Facilitating Pervasive Community Policing on the Road with Mobile Roadwatch

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ABSTRACT
We consider community policing on the road with pervasive recording technologies such as dashcams and smartphones where citizens are actively volunteering to capture and report various threats to traffic safety to the police via mobile apps. This kind of novel community policing has recently gained significant popularity in Korea and India. In this work, we identify people's general attitude and concerns toward community policing on the road through an online survey. We then address the major concerns by building a mobile app that supports easy event capture/access, context tagging, and privacy preservation. Our two-week user study (n = 23) showed Roadwatch effectively supported community policing activities on the road. Further, we found that the critical factors for reporting are personal involvement and seriousness of risks, and participants were mainly motivated by their contribution to traffic safety. Finally, we discuss several practical design implications to facilitate community policing on the road.

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Community Policing; Neighborhood Watch; Traffic; Mobile; Privacy

INTRODUCTION
Community policing is defined as the police's efforts to partner with community members and civic organizations to enhance community safety. This means that the public are considered as co-producers of safety, along with the police [39]. The public get involved in identifying and prioritizing a wide range of neighborhood safety issues (e.g., crimes, norms) and in working with the police to address the issues by participating in

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Figure 1: Mobile Roadwatch usage while driving

various prevention, problem-solving, and law enforcement activities. To foster citizen involvement, local police departments often maintain their websites as well as online communities using Facebook, Yahoo! and Nextdoor groups [28, 13, 32]. Furthermore, police departments organize and manage various neighborhood watch activities in which citizens monitor their neighborhood and report suspected activities to the authorities to prevent crime and vandalism.

Promoting traffic safety, also called "community roadwatch," is another form of neighborhood watch. For example, the police in New Zealand and Canada allow drivers to report bad driving behaviors such as crossing the centerline and tailgating (via phone and mail). As a corrective measure, the police send a warning letter to the offending drivers. The Community Speed Watch (CSW) program [10] in UK allows participants to carry speed detection equipment and identify speeding vehicles in residential areas. The police will then send warning letters to the offenders who may be fined or summoned if warnings are repeatedly ignored.

Recently, the police started leveraging mobile video recording by smartphones and in-vehicle dashcams for community policing. Likewise, researchers explored novel community policing service opportunities with pervasive technologies such as Digital Neighborhood Watch with intelligent surveillance cameras [20] and ComfortZones [4] for fear mitigation with location-based information sharing. In the US, the National Sheriffs Association that organizes neighborhood watch groups introduced a mobile app called the ICE BlackBox that supports video recording, location tracking, and secure reporting to the police. Also, the American Civil Liberties Union (ACLU) developed Mobile Justice, an app launched in Michigan in June 2015 as well as in 17 states and Washington, D.C. that allows citizens to capture videos and send them to the state officers. In India and Korea, citizens can use the mobile apps to report traffic violations captured on video by their smartphones and dashcams, and then the police use the video evidence to issue traffic tickets to the violators. According to the recent news articles, Traffic Sentinel in Delhi Police (released in Dec 2015) received more than 78,000 violations reported by about 5,000 users as of March 2016 [41]. In Korea, Looking for a Witness (released in April 2015) received 516,401 violations reported in 2016 [25].

Despite recent popularity, pervasive mobile recording with smartphones has received little attention in the research communities unlike traditional tools such as online forums and social media [28, 13]. In this work, we explore how pervasive mobile recording with smartphones enable community policing on the road. To our knowledge, none of the prior studies performed real field trials to understand how people use this kind of pervasive video recording on the road for community policing.

Towards this goal, we first perform an online survey to understand people's general attitudes and concerns toward participating in community policing for traffic safety. Our results show a high willingness to report the safety risks that people witness on the road. We found several barriers to reporting threats such as the complicated logistics of the process to secure evidence, and privacy concerns. To solve these problems, we developed Mobile Roadwatch (see Figure 1), a mobile app that supports pervasive community policing by making it simpler and easier to report safety risks on the road with pervasive mobile recording technology. The key idea of Mobile Roadwatch is to provide easy capture of and accessibility to the video with smartphones, as well as contextual information (e.g., date, time, and location). Mobile Roadwatch enables a driver to record any safety risk incidents on the road by simply touching a smartphone screen while driving. It also provides the primary privacy-preserving features of video cropping and audio muting.

We then perform a two-week field trial with 23 participants to understand what and why people capture and report, what they learn, and how they use privacy preserving tools. We find that (1) the key factors for capturing are the risk involvement and seriousness, (2) reporting motivations were mainly about contribution to traffic safety, (3) community policing participants had unique learning experiences about traffic safety, and there were positive influences on the personal norms of law-abidance. From these findings, we propose several practical design implications such as fostering community, raising awareness, and supporting computational tools.

RELATED WORK

Information systems are used to support various forms of civic engagement, such as community policing (e.g., SALUS [20] for digital neighborhood watch), urban infrastructure maintenance (e.g., FixMyStreet [23] and Flooder [15] for making maintenance requests), participatory urban sensing (e.g., air quality sensing for environmental activism [2]), disaster relief (e.g., CrowdMonitor [29] for sharing physical and digital activities), and government budgeting (e.g., BudgetMap [22] for issue-driven budget browsing). In this section, we focus on reviewing the related human-computer interaction studies on community policing such as those investigating online community usage behaviors, and designing software for assisting in conventional community policing as well as enabling new forms of community policing. Furthermore, we review the prior studies on participatory urban sensing with mobile devices, and privacy concerns about pervasive video recording.

Lewis and Lewis [28] analyzed two online community policing communities: (1) the CLEARpath website of the Chicago police designed for citizen involvement and information sharing and (2) an informal web forum (using Yahoo! Groups) organized by local citizens to have problem-solving conversations. They found that the residents used the informal web forum more frequently than the official site, and had diverse usage motives such as building relationship, taking collective action, sharing information and advice, and regulating online/offline norms. As shown in Erete's work [13], online participation can improve the overall engagement in community organized activities and community police meetings.

