Participatory Design of Sensing Networks: Strengths and Challenges

K. Shilton, N. Ramanathan, S. Reddy, V. Samanta, J. Burke, D. Estrin, M. Hansen, M. Srivastava
Center for Embedded Networked Sensing (CENS), University of California, Los Angeles
{kshilton, nithya, vids, sasank, jburke, destrin, cocteau, mbs}@ucla.edu

ABSTRACT
Participatory design (PD) involves users in all phases of design to build systems that fit user needs while simultaneously helping users understand complex systems. We argue that traditional PD techniques can benefit *participatory sensing*: community-based participatory research (CBPR) projects in which complex technologies, such as sensing networks using mobile phones, are the research instruments. Based on our pilot work on CycleSense, a community-based data gathering system for bicycle commuters, we discuss the benefits and challenges of PD in participatory sensing settings, and outline a method to integrate PD into the research process.

Keywords
Sensing networks, community-based participatory research

INTRODUCTION
Mobile phone networks provide billions of users with potential platforms for data collection. Using image, sound, and location-gathering modalities, phones can collect data previously too granular, time-consuming, or difficult to record [1-4]. Mobile phones are also familiar, easy to use, and widely available. This gives them widespread potential to serve as tools for *community-based participatory research*: methodologies that integrate community members into research projects as co-investigators [5, 6]. When people use mobile sensing systems as instruments in such research, we call it *participatory sensing*. Participatory sensing is inspired by decades of research promoting community involvement in neighborhood documentation and representation. By coordinating increasingly-available devices, participatory sensing offers automation, scalability, and possibilities for real-time upload, processing and feedback. These features can augment traditional CBPR efforts such as participatory urban planning [7], geographic information systems [8], and Photovoice initiatives [9].

For example, the Center for Embedded Networked Sensing (CENS), a science and engineering research center, recently collaborated with the nonprofit Livable Places[1] to asses the pedestrian and bike-friendliness of two Los Angeles neighborhoods. Teams equipped with GPS and mobile phones travelled the neighborhood to gather geo-tagged images and apply tags to document impediments to pedestrians and bikers. Inspired by this pilot, we are working with bike commuters to design the "CycleSense" system, which enables cyclists to plan campaigns—targeted data collection efforts—to document the safety and quality of their routes. CycleSense builds on previous work instrumenting bicycles for data collection [10] to enable bikers to specify route needs and preferences, collect data about their existing routes, and learn from other's data to discover safer, more comfortable rides.

Figure 1: Participants use mobile phones to update and improve a map interface

In systems such as CycleSense, research decisions about what data to collect, and at what granularity, affect design of the collection instruments. For example, how can designers equip mobile phones to document data of interest to cyclists, such as potholes, without inconvenience or safety risk to the rider? Traditional CBPR tackles these challenges by involving participants in the design of paper-based research instruments such as maps or surveys [11]. Cooperation to create surveys is a relatively straightforward process; cooperation to design sensing networks may be less so. Participatory sensing data collection instruments include a network of mobile phones, a central database, and web- and phone-based user interfaces. Creating complex technologies for data gathering in a participatory research environment requires incorporating *participatory design* (PD) as a component of participatory sensing.

[1] http://www.livableplaces.org/

Participatory design involves a technology's intended users throughout the design process. Traditional CBPR methods do not explicitly address technology design. But in research settings that rely upon technology for data gathering, PD can ensure participation in specifying and designing research tools. In the following section, we outline benefits of PD for participatory sensing. We then discuss the challenges of applying PD in participatory sensing, and propose methods to meet those challenges.

BENEFITS OF PD FOR PARTICIPATORY SENSING

Harnessing known strengths of PD will not only improve the functionality of participatory sensing technologies, it will also enable community participants to use these technologies more effectively. Advantages of PD for sensing network development include methods to target local knowledge and address relevant community challenges; techniques to foster participant understanding of sensing systems and consequently improve systems with participant feedback; and processes to mitigate privacy concerns through engagement and participant control.

