TapShare: Low-Effort Crowdsourcing Through Physical Gestures and Mobile Sensors

1st Author Name
Affiliation
Address
e-mail address

2nd Author Name
Affiliation
Address
e-mail address

3rd Author Name
Affiliation
Address
e-mail address

ABSTRACT

The pervasiveness of sensor-rich mobile devices enables citizens to contribute to sensing and data collection efforts by participating in citizen science and communitysensing. While millions of people can potentially contribute, projects mainly rely on dedicated volunteers and many fail to garner widespread participation due to a lack of attention to human factors, such as the time required for contributing. In this paper, we consider the use of low-effort interactions that allow people to contribute through their existing routines. We present TapShare, a mobile application that supports people tracking events of interest while on the go using physical gestures, such as a double tap. TapShare allows users to make reports without looking at their phone, without taking out their phone, and without stopping. Results from benchmark tests and a pilot study showed that TapShare allowed events to be tracked accurately, in minimal time (2 seconds), and through existing routines.

Author Keywords

Low-effort crowdsourcing, physical crowdsourcing

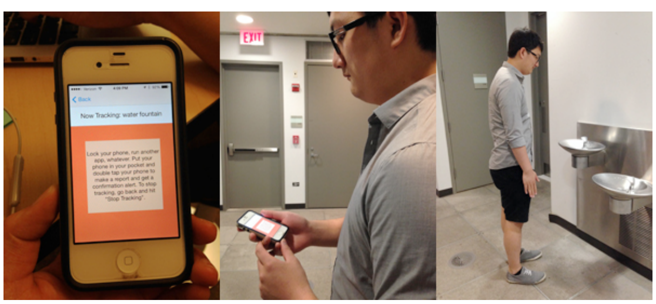

Figure 1. A TapShare user reports the location of a water fountain by tapping on their phone while stopping for a drink.

INTRODUCTION

The pervasiveness of sensor-rich mobile devices enables everyday citizens to contribute to *physical crowdsourcing* by taking actions in physical spaces to help achieve desired goals. Examples include *citizen science* [1, 2, 3, 4, 5] and *participatory communitysensing* [6, 7, 8, 9, 10, 11]. People use mobile apps to report potholes [12] and to help scientists track bird species [13]. Machines and people work to assure the quality of the collected data [13, 14]. New network and sensing technologies connect people to tasks and lower participation barriers [15, 16, 17, 18].

Despite technical advances and a handful of success stories, the number of people actively engaged in participatory communitysensing and citizen science projects today is a tiny percentage of the more than one hundred million Americans on-the-go each day, 58% of whom carry a smartphone [19, 20]. This collective human mobility is a valuable potential resource, yet we do not have comprehensive tools and methods to utilize it. For people who are commuting to work or school, exercising, or spending time with friends, the effort required to make a contribution to a project can far exceed the perceived benefit of contributing. Even opening an app and submitting a short report may discourage contributions. As a consequence, projects mainly rely on a much smaller crowd of dedicated volunteers [21]. Another approach collects sensor data passively through device-carrying participants. While this has proved useful for some applications such as tracking traffic patterns [22], it cannot be used for tasks that require human sensing capabilities, e.g., recognizing cracks on the sidewalk or places with interesting architecture.

In this paper, we take an alternative approach to consider the use of *low-effort interactions that support people contributing to physical crowdsourcing while on the go, through their daily routines*. We introduce *TapShare*, a mobile application that allows people to collectively track objects and events without looking at their phone by using physical gestures, such as a double tap (Figure 1). Users first join an existing tracking effort or start their own. TapShare then listens in the background. While on the go, users may notice the object or event they are tracking and make reports by double tapping. A gesture recognizer detects the action, ties the report to sensor readings (e.g., position, orientation), and submits the combined event to the TapShare database. Multiple users can contribute to the same tracking mission, increasing coverage and confidence in the collected data over time.

The main technical contribution of this paper is an *eyes-free input modality [23] that ties physical gesture recognition to location tracking for the purpose of reporting an event.* TapShare takes as input physical interactions such as taps that can be accurately detected using smartphone sensors. A user can make a report without looking at their phone, without taking out their phone, and without stopping.