Most municipal police departments maintain online communities on social media such as Facebook. Prior studies have also examined how such social media are used and for what purposes in community policing. The South African Police Service used a Facebook group to support neighborhood watch (e.g., reporting suspicious activities), and building relationship (e.g., sharing tips and advice) [17]. In the US, social media was mostly used for publishing announcements about crime and traffic, requesting information about urgent issues, and building relationships [19]. Interestingly, Denef et al. [7] found that the language style used by the police had a significant impact on online community involvement: informal and personalized styles elicit better user involvement than formal and depersonalized styles. Violio et al. [45] used Batson et al.'s motive framework [3] and showed that the key motives for participating in online neighborhood watch communities are egoism (for my safety), altruism (for others' safety), collectivism (for our community safety), and principlism (for social justice).

Several recent research prototypes for mobile neighborhood watch include SALUS [20], CrowdSafe [36], and S4S [42]. SALUS [20] visualizes crime related information (e.g., crime maps and safety tips) and allows users to report crimes in real time. CrowdSafe [36] recommends safe paths on a map by incorporating crime data into routing algorithms. To promote campus safety, S4S [42] supports text- and voice-based incident reporting and personalized notification delivery (e.g., preferred paths and places). Another active area of research in the field is the exploration of novel community policing service opportunities. Brush et al. [5] proposed the concept of Digital Neighborhood Watch, in which intelligent surveillance cameras installed at home are interconnected for the neighborhood watch. ComfortZones [4] is a crowdsourced app designed to mitigate fear at night in an urban context by allowing users to capture and share location based safety or comfort attributes and provide social support and interaction to mitigate fear. As shown earlier, pervasive recording with smartphones has become an essential tool for community policing, as is the case with recent apps such as ICE BlackBox, Traffic Sentinel, Looking for a Witness, and Mobile Justice. We significantly extend these prior studies and build a customized tool for a mobile neighborhood watch behind the wheel, by supporting dashcam-like continuous video recording, convenient and safe event tagging, and privacy preserving mechanisms such as video editing and audio muting. To our knowledge, none of the prior studies performed real field trials to understand how people use this kind of pervasive video recording on the road for community policing (e.g., what events they capture, why they capture these events, and how they report videos).

Our work belongs to a body of research on participatory urban sensing in that mobile users capture and share road events via their mobile devices. In general, urban sensing projects aim at collecting sensor data from the crowds through mobile devices, analyzing the sensor data, and sharing the analysis results to inform and persuade participants. Researchers have built various systems for monitoring air pollution (e.g., HazeWatch [37], GasMobile [16], Common Sense [12]), noise pollution (e.g., NoiseTube [31]), and traffic and road conditions (e.g., VTrack [43], Pothole Patrol [14], Mobeyes [27]). The mobility of users ranges from simple walking to riding on vehicles such as vehicular urban sensing [26, 1, 2]. For example, NoiseTube [31] allows citizens to report their GPS-tagged noise measurement with their phones, and these measurement data are aggregated to build a collective noise map. Our work shares the same goal of improving public awareness through urban sensing. While prior studies focused on air or noise pollution and traffic jams, our work focuses on traffic safety. In addition, data collection and sharing behaviors are different. In Roadwatch, participants manually capture events and then report the captured videos to the authorities. The reported data were not shared with the other participants due to privacy reasons, but were directed to the authorities for corrective purposes (e.g., sending warning letters or issuing tickets), and the participants will receive direct feedback from the authorities.

Our design leverages the recent privacy studies on pervasive video recording technologies such as home surveillance, wearable cameras, and vehicle dashcams. The privacy concerns of wearable cameras (e.g., SenseCam and wearable glasses) are nuanced in relation to major contextual factors such as people, objects, activities, and locations [8, 18]. Brush et al. [5] studied the concerns of sharing home surveillance videos for neighborhood watch and found that video sharing for evidence is well-accepted but, because of security and privacy reasons, participants wanted limited information disclosure about their cameras (e.g., location and field of view), and limited video access (e.g., not allowing video streaming to the neighbors). Regarding vehicular sensing (e.g., video and sensing), Sleeper et al. [40] found that vehicle mobility significantly influences people's mental models of recording awareness. Park et al. [34] identified various concerns behind the sharing of vehicle dashcam videos for urban surveillance purposes such as privacy sensitivity of recorded data (e.g., location and voice), data management practices, and sharing efforts (e.g., examining dashcam devices and uploading content). Our design carefully considers the major concerns reported by these prior studies and we attempted to minimize privacy threats by limiting information disclosure and incorporating privacy-preserving features such as clipping relevant video sections and removing the audio.

PRELIMINARY STUDY ON COMMUNITY POLICING ON THE ROAD

As a preliminary study, we conducted an online survey of experienced drivers in order to understand people's general attitudes and concerns toward participating in community policing for traffic safety. The online survey content comprised of two parts, using a five-point Likert scale and open-ended questions. We first asked about their willingness to participate in community policing, which is reporting incidents of traffic safety risks, including traffic violations. We then inquired about the barriers to reporting the safety risks. We finished the survey with demographic questions. The survey was posted to several online car forums and Facebook groups in Korea.

A total of 150 participants responded to the online survey (124 males), with an average age of M = 32.91 (SD = 7.33). The average years of driving was M = 9.52 (SD = 7.04), and 72.7% of the participants had vehicle dashcams. This amount is slightly higher than the 61.1% adoption rate in Korea as of February 2015 [44]. This might be because we recruited participants from online forums for car enthusiasts. Most participants commuted by car since the average days of driving per week was M = 4.82 (SD = 2.22).