Gathering Local Knowledge

In participatory sensing projects, participants are experts on their surroundings and the associated challenges of their environments. Fully involving community members in the design process can therefore help researchers develop sensing technologies that will gather not just data, but local knowledge. Local knowledge is the understanding gained by living within a particular setting and social group [7]. An integral part of community-based participatory research projects, local knowledge is notoriously difficult for outsiders to access [12, 13]. Participatory design methods are intended to incorporate local knowledge within the technology design process [14]. Adding techniques such as participant observation [15], storytelling, and cooperative prototyping [16] to the design of sensing networks can ensure that participatory sensing efforts collect data that both reflects and contributes to local knowledge.

Local knowledge can benefit participatory sensing in two ways. Designing sensing technologies with the cooperation of community partners enables projects to target the documentation of phenomena known to local residents, but difficult to prove to decision-makers and authorities. In CycleSense, for example, riders may know of poor bike path surfaces neglected by city authorities. Prior knowledge of poor surfaces can prompt design of sensing networks that safely and easily record time-stamped, geo-tagged images of road hazards. Automatically aggregating these images can document the safety risks posed to bikers.

Participatory sensing systems can also help participants establish the credibility of their data. To make a case for change in a community, participants must be able to defend data validity. Working with participants to define validity needs and threats, we can increase validity with a variety of measures. These include infrastructure-based verification of data, in which participants use trusted networks (e.g. wireless networks managed by project leaders) to upload data. The network adds time and location tags to data. An attestation service can check these tags for consistency with metadata attached by the phone. Organizers could also ask participants to verify other's contributions. In CycleSense, for example, the system might send an image and tag uploaded by Participant A to Participant B, who takes a similar route to work. The system would ask B to overlap with A's route to verify the image and associated tag.

There is an epistemological benefit of incorporating and verifying local knowledge during participatory sensing. Local knowledge recognizes local problems. Identification of local problems can spark new community research projects that outside researchers might otherwise miss. The design cycle for sensing technology is long and the process can be expensive. Focusing design on the realities of participating communities will help researchers target systems to relevant community challenges.

Understanding and Improving Systems

Sensing networks provide accurate and granular data, but they also produce more data than a human can easily parse. CycleSense, for example, might collect hours of latitude and longitude readings to tie to complex models of traffic density or air quality. Because copious sensing data often must be aggregated or visualized to be legible, participatory sensing systems require sophistication and experience to analyze research results. For community members to participate effectively in participatory sensing projects, they will need to understand the system's data flow and analysis process. Cooperation between researchers and community members to design data analysis and visualization interfaces can make complicated data legible to communities relying on that data. Cooperating to decide what data is collected, where the data is sent and stored, and how the data is processed, interpreted, and displayed will additionally help participant designers be effective researchers and contribute to their understanding of the accuracy and reliability of that data. Participants who understand precisely where their data comes from, how it is verified, and what it means will be able to understand and argue for the validity of the evidence they collect. They will also be better able to identify data that indicates breakdowns in the sensing system.

Feedback from participants will also help designers improve sensing systems. Iterative work with Livable Places' volunteers helped us refine our first implementation of a mobile-phone based image capture and tagging system. Participants who had trouble using the system were able to work directly with designers to improve the system's interface, which improved participant technology literacy while concretely benefitting sensing system design.

Mitigating Privacy Concerns

Because participatory sensing systems use mobile phones to capture data at unprecedented resolution, the technology is inherently intrusive. In CycleSense, for example, bikers might contribute GPS traces that identify their home, work, and daily routines. People's willingness to have devices record, share, and retain such personal data depends upon a host of personal and social factors, including at what granularity data is captured, where data is captured, who will have access to the data, and for how long [17]. Because people's willingness to share their personal data is variable and highly contextual [18], system privacy design must respect this variability.

Participatory sensing attempts to address this variability by encouraging participants to discuss privacy and make choices throughout design and use of the system [19]. Participant research decisions include weighing the sensitivity of a campaign's data against research benefits. Throughout the system design process, PD methods can encourage community members towards understanding of, and consensus on, system defaults and user choices for data granularity, data sharing, lengths of time for data retention, and permissions for data reuse.

