for the operators and observers were 96.2% and 13.2%, respectively. Fig. 11 shows the overall distribution of the time needed by operators to find their target vehicle under both experimental conditions. The median time needed by the operators to identify their target vehicle under both conditions was 9.39 seconds, and the standard deviation was 5.00 seconds.

C. Discussion

As Fig. 10 illustrates, overall the operators correctly identified their target vehicles more than 95% of the time. In contrast, the overall detection accuracy of the observers was less than 15%. Moreover, the overall median time needed for the operators to find their vehicle was less than 10 seconds. These findings indicate that using SecretSign on vehicles allows users to quickly identify their target vehicle without revealing the target to other people, even under daytime conditions. However, operators sometimes needed a longer time to identify the target vehicle, for instance, over 15 seconds and even up to about 25 seconds. Some operators reported that it was hard to identify the target vehicle when the area of the windshield around the SecretSign device reflected the sunlight directly towards the operator. When this occurred, operators needed to move around in order to obtain better visibility of the SecretSign beacon, even though the participants were asked to stand in one place during in this experiment. Thus, although the SecretSign system is effective under daytime conditions, it can occasionally be difficult for users to identify the target vehicle due to the direction or intensity of the sunlight.

Operators needed more time to identify the target vehicle during the field experiment when five vehicles were used (median time = 9.39 seconds), in comparison to finding the target during the on-screen experiment when five circles were used (median time = 5.00 seconds). The environment of on-screen experiment is more ideal for the SecretSign system than that of the field experiment, because it can be more difficult to recognize the LED light of the SecretSign device under direct sunlight conditions due to the lower contrast, in comparison with viewing circles on a screen. Additionally, operators needed to observe a much wider area during the field experiment in order to identify the target vehicle, in comparison with the area they needed to scan to locate circles on a screen. We believe these factors explain why it took longer for users to identify the target during the field experiment. In addition, some participants reported that it took longer for them to find the target at first when using SecretSign, but once they became familiar with it they were able to find the target in just a few seconds. We would like to further investigate how experience using SecretSign decreases identification time for operators.

There were only a few trials in which the operators did not correctly identify their target vehicle. The operators in those trials reported that non-target vehicles seemed to blink in conjunction with their operation of the controller. The vehicle that they mistakenly thought was theirs was not even the target vehicle of another operator. It's possible that the operators in these situations used the same, common 'random' pattern as the users who supplied the 'random' patterns for the system.

As Fig. 10 illustrates, the detection accuracy for operators under the two-operator condition was slightly lower than for a single operator, but still over 90%. This indicates that SecretSign is effective even when there are multiple operators using the system at the same time.

In most of the trials, the observers incorrectly identified the target vehicle; they reported that the device attached to a non-target vehicle seemed to have a distinctive pattern. This indicates that using the user-generated 'random' patterns for the blinking lights made it more difficult for observers to identify the light on the operator's target vehicle, which was being controlled by the operator. One participant reported that they remembered the distinctive characteristics of the pattern used by a specific operator from a previous trial. Although the devices attached to the vehicles blink on and off in user-generated patterns, it is still possible for persistent observers to identify the target vehicle if they understand the characteristics of a particular operator's consistently used blinking pattern.

An important limitation of the current implementation of SecretSign, when used in active mode, is the difficulty which users would encounter if many operators were trying to locate the same target vehicle at the same time, such as when they are trying to find the same autonomous shuttle, due to conflicts among users who are operating their activation buttons at the same time. However, if SecretSign were used in passive mode in these situations, as described in Section IV, there would not be any conflict among users since they do not control the flashing of the light in passive mode. By expanding the functionality of SecretSign to allow operation in both passive and active modes, depending on the situation, would overcome this limitation.

IX. CONCLUSION

In this paper we proposed an interactive system which enables users of shared-mobility vehicles to find their allocated vehicle without other people detecting which vehicle they are looking for. The idea is very simple; blinking lights are attached to objects and the lights attached to the target can be turned on and off using a remote control device, while the lights attached to the other objects turn on and off in human-sourced 'random' patterns. We also tested a passive mode, which would ensure that observers would have no chance of identifying the operator's target due to the distinctive characteristics of the blinking pattern employed by the user. However, we decided to use the active mode for SecretSign because the time required for operators to identify the target was significantly shorter when they used the system in active mode. After an experiment with circles on a screen, we decided to use only the timing of the blinking lights for SecretSign instead of also using colors, because color change information made it easier for observers to correctly identify the target circles. Additionally, the results implied that the upper limit on the number of objects which can be quickly and privately discriminated among by an operator, is around 100. We also evaluated SecretSign's performance in a sunny parking lot and found that the system can be used successfully even during the daytime. We also found that the system performed well even when two operators were using the system at the same time to identify two different target vehicles. We hope our simple, safe and effective method of finding specific vehicles, which could be used when allocating vehicles by computer in real environment, will greatly improve the user experience for future mobility services, such as shared mobility systems using autonomous vehicles.

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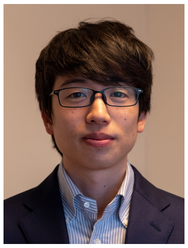

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