Participation Willingness

We first asked the respondents to give their perceptions of current traffic safety. In response to the question, *"I think people obey traffic rules well,"* participants responded that traffic rules are not obeyed well in Korea (M = 2.53, SD = 0.85). Respondents believed that people should abide by the traffic laws (M = 4.41, SD = 0.72); but for the question, *"It should be the norm in our society that citizens report any law violations they witness,"* participants responded that they felt a slightly lower obligation toward reporting (M = 3.69, SD = 0.89).

Barriers to Reporting

In the survey results, we found that only 30.0% of the respondents had actually reported safety risks on the road, despite their high willingness to report such risks. To better understand the reasons for this under reporting, we asked those respondents who know the reporting procedure, through an open-ended question, to describe the cases that they witnessed but did not report. We excluded the responses related to seriousness of safety risks, and performed affinity diagramming.

Our results revealed that the major hindrance was attributed to the complex reporting procedure with the respondents frequently calling it "burdensome" and "annoying." In response to the question, *"The process of reporting traffic safety risks I witness on the road is complicated,"* these responses well align with their answers to the question about reporting complexity (M = 4.01, SD = 0.92). In fact, the current process involves a series of steps: i.e., drivers locate a video footage (by accessing their dashcams), edit and upload a video footage to the site, and input contextual information (i.e., time, location, and description of an event). One respondent complained, *"The process of taking out the memory card from my dashcam and transferring it to a computer is too complicated. Also, I have to put the card back into my dashcam. If I forget to put it back, it will continue to beep, which is quite bothersome."* Note that file uploading in the Korean police's reporting app (i.e., Looking for a witness) is currently limited to 50MB, which often mandates that users to utilize video editing tools for cropping to reduce the file size. For these reasons, this respondent added that he only reported the cases that severely threatened his safety.

Another major theme was the difficulty of remembering: *"I mostly forget about reporting when I get out of my car"* and *"It requires some effort to recall the exact time and place of the violation."* There were also concerns about privacy and security. The recorded videos might include a driver's sensitive personal information, such as singing or talking with a fellow passenger in the car; but respondents complained that editing video files requires significant effort and separate video editing software. There was also some concern about retribution due to disclosure of personal information.

Design Implications

We found that respondents had a high willingness to report safety risks that they witnessed on the road. At the same time, the barriers to reporting include reporting costs (i.e., time and efforts) involved in various steps of the reporting procedure, and the concerns of privacy and security. Thus, it is very important to design a mobile system for community roadwatch that can significantly lower these participation barriers. We drew several design implications from our preliminary study results as follows.

First, we need to reduce the burden of capturing video footages and contextual information (e.g., time, location) and reviewing captured events. Dashcam devices are designed to capture accident related events. Reviewing video footages rarely happens and thus, data access is inherently inconvenient. Alternatively, we can use smartphones to enable dashcam-like continuous recording and event capturing with contextual information (e.g., time, address), which can be integrated into a reporting app—however, none of the current reporting apps support continuous recording yet.

Second, we need to provide a privacy-preserving tool to mitigate privacy and security concerns (e.g., chopping relevant parts, muting audio). Again, none of the current reporting tools fully supports privacy-preserving tools. In the next section, we present a mobile service that is designed to deal with these issues.

We believe that developing such an app is essential to evaluate how pervasive recording technologies that fully support the entire reporting process in a single app can be used for community roadwatch scenarios.

ROADWATCH DESIGN

In this section, we describe Roadwatch, a mobile app that supports pervasive community policing by making it simpler and easier to report safety risks on the road with pervasive recording technology. The key idea of Roadwatch is to provide easy capture of and accessibility to the video, as well as contextual information (e.g., date, time, and location). Roadwatch enables a driver to record any safety risk incidents on the road by simply touching a smartphone screen while driving. It also provides the primary privacy-preserving features of video cropping and audio muting