CHALLENGES FOR PD AND PARTICIPATORY SENSING

Participatory design methods bring a number of strengths to participatory sensing, but these projects also pose difficult problems that remain open challenges in the PD literature.

Working with Diverse User Populations

Participatory design projects have traditionally focused on workplace technologies with discrete user groups [16, 20-22]. Participatory sensing necessitates partnership with organizations representing diverse demographic groups. Sensing participants will have different levels of technology experience, speak multiple languages, and be variously comfortable taking on design and research roles. Working with loosely-affiliated communities not united under a work organization is an unsolved PD challenge [16].

Compounding the problem of diverse user groups is the newness of participatory sensing technologies. Our introductory experience broaching and planning participatory projects with community groups points to a major challenge often faced in participatory design, and exacerbated by moving PD into the context of data gathering and CBPR. Not unlike the challenges of introducing internet-based workplace technologies a decade ago [22], communicating the possibilities and limits of sensing systems, and in turn learning from community groups, is hampered by the newness of the technology. Developing methods to describe the possibilities of sensing technologies without imposing creative limits on participant groups is a major challenge for participatory sensing projects. To address this challenge, we are exploring PD methods such as scenario construction and design games, which encourage movement from discussions and scenarios focused on data ("what information do you need to know?") towards systems ("what could help you find that out?")

Diverse user populations also present challenges to system scalability. Though some participants are actively involved in design and implementation, the privacy and ethical preferences of this subset may not be indicative of needs as wider populations adopt the technologies. Designing customizable systems for new user populations (for instance enabling flexible privacy defaults and customizable levels for data sharing) can help address this challenge.

Institutional Challenges

CENS faces internal cultural challenges that will affect participatory design projects. Foremost among the internal challenges may be reliance on a distributed design process. As a research institution composed of faculty, graduate students, undergraduates, and staff, CENS disperses authority for design and implementation throughout the organization. A project may involve a dozen designers responsible for different aspects of planning, coordination, and code. How will the center manage the logistics of PD while cooperating with a large number of community members and a large number of designers? Pekkola et al's definition of "mediators"—a few designated go-betweens—may prove useful in the CENS design environment [23].

A further challenge will arise if participatory design techniques slow sensing system implementation. In an academic environment where researchers must build models, test systems, and publish results, how do we justify a slower, stickier design process? There is some evidence that a prolonged design process may enable new nodes of innovation [14, 20]. We hope to find that a slower, user-centered design process prompts advances to answer many of the challenges inherent to participatory sensing systems.

LINKING PD AND PARTICIPATORY SENSING

Participatory sensing is a *research* process: people gather data to learn about a phenomenon of interest and come to new understandings. Participatory sensing participants will formulate research questions; plan campaigns and design instruments to answer those questions; deploy campaigns; and analyze and present results. During this process, participants form flexible *communities of practice*: groups bound by common purpose that develop a shared store of knowledge and set of accepted work behaviors [24]. Designers can observe and participate in the formation of these research groups to find spaces for participatory design decisions and interventions. Building on PD methodologies such as visioning [25], scenario-based design [26], software prototyping [23], and design games [25], sensing researchers can actively incorporate design elements into the participatory research process.

CycleSense will be our first systematic exploration of participatory design of sensing systems. We are recruiting self-identified members of the bike commuter community through the Los Angeles Bike Coalition,[2] blog outreach, and word-of-mouth. Design methods will include leading visioning workshops with bikers during research planning ("In an ideal world…") [25]; discussing incomplete scenarios to spark debate and iteration on potential designs [26]; prototyping systems with users to gather observational data and explicit responses [23]; and asking users to keep journals during system pilots to gather ideas, criticism and feedback. The CycleSense PD plan takes advantage of the existing structures of the research process to incorporate design of the research instruments.

FUTURE WORK

As researchers continue participatory sensing projects, future work will explore instances of creativity and understanding that arise in the cooperative design process. Case studies of PD will also illuminate new challenges for incorporating PD into participatory sensing and research.