Compared to existing communitysensing applications that require users to interact with a visual interface on their phone to make a report, we hypothesize that TapShare significantly lowers the amount of time required to make a report. While the collected data may be lower in fidelity (e.g., consists of only event-location pairs and not photos or text descriptions), the ease and speed of reporting enables lightweight contributions through people's existing routine, with the potential to broaden participation to a larger, mobile crowd.

We first conducted benchmark tests to evaluate the speed and accuracy of TapShare's input method. Results showed that making a report averaged 2 seconds, compared to 55 seconds in SeeClickFix, a popular 3-1-1 app for reporting city problems. Even when making reports on-the-move, object locations recorded by TapShare were close to actual object locations and within the GPS's margin-of-error. We then conducted a pilot study to learn how people use TapShare to contribute to tracking efforts. 17 people used TapShare over 5 days, contributing 214 reports for tracking local problems (e.g., cracks in the sidewalk), points of interest (e.g., interesting architecture, places to do homework), and public infrastructure (e.g., recycle bins, bike racks, benches). Users report through post-study surveys and interviews that reporting was low-effort and they chose items to track based on their expectations of seeing that item during the day.

The paper proceeds as follows. We first review related work in physical crowdsourcing and eyes-free, gesture-based interactions. We discuss the space of design decisions considered when making TapShare, and then describe the TapShare system and its implementation. We present results from benchmark tests and the pilot study, demonstrating that events can be tracked accurately, with minimal effort, and without stopping. We conclude with a discussion of future work on TapShare and a larger agenda around *on-the-go crowdsourcing*.

RELATED WORK

Our work builds upon and extends prior work in (1) physical crowdsourcing systems and (2) gesture-based and eyes-free interaction techniques.

Physical crowdsourcing systems

There is increasing interest in systems that engage a crowd to take helpful actions in physical spaces to achieve desired goals [24, 25, 26, 27, 28]. Many of these systems engage people *outside of their existing mobility*. They draw on a wide range of user motivations, from earning additional income to contributing to science [1], improving the community [12], socializing [29], and having fun [30]. For example, citizen science and communitysensing projects recruit volunteers to collect data for environmental monitoring [2, 31, 32], surveys [5], and tracking migration patterns and invasive species [3, 33, 1, 4]. Physical games with a purpose have players visit locations and take photos that will be used to tag points of interest [34, 35], construct 3D models [30, 36], and refine maps [37]. Commercial systems such as TaskRabbit, Uber, GigWalk, and Favor recruit paid crowds to run errands, transport passengers, monitor businesses, and deliver food. In contrast to these systems, we seek to crowdsource through people's *existing mobility*, with the aim to significantly broaden participation in physical crowdsourcing and voluntary contributions.

A few applications utilize people's existing mobility to achieve desired goals. Some, such as NoiseSpy, Strava, and Google Maps, collect data from machine sensors (e.g., GPS) and require no user input [38, 39, 22]. Others, such as Tiramisu, Twitch, Foursquare, and Waze, receive user input *opportunistically*, only in situations or locations where users are likely to interact with the application [40, 47, 29, 11]. While useful for some applications, machine sensing and opportunistic data collection are unable to achieve a wider scope of data collection objectives that can result from people performing human sensing on the go through their existing routines. TapShare seeks to seamlessly weave existing mobility with opportunities to contribute to achieve what machine sensing and opportunistic strategies cannot.

Interaction Techniques

TapShare promotes the use of lightweight interactions for making reports. Conceptually, it builds on eyes-free input [41, 23] and ties physical gesture recognition to a user's location to enable event tracking and sensing. Eyes-free interactions can improve safety in situations when switching visual focus may be hazardous, and moreover, may be associated with lower perceived cognitive and physical effort when compared to visual interaction on mobile devices [41]. We focus on physical gestures, which can be accurately detected using accelerometer or microphone sensors embedded in smartphones, even when they are placed inconsistently on the bodies of subjects [42, 43, 44]. There has been growing commercial interest in using physical gestures as input; for example, Knock to Unlock uses a knock gesture to log a user into their computer, and the recently released Kiwi Motion Library offers a simple gesture detection API. In developing interaction techniques for TapShare, a core challenge is the need to advance and balance the goals of appropriateness and ease of interaction, high accuracy, and usefulness of collected data.