Design Method

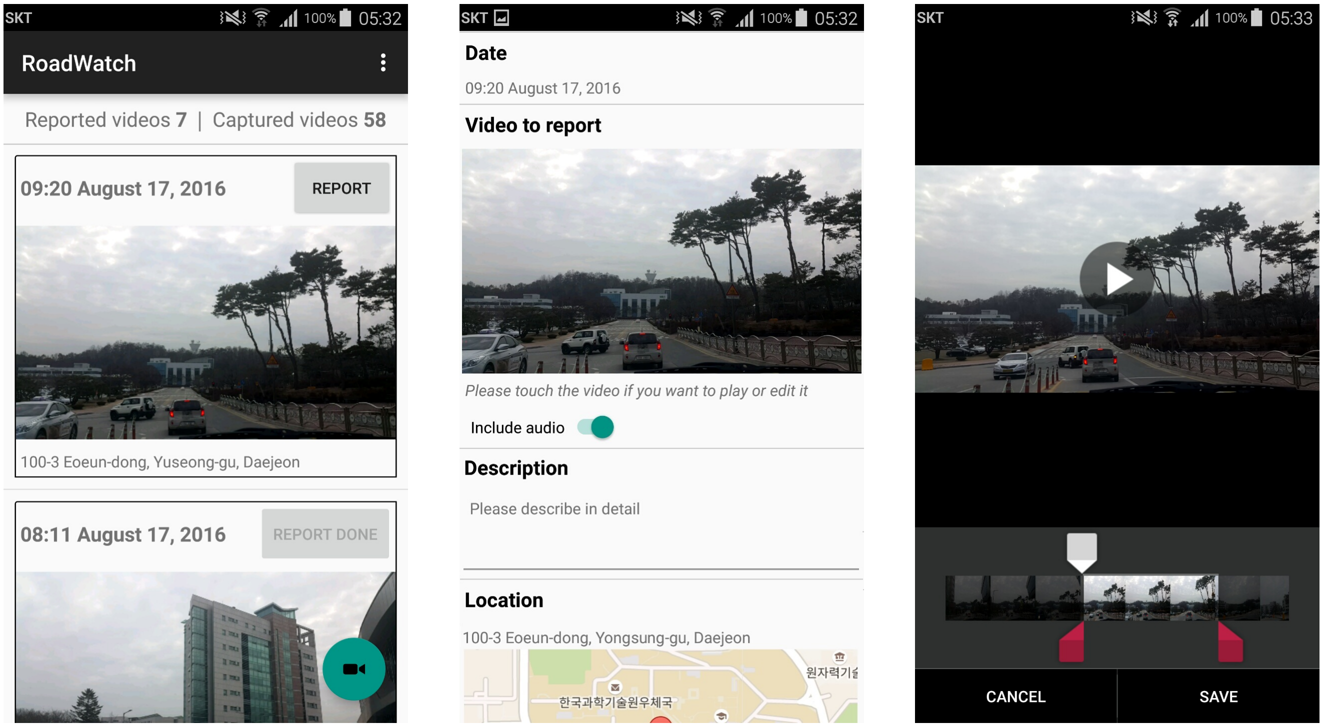
For the software design, we used a rapid iterative prototyping that included several rounds of low-fidelity prototype tests (n = 4-5) and high-fidelity prototype pilot tests (n = 4-5), as well as one round of a high-fidelity prototype field test (n = 14). During the several rounds of prototype tests, we enhanced the prototypes by improving errors in the app (e.g., capturing and reporting) and UI inconveniences mentioned in interviews (e.g., video editing method and button location). In the high-fidelity prototype, we recruited 14 participants in May 2016 from a large university (13 males; age: M = 29.93, SD = 5.00) who regularly commute by car to the university. Each participant was compensated with KRW 50,000 (approximately 45 USD). We instructed the participants in how to use Roadwatch and asked them to use it while commuting for a week. We provided each participant with a smartphone car kit that consists of a smartphone dash mount and a USB car charger. After the field trial, we interviewed the participants to discover any usability and user experience issues. We performed affinity diagramming to find major themes, which were then prioritized. Again, this second high-fidelity prototype went through a pilot test, which resulted in our final prototype. We describe this final prototype in the following section.

Roadwatch Design

Roadwatch has two major components: event capture and reporting. In the following, we first present event capture, followed by event reporting.

Event Capture

Roadwatch should support dashcam-like continuous recording with simple event capture. When observing a safety risk, a user will start video capture. To properly capture the risk, video recording should cover α and β seconds before and after the capture request moment. If we start to record a video only after the capture request moment, we may miss some important scenes, as risk behaviors may happen over a short time period. We initially set these parameters to 10 s. Thus, a captured video was 20s long. After the first field trial, several participants wanted a longer duration. In our final prototype, we set α = 15s and β = 10s. Furthermore, we permitted resetting the β value if a user made a capture request before it expires, which means that the minimum video length is 25s.



(a) Reviewing captured/reported videos (b) Reporting form (c) Video editing

Figure 2: User interfaces of Roadwatch

Given that a user may have limited storage space available for our service, continuous recording should properly consider storage space constraints. Our design carefully sets two important parameters: video resolution and maximum video file size for continuous recording. In our field trial, we allowed users to choose video quality: HD (720 p) and Full HD (1,080 p). The participants preferred higher quality because they sometimes wanted to enlarge the video to examine the scene (e.g., to identify car models and license plate numbers). In addition, the maximum video file size should be properly set for continuous recording because we could lose data if memory becomes full. However, we found a technical challenge in the Android platform; i.e., to flush a file, the camera object has to be released and then it has to be re-enabled. This transition takes about 1–2s, during which continuous recording will fail. The maximum file size should be small enough to fit into the available storage and yet it has to be big enough to minimize recording blackouts. We have to be aware of the fact that a user can request an event capture near the transition boundary. Indeed, we can easily derive the probability of blackout as follows: $(t_r + 2t_d)/(t_c + t_d)$, where t_r is the capture duration, t_d is the transition delay, and t_c is the maximum capture duration under a given maximum file size constraint. We bound this probability to below 0.05 by setting the maximum file size as 1.8 GB, which is about 15 min long—in our empirical study, Full HD (H.264/MPEG-4 AVC) recording generated about 2 MB per second.

To enable simple event capture, we initially considered various approaches, ranging from pressing a button to recognizing speech. During low-fidelity testing, our participants generally agreed that simple touch is preferable, because touch was simple enough, and speech was prone to errors, particularly when the ambient environment is noisy (e.g., when the user is listening to music). For visual-manual operations, we follow the National Highway Traffic Safety Administration (NHTSA)'s Driver Distraction Guidelines, which suggest that any secondary task performed while driving should not exceed the workload associated with a baseline reference task of manual radio tuning, and single glance duration should not exceed two seconds [46].

During our pilot study, we found that the potential sources of distractions include (1) the location of a smartphone holder, (2) the physical button size for reporting, and (3) manipulation of menu options while driving. According to the Fitts' law, the time to click a button is a function of the distance to the button and the width of the button [11]. In our field trials, we instructed that a holder should be properly located nearby such that the phone can be easily reachable, as shown in Figure 1. In addition, we decided to use the entire screen as a button for capturing to save time. Furthermore, Roadwatch automatically disables the menu button if a vehicle is moving by monitoring the speed fields of GPS readings. When an event is captured, Roadwatch saves the GPS reading, and its reserve geocode, or postal address. While capture was quite intuitive and easy to perform, our field trial showed that participants sometimes had difficulty in knowing whether capture was actually in progress because sometimes it was hard to read the screen in sunlight. In our final prototype, we enabled text-to-speech to illustrate the capture progress, which significantly lowered eye glance frequency.

Event Reporting

As shown in Figure 2a, a user can browse all the captured videos at the main list view. The user can easily go back to the continuous recording mode (see Figure 1) by clicking the video button located at the bottom right. A captured video in the list can be replayed in the app. To send a report, the user needs to fill out a form that includes the reporting targets (e.g., license plate numbers), detailed explanation of safety risks, and capture location, as shown in Figure 2b. These fields are the minimal information required in order for us to report the event to the authorities. We also asked about the purpose of the car travel for user experience research. The app supports video manipulation for privacy preservation (i.e., muting and editing). To remove audio from the captured video, the users can change the "Include audio" option with an on/off toggle button. If the user clicks the video image, that will lead to the cropping page, as shown in Figure 2c. In that view, a video can be replayed. In addition, the user can select the parts of interests by dragging the two red arrows at the bottom of thumbnails, and then crop the selected segment between the two arrows.

After reporting, a user can check the progress of reported events in the main list view. The current status is displayed below a reported video in red. Police officers can use our Roadwatch management interface to update the current progress in the app as well as via text messaging. Alternatively, it is possible to directly link to the existing police service. However, the police have not yet released an open application programming interface (API) for their service yet—given that most online government services in Korea have already released their open APIs, we expect that an open API for the police service will be available soon.

ROADWATCH EVALUATION

This section presents the results from our field study. Our experiment was designed to answer the following three questions:

1. What safety risks do people capture and report via Roadwatch?
2. Does Roadwatch help lessen the burden of securing evidence and preserving privacy?
3. What did people learn while participating in pervasive community policing via Roadwatch?

First, we explored what people captured behind the wheel and which videos were (or were not) reported via Roadwatch. This analysis helps us to understand how Roadwatch supports community policing with pervasive technologies. Second, we studied how Roadwatch, with pervasive recording and privacy-preserving tools, helps people to participate in pervasive community policing on the road. Finally, we investigated what people learned from this experience via Roadwatch, such as their attitude towards traffic safety and knowledge about road infrastructure and traffic flow.

Experiment Design

We designed a field study to examine the user experiences of Roadwatch for pervasive community policing on the road. In August 2016, we recruited 23 participants from a large university (11 males; age: M = 31.17, SD = 4.47) who regularly commute by car. 14 participants were university workers and nine participants were graduate students. The participants went through an introduction session. A pre-survey was first administrated to probe their experiences of traffic safety and reporting, and what kinds of threats to traffic safety they had reported. Eight participants (7 males, 1 female) answered that they had experiences of reporting safety risks, such as traffic violations, illegal parking, and reckless driving, to police or government authorities using their dashcam videos. We then instructed the participants in how to use our app and asked them to use Roadwatch for two weeks whenever driving. We also instructed that a smartphone holder should be properly located nearby, and their phones should be placed in the holder (see Figure 1). We informed the participants that their reports would be filed with the police or government authorities within a day, and the violators would be given traffic/parking tickets according to the law.

To deepen their understanding of the app's usage, we collected the following data. First, we collected the Roadwatch app usage log data. The data contained a timestamped on and off history of the app. Second, we collected a timestamped capture history with location data (GPS), but the recorded videos were locally stored due to privacy concerns—the videos could contain sensitive information such as private conversations and the driver's own traffic violations. Third, we collected reporting data. Reporting a safety risk incident requires not only video evidence but also additional contextual information. For example, individuals should describe what they want to report in detail, i.e., which car made what kind of law violation, and which action needs to be done to maintain traffic safety (e.g., removing potholes). The video data could be edited for privacy; we collected the edit information, such as whether audio was removed from the video and whether the video was clipped.

After the field study, we conducted a post-survey and interviewed the participants to understand their overall user experiences. The survey included several questions about usability, such as the USE questionnaire [30] and privacy/security concerns. There were also questions about the users' feelings about participating in the pervasive community policing on the road. To analyze the interview data, we performed a qualitative analysis using ATLAS.ti 7 to iteratively develop a classification scheme.

Usability of Capturing and Reporting

In the preliminary study, we found that the complicated process was the major barrier to participation. Roadwatch attempted to ease this burden by simplifying the overall process. We implemented convenient video capture with contextual information such as date and time, and location information, which is required to file a report with the police or government authorities via their online services.

Overall our participants liked the event capture interface. As P3 commented, *"It was very convenient because it was just a simple screen touch, and there was no need to pay attention to control it or even look at the screen."* Four participants,

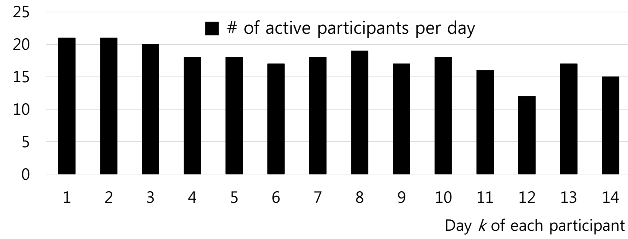


Figure 3: Usage distribution across days

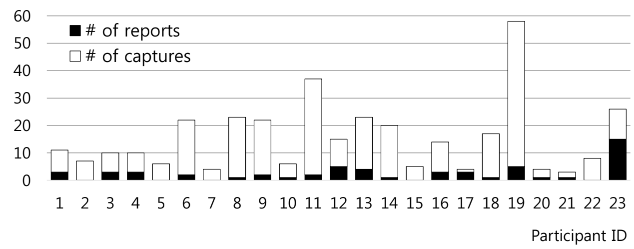


Figure 4: Capture and report distribution of each participant

however, felt that reaching their smartphone was a slight inconvenience, as P21 expressed, *"There was some distance to the smartphone mount, and reaching out my finger to touch the smartphone screen was a little inconvenient."* Our participants typically placed their phone mount near the center of the dashboard, but we found that these participants mounted their phones slightly toward the passenger side.