DESIGN SPACE

In designing TapShare we faced a number of design decisions. This section explores these decisions and the design space for enabling data collection on the go with low-effort interactions and through mobile sensors.

What kinds of gestures or interactions should be used? While on the go, even opening a mobile app and submitting a one-minute report may discourage contributions. These small yet critical barriers to action, also known as *channel factors* [45], can disproportionately affect whether people complete a task. Adopting this view, we hypothesize that low-effort interactions can enable people making reports through their existing routines.

We explored gestures that can be detected reliably by mobile sensors and that allow fast contributions without disrupting the user's mobility. Because our system targets people who are walking or biking, this eliminated leg movements such as stomps or full-bodied movements such as jumps that we initially considered. To avoid requiring users to take out and look at their phone, we focused on eyes-free input that can be self-monitored and relies only on limb movements [46]. With double taps on the phone, users feel both the outline of the phone against their hand and the tap on their body where the phone is stored. We also considered the ease and comfort of performing the physical gesture. During initial prototyping we used knocks as input. However, testers felt that knocking was hard and unnatural; some even complained of sore knuckles. We adjusted our gesture detection to accept taps instead, which can be detected similarly but allowed for softer input.

The current TapShare prototype assumes that users will keep their phones in their pockets while using our application. While taps can be accurately detected when the phone is a (coat or pant) pocket, they are much harder to detect reliably and perhaps less natural when the phone is in a backpack or a handbag. Future prototypes will consider interaction techniques for other use cases, e.g., when phones are in a handbag, carried in a person's hand, etc., as well as for other wearable devices, e.g., smart watches or glasses. When doing so, the design goal is still to use low-effort interactions that can be accurately detected. We will return to consider these use cases in the discussion section.

How much direct interaction should we require? To encourage users to focus on their tracking efforts in their physical surroundings, we sought to minimize direct interactions with the mobile application. We background TapShare so that tap detection is activated even when the phone is locked. To let users know that the system is working, TapShare provides audio (tones) and tactile feedback (vibrations) when a report is detected. In preliminary studies, people felt assured by the feedback.

When and where should users participate in low-effort crowdsourcing? Existing communitysensing applications are typically hyperlocal. To support people using TapShare through their everyday routines, we limited its scope to people's neighborhood to support individuals tracking items or events of personal importance and contributing to data collection that may interest the local community.

How many items or events should users be able to track at a time? To support users' focus on the current tracking effort, our current prototype limits users to tracking one item at a time. While we considered making it possible for users to track multiple items with different patterns of tapping, results from early prototyping suggest that this may be overly complicated for a user who could easily confuse different report signals. We thus focused on simplifying the interaction as much as possible, so that new users can quickly learn how to use the app.

Who should specify the items or events for users to track? Following mobile applications such as Lift, which tracks community habits and personal goals, we allow users to either join existing tracking efforts or create their own. This allows for both a degree of structure in the types of things people can track, and helps us gain a better understanding of people's personal motivations behind their tracking choices. For our pilot study, we preloaded items to track based on the following topics: civic engagement, fun and leisure, productivity, and exploration. Users were also able to enter their own items or events to track that do not fall under any of the aforementioned categories.

How can users see the collected data? Although in our preliminary studies a few people found it satisfying to just report events, most people wanted to see the data afterwards. Seeing the data can also help people make sense of objects or events in a neighborhood, for example to recognize issues in their community (e.g., as in SeeClickFix). TapShare provide a map view that displays the collected data, with the option to view both personal and collective contributions to a tracking effort.

How public should reports be? Social mobile applications such as Yelp and Foursquare usually make geolocation data public when a user "checks in" to a specific location. TapShare makes all reports public but keeps the users' identities private to support users tracking potentially sensitive events (e.g., places they feel unsafe in). As such, TapShare displays individual contributions only in aggregate to other users.

TAPSHARE

Upon first downloading and opening TapShare, a user is greeted with a short tutorial followed by a video demonstration. TapShare's main interface consists of two views, one for reporting and another for seeing submitted reports. The reporting view (Figure 2) allows the user

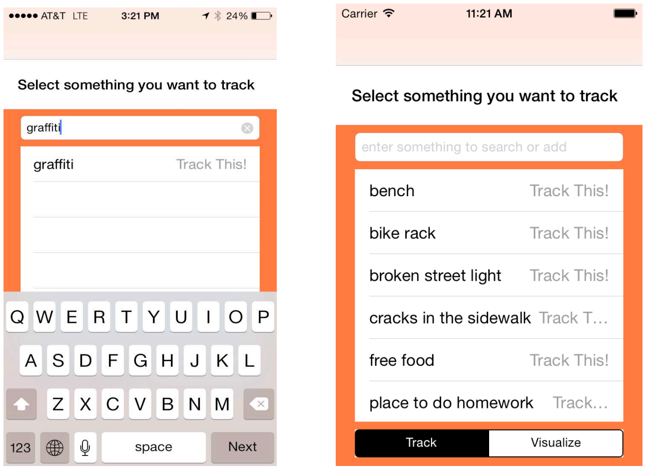

Figure 2. TapShare users can add something to track (Left) or choose an existing effort to contribute to (Right).

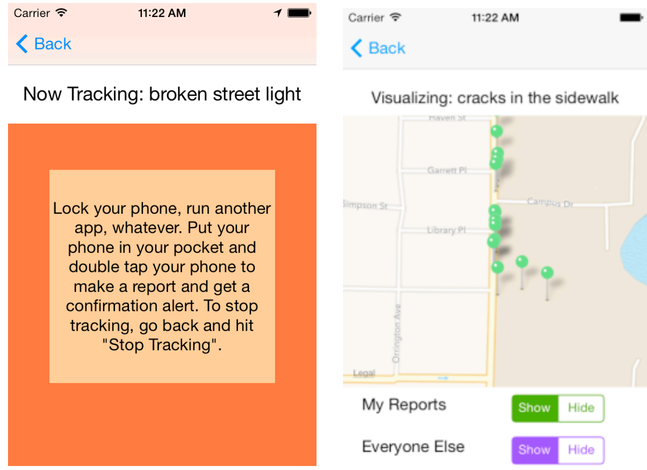

Figure 3. TapShare's reporting screen provides information about the reporting gesture and feedback (Left). Users can see their contributions alongside those of other users (Right).

to either join an existing tracking effort or create a new tracking effort that others can then join. When a user selects an object or event to track, they are taken to a reporting screen with instructions detailing the feedback mechanism and how to track with gestures (Figure 3, Left). Once the user is on the reporting screen, the application listens in the background for double taps. At this point, the user can put their phone away and go about their day. Users can make reports at any time, including times when the phone is locked or the user is running a separate application.

A user can revisit the reporting view at any time to switch their current tracking effort or stop tracking altogether. In the submitted reports view, users can see the number of reports made for each tracking effort by all TapShare users thus far. Each tracked object or event can be selected to see a map of its reported locations (Figure 4, Right). In this map view, users can see their own reports alongside others' reports, as well as toggle the visibility of each.

Technical Details

We detected single taps with three accelerometer readings at 100Hz, from which we extracted four features: jounce, jerk, acceleration, and rotation rate. We recorded 200 positive and negative examples; negative examples include a mix of movements in stationary and active settings. Using these features and examples, we built a logistic regression model using Weka to classify single taps. To detect double taps, the system determines two taps within a predefined time window. Based on initial testing, we empirically set 0.1 and 0.5 seconds as lower and upper bounds for the time window. To improve detection accuracy, we added false negative examples through initial testing. This helped to capture and correct cases where a double tap was detected while a user was walking but no double tap actually occurred.

TapShare combines gesture detection with GPS to enable lightweight on-the-go reporting. To do this, we activate the GPS and accelerometer as soon as a user selects an event to track. To reduce battery consumption, sensors are activated only when users are on the move. We also set a low GPS accuracy while idle, then increase it on-demand upon gesture detection. Since the current prototype already allows users to keep TapShare running throughout the day, we will leave managing battery consumption for future work.