Roadwatch helps to lessen the burden of video accessibility and providing contextual information (e.g., location). One participant said, *"Many steps were removed, such as taking out a memory card from a dashcam and the encoding, so I can easily report events."* (P4) Another participant mentioned, *"In some cases I did not know the exact address or place that the event took place, but I could save a lot of time when reporting because the location was automatically pinned to the map."* (P19) Contextual information was particularly useful when participants travelled unfamiliar places, as P7 said, *"Automatic GPS tagging was very useful when I went to an unfamiliar place. It was useful to explain where the incident happened."*

Also, the app provides privacy-preserving tools that remove audio from the captured video or select particular excerpts of the captured video. We asked usability of the privacy-preserving tools. The participants answered that interfaces of the privacy-preserving tools are very simple and easy to use. P4 commented, *"It was very easy to trim the videos."*

Before the exit-interview, we asked the participants to fill out the USE questionnaire [30] which measures four constructs, namely usefulness, ease of use, ease of learning, and satisfaction in a 7 point Likert scale. Our participants highly rated in all constructs with usefulness (M = 5.56, SD = 1.25), ease of use (M = 5.74, SD = 1.22), ease of learning (M = 6.53, SD = 0.73), and satisfaction (M = 5.78, SD = 1.01).

		Involvement	
		Low	High
Seriousness	Low	15	3
	High	2	3

<Capture>

		Involvement	
		Low	High
Seriousness	Low	6	1
	High	8	4

<Report>

Table 1: Participant distribution based on decision-making criteria in the capture and report stage (excluded 5 participants who did not report any incidents)

What Events Were Captured and Reported?

As shown in Figure 3, The participants used the app fairly consistently in the two-week field study. The average number of actively participated days per user was 10.74 (SD = 2.43). Participants captured 355 events (M = 15.43, SD = 12.90) and reported 56 events (15.8% of the captured events); 5 participants reported no events, although they captured several events (see Figure 4). Two of the authors manually examined the 56 reported video files using the affinity diagramming technique to iteratively develop a classification scheme for the safety risks the participants faced. The reports were mostly about moving violations, such as traffic signal violations and illegal U-turns (n = 49). The remaining reports included parking violations (n = 4), requests for resolving illegal parking (n = 2), and a request for removing an obstacle on the road (n = 1). Our participants commented that some events were not captured because they forgot to capture the events or it was too late to capture them. As P10 commented, *"One driver suddenly cut in front of my car, then I honked my horn at him/her, and after avoiding the car, I touched the screen, but it was already too late to capture it."*

Decision-making criteria in the capture and report

In the interview during the preliminary study, we asked, *"Why did you capture and report the events?"* From the responses, we identified two dimensions, namely risk involvement and risk seriousness, using affinity diagramming. In the exit-interview, we asked the participants to select their criteria for making the decision to capture or report, using these two dimensions. The risk involvement is about whether a driver is a victim of a safety risk. Involvement is high if a driver is a victim of the safety risk. One participant commented, *"I primarily captured the incidents which annoyed or threatened me."* (P12) The participants also considered how serious a traffic safety risk was. This was judged based on whether that can cause car accidents. P15 said that even a traffic signal violation looked okay since at that moment, there was no safety risk at all, by saying *"It was not serious, so I did not do anything. It was a traffic signal violation, but it looked okay."* (P15)

We presented individuals' decision-making criteria in the capture and report stages in Table 1. From our interview data, we were able to divide participants into groups based on levels of involvement and seriousness. *Low involvement* means that participants reported traffic safety risks although they are not highly affected by the risks. *High involvement* means that participants reported traffic safety risks only if they were affected by the traffic violations. *Low seriousness* means that participants reported traffic safety risks even when the incident was not serious. *High seriousness* means that participants reported traffic safety risks only if the violation was serious. Interestingly, in the capture stage, many participants (n = 15) attempted to capture all violations even where the violation did not affect them (low involvement) and was not serious (low seriousness). In the report stage, however, participants tended to report serious violations (high seriousness) although they are not involved to the violations (low involvement) (n = 8).

Reasons for not reporting captured events

During the exit-interview, we asked for the major reasons for not reporting captured events by letting them quickly browse the captured events using the app. The primary themes for not reporting were (1) lack of evidence, (2) low level of seriousness, (3) mistakes, and (4) security concerns.

First, many participants were not able to recognize license plate numbers because they were not captured because of the limited field of view, or images were blurry because of bad weather or nighttime driving. Second, many participants thought after reviewing them, the captured events looked trivial or did not cause any safety problems. P1 commented, *"In some cases, it was too much to report. For example, it was an illegal U-turn on an empty road."* Such events may not be even captured. As P6 stated, *"I did not capture violations that looked like a mistake, such as crossing the stop line a little."* Third, events were mistakenly captured while they manipulated their smartphones. Fourth, there were security concerns. Our participants commented that offenders could find out who the reporters were by examining their dashcams—2-channel dashcams record both front and rear views, and the offender may retaliate for receiving fines. In our survey, the participants answered that they had concerns about retaliation from offenders by their own reporting (M = 4.77, SD = 1.81). We then asked the participants why they reported, in spite of their concerns about retaliation. They responded that they reported traffic threats with the expectation that offenders would not be able to identify them. One participant commented, *"Would the offender really find me like that? ... Having my license plate known does not scare me"* (P10). Another participant mentioned, *"What can they do to me? They're the ones who did wrong"* (P12). In contrast, one participant mentioned, *"I asked approximately 10 of my friends why they didn't report. Everyone mentioned retaliation. Women usually think about it."* (P11). There are miscellaneous cases: throwing a cigarette out of a car, a captured car accident, and scenes captured for personal records.

How Did They Feel About the Results of the Report?