TapShare is built using Apple's native iOS SDK and frameworks, including the Core Motion and Core Location Frameworks. From this, we built a natural physical gesture interface, which can be extended to include gestures outside of taps and allows for interactions that combine multiple gesture events. All collected data containing usernames, reported events or items, and geolocation coordinates are stored on Parse.

BENCHMARK TESTS

Method

We performed two benchmark tests with TapShare, one to evaluate the speed of making a report and another to evaluate the accuracy of the location data collected.

For speed, we made ten reports of potholes. Each trial measured the time duration from tapping to feedback in acknowledgement of receiving a report. As a point of comparison, we also measured the time it took to make reports at the same sites with SeeClickFix, a popular app for reporting city problems. For SeeClickFix, we define the duration of a report as the time it took to remove the phone from a pocket, to fill in the title, description, location and photo fields, and to receive a submission confirmation. Each report used the same one-sentence description.

For accuracy and distance, we made reports while walking by ten static sites: five on street corners and five on fire hydrants. Measurements were collected from ten trials. We measure the distance between reports made at the exact location of the site to reports made on the go (e.g. reporting a fire hydrant on the grass while walking on the sidewalk). This gives us an idea of how close the locations gathered would be to actual site locations under intended usage.

Results

For speed, reporting potholes with TapShare took an average of 2 seconds, with a standard deviation of 0.4 seconds. In comparison, reports made with SeeClickFix took an average of 55 seconds, with a standard deviation of 11 seconds. With TapShare, the user does not need to remove their phone from their pocket, has chosen a tracking effort in advance, and receives immediate confirmation that a report was received. In contrast, SeeClickFix required users to interact with a visual interface and fill in a detailed form. The 24 times speedup makes it possible for someone to report on the go, albeit at a lower fidelity.

For distance, with fire hydrants the distance between report and reference coordinates averaged 15.2 meters, with a standard deviation of 8.4 meters. The distance for street corners was 10.0 meters on average, with a standard deviation of 3.6 meters. Since iPhone's GPS guarantees accuracy within 10 meters, the distances recorded are within a reasonable error range.

PILOT STUDY

Method

We conducted a pilot study to learn how people use TapShare to contribute to tracking efforts. We recruited individuals from a university campus through departmental and group mailing lists. The recruitment email explained the study's goals, the procedure for signing up for the study, and qualifications required to participate. Participants were asked to download TapShare onto their mobile phone and to track items of interest while going about their daily routines over a period of five days. Users did not receive payment or any other form of compensation; participation was completely voluntary and users can stop at any time.

We record in log data the items and events users tracked and the locations and times of reports. We gathered several pieces of additional feedback through post-study surveys and interviews. First, we asked users to rate the ease of making a report on a scale of 1 to 10. To learn about use cases, we asked users to describe the situations in which they used TapShare, and why they chose to track the things they did. Users were also asked to comment on if and why they did not make a report when encountering an object or event they were tracking, potential privacy concerns, as well as their overall experience with the application.

Results

Over five days, 17 users made 214 reports in 12 different categories. Users added 6 of these categories and the other 6 were originally seeded for the study. Out of 17 users, 14 only joined existing tracking efforts, 1 only created their own, and 2 created their own and joined existing efforts.

Tracking Effort	# of Contributors	# of Reports
bench	3	7
bike rack	4	20
cracks in the sidewalk	3	98
free food	1	1
good drunk food	1	3
interesting architecture	2	27
place to do homework	4	6
places to fall asleep when drunk	1	1
places to recover and rally	1	1
recycling bin	5	31
street food vendors	1	8
whiteboard	2	10

Figure 4. Results from the pilot study showing the number of contributors and number of reports for each tracking effort.