Our experiment fully supported the entire reporting process. The authors manually forwarded reports to the police or government authorities. When we received the results about how the reports were handled (for example, what fines or how many traffic penalty points were imposed on the violators), we updated the results in the app and sent an SMS to the participants. During the experiment, 18 participants actually reported, and two of those did not receive any further feedback from the police; their reports were not handled at the time of the interview. Then we asked the 16 participants who had received the results of their own reports how they felt when they received the result of their reports. Some participants had mixed feelings. Two of the authors manually analyzed the responses using the affinity diagramming. As a result, we found that there were three kinds of responses.

Participants mostly felt very good about their contribution to traffic safety (n = 6). They thought that their reporting of traffic safety risks would improve traffic safety by making the violators more likely to stop dangerous driving behavior. One participant commented, *"I felt great (because) I thought I contributed to traffic safety by doing this."* (P6)

This contributive feeling was contrasted with the regretting feeling for the punishment (n = 7); e.g., a traffic ticket and penalty points for critical violations. One participant said, *"I felt really sorry. The driver might ordinarily be a good driver. It might only have been a mistake."* (P19) Some participants had simultaneous, contrasting feelings at the same time. For example, one participant commented, *"I was a little sorry, but I thought I did the right thing because the traffic violation was wrong."* (P16)

Interestingly, some participants also felt pleased to know the results, because they thought the offenders deserved to be ticketed (n = 5). This was particularly true when the reporter's safety was severely at risk or when vulnerable people were affected. One participant mentioned, *"I was gloating over a violator's ticket for illegal parking in the disabled parking space, because other people are all willing to park in remote parking spaces located far away."* (P9)

What Are the Lessons Learned?

We found that Roadwatch helped participants reflect on their own driving behaviors, thereby possibly improving their personal standards of traffic safety. In the exit-interview, we asked whether there was any behavioral change. Participants answered that they tended to drive more safely as they became more law-abiding. Responses to the post-survey questions, *"During the experiment, I became more law-abiding,"* lined up with their answers to the interview question about safe driving (M = 5.91, SD = 1.32).

One reason for this tendency was to be as fair as they could be while confidently capturing others' violations. One participant commented, *"I was more careful in my own driving ... because I was reporting others, I could not violate (traffic rules) myself."* (P01) Some participants self-reflected on their own illegal driving behaviors during the field study. They became aware that they unconsciously drove illegally in some ways. They said that their awareness increased. One participant mentioned, *"Many drivers usually turn left in the lane for going straight in front of the university. Yes, I actually did, too. But I have not done it lately."* (P10) Some participants even corrected their habitual traffic violations. One participant said, *"Everyone does illegal U-turns in that place before the U-turn lane ... but I have started only doing U-turns in the U-turn lane."* (P08)

Another reason is due to the awareness that others can report their violations. Most participants knew before this study that anyone can report any traffic threats to the police or government authorities. Nevertheless, the participants answered that their awareness considerably increased during the field study. One participant commented, *"Someone could capture my violations, so I thought I should obey the traffic rules as much as I can."* (P15) In addition, in the post-survey, they answered that the fact that their driving can be captured by nearby drivers affected their observance of traffic laws (M = 5.95, SD = 1.34). Also, even after the experiment has finished, the participants said that they are still much more careful than before.

Dealing with Privacy Concerns

We analyzed how drivers used the privacy-preserving tool when they made reports. We found that 33 videos did not have audio (14 participants) and 17 videos were cropped (9 participants). 14 videos had both cropped video and muted audio. We then asked the participants the reason why they used the tools. To investigate the reason for using the audio muting feature, we asked those who had removed audio from the captured video when they had made their reports.

Their primary reason was to remove their spoken words such as singing and swearing in the car. Some participants said that they usually sing along with what they are listening to. Other participants confessed that they swore after encountering the incidents. They all agreed that it would be very embarrassing to imagine that someone would listen to the recorded audio. As P10 said, *"It would be embarrassing because I drive while singing along with the music I am listening to in my car."* We also asked the participants why they cropped the captured videos. We found that most of these participants cropped the video to deliver only key scenes. One participant stated, *"Someone needs to deal with this report. To make it clear what is important, it would be helpful to use only the most relevant clip."* (P22) None of our participants mentioned that they used video cropping to address their privacy concerns. This was partly because events were selectively captured and reported, and videos that contained private events were not even considered for reporting.

Park et al. [34] investigated data management concerns in dashcam video sharing and found that people were most concerned about nondisposal of shared data (M = 5.34, SD = 1.59) and misuse of shared video (M = 5.21, SD = 1.61) in a 7-likert scale item. In our work, however, the participants stated that they were relatively less concerned about nondisposal of reported data (M = 4.32, SD = 1.62) and misuse of reported video (M = 4.32, SD = 1.84), responding to those same questions. The main difference between dashcam video sharing and video reporting of traffic safety risks is in the requester's trustworthiness. In dashcam video sharing, anyone can request to share a video, while Roadwatch is only for voluntarily reporting to the police or government authorities.

DISCUSSION

Our work explored community policing on the road with pervasive mobile recording technologies. The key contribution of this work is the design of Mobile Roadwatch, a novel app for community policing on the road that supports continuous video recording, event capturing with contextual information, and privacy preserving tools such as video editing and audio muting. We performed a real-world field study to understand what and why people capture/report, what they learn, and how they use privacy preserving tools.

Our work contributes to the body of work in urban sensing [26] since Roadwatch could be considered as a novel urban sensing service where citizens capture and report safety-related events using smartphones. Our work provided technical details about enabling continuous video recording in the Android platform, and safe user interaction design for participatory sensing in vehicular environments. We found that the key factors for capture and report decision making are risk involvement and seriousness, and in the reporting stage, seriousness is considered important. Our finding concurred with the prior study where one of the major factors of reporting crimes to the police is seriousness [38]. In Roadwatch scenarios, we found that risk involvement is another important factor.