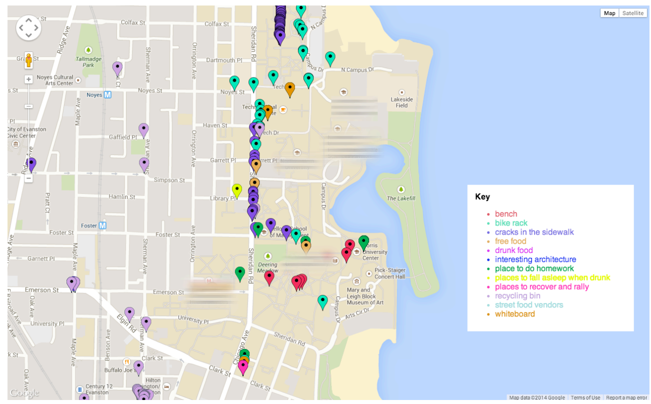

Figure 5. Map of TapShare user reports during the pilot study.

Figure 4 shows a breakdown of the tracking efforts with the number of contributors and reports made for each effort. Popular items being tracked include bike racks, cracks in the sidewalk, interesting architecture, and recycling bins. From Figure 5 we see that most reports were made right on campus, but that some users also used the app when they ventured off-campus.

From log data we found that TapShare allowed users to make a large number of reports in a short period of time. For example, one user contributed 87 reports to tracking cracks on the sidewalk in a three-minute period. Since TapShare allows users to make reports on the move, they can keep focus on something to track while walking to a destination, making reports at multiple locations that would have otherwise been difficult with existing approaches.

7 of the 17 users responded to our post-survey; we additionally conducted 2 in-person interviews. Since users were not paid and some did not use the app as much as others, not all users responded to the survey request. Of those who did respond, users rated the ease of reporting with an average rating of 7.2 on a scale from 1 to 10, suggesting that reporting was somewhat easy.

Using survey and interview responses, we discuss below how users chose what to track with TapShare, their experience using TapShare through their existing routines, and their general impressions about effort and use.

Choosing What to Track

Many users said that they were inclined to track items or events that they anticipated they would see in their physical surroundings. *"I tracked whatever interested me and I felt like I would see in my daily life."* An individual explained that *"it takes more of a cognitive load to actively track"* things they did not normally see. One participant tracked things that they hoped to refer back to for later use: *"I was actually thinking that I could use this to keep track of coffee shops or restaurants I like. If I had previously tracked some coffee shops, it would have been easy to find what I was looking for."*

While some people tracked things of personal significance or even at random, some individuals decided to contribute information that could be potentially useful for other users to know about. *"I wanted to do something that I normally observe and would want to clue others into."* For one participant, the physical location influenced their tracking choices even further. *"I didn't want to pick some random category. I was thinking about the place where I was and tried to add to categories that people would also be thinking about on that day or in that situation."*

Tracking On-the-Go

The majority of participants used the application while outside or on the go. They participated in tracking efforts usually "while walking outside" or even when "riding the train." One person found that tracking on the move was distracting and instead used it while waiting, for example at stoplights. *"I used TapShare most when I had a few extra minutes, like when I'd otherwise use Facebook."*

Some considered TapShare to be a more solitary activity in order to focus on the task at hand, using the application when "mostly alone." One person expressed this very strongly. *"It's less likely for me to think about tracking when I am with other people and/or have a bunch of things to do."* However, others said that they were able to track things even when "walking with others."

Tapping was Low-Effort and Fun

A number of users noted that the double tapping gesture was easy to learn and the "capture mechanism was great." *"In terms of ease of use, the interaction method is next to zero. Just knock [tap] to go!"* Another participant found TapShare to be "an easy way to capture a lot of information about location." Moreover, several participants found TapShare's interaction enjoyable. *"The tapping gesture was really fun. When the phone vibrated to confirm the report was received, it felt rewarding."*

DISCUSSION AND FUTURE WORK

The goal of TapShare was to enable low-effort, high-accuracy contributions through people's existing mobility and routines. TapShare uses an eyes-free input modality to tie physical gestures to location tracking for the purpose of making reports on the go. Benchmark tests and pilot results show that users can make reports accurately without stopping, with minimal effort, and without having to take out their phone. We now revisit the design decisions in TapShare and discuss future design opportunities and challenges for low-effort, on-the-go crowdsourcing.

Accuracy of the Collected Data

Although tap detection was generally robust, a few users reported frustration with occasional cases of false positives and negatives. One user noted, *"There are four reports of interesting architecture around this area of the map. In reality, that is just my apartment."* At the individual level, one way to increase detection accuracy is to include a short, individualized training phase prior to tracking to customize the detection algorithm to each user. At the aggregate level, assuming sufficient participation, we can remove most false positives by aggregating and consolidating nearby results. We will also explore the use of external *verification tasks* to further improve data accuracy.

Fidelity of Collected Data vs. the Ease of Data Collection

In the current TapShare prototype, users can only report whether an object exists or an event occurs at a location. Compared to applications such as SeeClickFix, the collected data is lower in fidelity and illustrates a natural tradeoff between the amount of detail that can be captured with a report and the ease of making that report. By lowering the barriers to contribution, TapShare shows the potential for engaging a large crowd of people contributing through their existing routines, and for reporting a wide range of objects and events of interest. With existing approaches, the barrier for participation is higher and thus reduces the number of contributors and the scope of data collection.

Future work will explore *design patterns* for decomposing a data collection task into a set of low-effort tasks, and that compose smaller contributions to generate higher quality and fidelity data. In particular, we will study *scaffolding* as a general technique for splitting the responsibility of making a full report to multiple users. The coarse-grained data collected through TapShare can be used to inform or feed into potential opportunities that will yield finer-grained data. By providing this baseline level of data, future related tasks might be easier to accomplish by focusing other users' attention on specific locations where they may be prompted to contribute more detailed information. For example, a system can take reported locations of potholes to present a user passing by with a small task on their lock screen that focuses the user on where to look (e.g., using Google Streetview) and promotes quick sharing with binary questions (e.g., is that pothole on the crosswalk?).

A related direction is to explore the use of a mixture of casual contributors and more dedicated, expert crowds. For example, casual crowds can help collect vast quantities of location-event pairs, and the aforementioned scaffolding approach could target dedicated users who can improve information accuracy and quality.

Extend the Versatility of TapShare with New Interactions

Our future work will develop new interaction techniques for low-effort, on-the-go contributions. In one direction, we seek to expand the value of tap gestures. For example, tap gestures at the start and end of an interaction can be combined with continuous sensor readings to make continuous reports. For example, this interaction can be used to mark scenic walking paths, or little known shortcuts for others to discover.

In another direction, we will investigate other interactions that can enable higher fidelity tracking, for example to estimate quantities or track multiple events at once. We can incorporate other gestures, such as rubbing or scratching, to expand the ways a user can provide input. We can also compose taps in different ways; some users in the pilot study expressed an interest in tracking multiple items, suggesting using two taps to report Item A and three taps for Item B. Another user suggested using patterned taps to make the distinction between report types memorable. For example, music is often used as a way to remember a particular tempo or rhythm for an unrelated task (e.g. humming "Another One Bites the Dust" during CPR to maintain ideal compression speed); one can imagine associating the beat of one song with potholes and another with interesting architecture.

Considering Context of Use

When developing new interaction techniques, we will focus on lightweight interactions for walkers, runners, and cyclists that account for their situational impairments. With the current prototype, the use of tap gestures makes reporting easy when a user has their phone in a pocket, but some people often carry their phone in a purse or backpack, making tapping difficult. Gestures need also be appropriate; one user said *"I kept the phone in my back pocket so it felt weird beating my bottom in public."* In future work we will design with respect to these considerations and also explore new wearable devices such as smartwatches that can aid low-effort, on the go contributions.

Building Habits

Due to the short duration of our study, we cannot make any claims toward the habit-building nature of TapShare. We do note that several users contributed reports over multiple days and in multiple categories, indicating that they did remember to use it and were interested enough to switch tracking items. We plan to launch an extended deployment to better study use over time. One interesting side effect of lowering the barriers to contributing was that users sometimes forgot to report the items they were tracking, due to the low effort involved and not having their phone out. One user noted that it was "pretty easy to forget when you haven't formed some sort of habit," suggesting instead that TapShare should maybe send periodic reminders to promote reporting.

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