Reporting motivations were mainly about contribution to traffic safety, and punishment of offenders for behavioral correction. These motivators are unique in Roadwatch scenarios, and our work complements the prior studies on motives of neighborhood watch services and social crowdsourcing [45, 24]. During the experiment, community policing participants had unique learning experiences about traffic safety and safer driving, and there were positive influences on the personal norm of abiding by the law. These experiences are very different from those in traditional online neighborhood watch community, where information sharing and safety-related problem solving were mainly dealt with. Our privacy support tool design carefully reflected prior findings about location and video privacy [6, 5, 34]. Since usage purposes were clearly stated, our participants did not feel much privacy concerns. Nonetheless there were some concerns about security risks such as retribution from violators. From these findings, we propose several practical design implications: (1) community fostering for Roadwatch, (2) raising awareness of Roadwatch, and (3) supporting computational tools for Roadatch.

Online Community Fostering

We provided the mobile app, Roadwatch, to report traffic risks, but online interactions among participants were not supported. Existing neighborhood watch programs commonly use online communities such as Internet forums and social networks (Facebook, for example) [17, 19, 28]. As reported in a prior study [28], online community engagement helps community members to build relationships, take collective action, share information and advice, and regulate online and offline norms. One participant mentioned, *"I heard that it is illegal if a vehicle does not use turn-signal lights, but I wasn't sure."* (P12) This kind of ambiguity could be easily discussed in an online community. People could help each other and build relationships by sharing tips and advices.

In an online community, we can motivate users' participation by leveraging the community identification stimulated by feelings of collective identities [24], or the sense of local community, the feeling that members belong to the community and that it helps members to fulfill their needs [33]. We can create online communities based on users' local regions to discuss local traffic safety risks with neighboring drivers. Local government authorities or local police departments can then work together to solve identified local traffic safety risks. Another way to motivate users in an online community is gamification mechanisms such as badges, levels, and points [9]. This can be also used to further improve user commitment and reinforce contribute behaviors: for example, we can recognize contributive users by awarding good citizen badges. But introducing monetary rewards to community policing may hurt intrinsic motivation and, thus, monetary rewards should be carefully considered. If monetary rewards are proportional to reporting frequency, people may game the system by reporting all possible sources of violations, which will bring about a significantly negative perception about the Roadwatch program. Thus, any use of monetary rewards should carefully consider the possible gaming effects.

Note that besides online community fostering, Roadwatch users can proactively organize in-situ collaborative activities to promote road safety (e.g., group patrolling with vehicles). In this case, to facilitate in-situ collaborative patrolling, we can introduce various activity-space awareness features such as automatic sharing, contextual cue displaying, and embedded monitoring support [21]

Raising Awareness

Awareness of traffic safety risks

Prior studies [20, 36, 42] have constructed crime maps to help people share crime-related information on a map. This idea can be applied to on-the-road community policing as a crowdsourced traffic safety map to raise awareness of traffic safety risks. The traffic safety map can help people make others aware of traffic safety risks beyond sharing tips and advice in an online forum. For example, reports from Roadwatch can be automatically collected and displayed on the traffic safety map, showing people what kinds of safety risks happened in particular locations, and how many violations are occurring. This information can be shared with Roadwatch or vehicle navigation systems so that users can easily receive warnings about frequent-violation regions when they approach them.

Awareness of being watched

Because Roadwatch is a case of neighborhood watch, we can increase public awareness of being watched by displaying Roadwatch posters and stickers on cars or at frequent-violation sites. Drivers will realize that they are being watched by others when they see the posters or stickers. This will help motivate drivers to abide by the traffic laws.

Enabling New Features with Computational Support

Our participants sometimes had difficulties in reading license plate numbers, or recognizing capture moments. Advanced computer vision tools can be easily incorporated into Mobile Roadwatch. Various dangerous activities (or safety risks) are likely to be patterned and thus, computer vision technique can be applied, as shown in prior work on vision-based human action recognition [35]. This kind of visual analysis can enhance video capturing since proper starting and ending marks can be automatically detected. Besides images, audio and vehicle motion data can be simultaneously considered to make robust inferences about safety risks. Another design opportunity is to enable real-time requests such as removing dangerous objects on the road. At this point, this kind of real-time requests cannot be handled. One solution is that the police department can actively work with local residents to communicate via Roadwatch, and thus, they can report an event in real time. As shown earlier, some events can be automatically detected with computer vision technique, e.g., whether there is fog and whether there is an object on the road.

Limitations

The generalizability of this work is limited, in that our user study considered a limited user population over a relatively brief duration. Though we observed changes in driving behavior after Roadwatch usage, validating this observation requires a controlled experimental study for a longer period of time. Nonetheless we expect that our results could be generalizable to other contexts, since several key findings are consistent with prior studies (e.g., reporting factors and motivators). Further studies on various user populations possibly with different cultures should be performed to generalize the findings.

In this work we provided privacy-preserving tools to protect the users themselves, not the other drivers or bystanders recorded in videos. This is because the videos are directed only to the authorities, not to anyone else. Privacy-preserving tools for others, however, will be required if the videos are shared more widely. If, for example, the recorded traffic violations are shared in an online community, the privacy of other bystanders should be assured by using other video tools such as blurring or mosaic.

CONCLUSION

Pervasive mobile recording with smartphones is a novel medium for enabling community policing, and its adoption has significantly increased at least several nations such as Korea, India, and US. Despite such popularity, this new technology has received little attention in the research communities unlike traditional tools such as online forums and social media. Our goal is to explore how pervasive mobile recording technologies enable community policing on the road. We designed Mobile Roadwatch a novel app that supports continuous video recording, event capturing with contextual information, and privacy preserving tools. Our user study results (n=23) revealed that the key factors for making capturing decisions were the risk involvement and seriousness, the main motive for participation was traffic safety promotion, and participating in community policing had positive influences on safety awareness and personal norm of law abidance. Our findings provided several practical design implications such as fostering communities, raising public awareness, and supporting computing tools.

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