ACKNOWLEDGEMENTS

The authors would like to thank Livable Places' team and Dorothy Kieu Lê of the Los Angeles Bike Coalition. Thanks also to anonymous reviewers and colleagues in UCLA's Department of Information Studies for comments on earlier versions of the paper.

REFERENCES

1. Paulos, E., et al. Sensing Atmosphere, in *Proceedings of SenSys* (Sydney, Australia, 2007), ACM.
2. Burke, J., et al. Participatory sensing, in *Proceedings of Sensys* (Boulder, CO, November 2006), ACM.
3. Eisenman, et al. MetroSense Project: People-Centric Sensing at Scale, in *Proceedings of SenSys* (Boulder, CO, November, 2006), ACM.
4. Eagle, N. et al. Reality mining: sensing complex social systems. *Pers Ubi Comp* (2006), 255-268.
5. Cargo, M. et al. The value and challenges of participatory research: strengthening its practice. *Annu Rev Publ Health*, 29 (2008).
6. Byrne, E. et al. Questions of ethics: Participatory information systems research in community settings, in *Proceedings of SAICSIT* (Cape Winelands, SA, 2006).
7. Corburn, J. Bringing local knowledge into environmental decision making: Improving urban planning for communities at risk. *J Plan Edu Res*, 22 (2003), 120-133.
8. Elwood, S. Critical issues in participatory GIS: Deconstructions, reconstructions, and new research directions. *T GIS,* 10, 5 (2006), 693-708.
9. Wang, C., et al. Chinese village women as visual anthropologists: a participatory approach to reaching policymakers. *Soc Sci Med*, 42, 10 (1996), 1391-1400.
10. Eisenman, S. B., et al. The BikeNet mobile sensing system for cyclist experience mapping , in *Proceedings of SenSys* (Sydney, Australia, 2007), ACM.
11. Shallwani, S. et al. *Community-based participatory research: a training manual for community-based researchers*. Aga Khan University Human Development Programme, 2007.
12. Srinivasan, R. Reconstituting the Urban through Community-Articulated Digital Environments. *J Urban Technol*, 11, 2 (2004), 93-111.
13. Srinivasan, R. et al. The South Asian Web: An Emerging Community Information System in the South Asian Diaspora, in *Proceedings of PDC '06* (Trento, Italy, 2006), ACM.
14. Gregory, J. Scandinavian Approaches to Participatory Design. *Int J Eng Educ*, 19, 1 (2003).
15. Crabtree, A. Ethnography in Participatory Design, in *Proceedings of PDC '98* (Seattle, WA, 1998), ACM.
16. Muller, M. J. Participatory design: the third space in HCI. *Handbook of HCI*. Erlbaum, Mahway, NJ, 2003.
17. Waldo, J., et al. *Engaging privacy and information technology in a digital age*. The National Academies Press, Washington, D.C., 2007.
18. Nissenbaum, H. Privacy as contextual integrity. *Wash Law Rev*, 79, 1 (2004), 119–158.
19. Shilton, K., et al. Participatory privacy in urban sensing, in *Proceedings of MODUS '08* (St. Louis, MI, 2008).
20. Pilemalm, S. et al. Third generation participatory design in health informatics. *J Biomed Inform* (2007).
21. Dredger, S. M., et al. Using participatory design to develop (public) health decision support systems through GIS. *Int J Health Geo*, 6, 53 (2007).
22. Kensing, F. et al. Participatory design: issues and concerns. *Computer Supported Cooperative Work*, 7, 3 (1998), 167-185.
23. Pekkola, S., et al. Towards formalized end-user participation in information systems development process, in *Proceedings of PDC '06*, (Trento, Italy, 2006) ACM.
24. Davenport, E. et al. Organizational Knowledge and Communities of Practice. *Annu Rev Inform Sci*, 36 (2002), 171-227.
25. Brandt, E. Designing exploratory design games: a framework for participation in Participatory Design? in *Proceedings of PDC '06* (Trento, Italy, 2006), ACM.
26. Carroll, J. M. *Making Use: Scenario-Based Design of Human-Computer Interactions*. The MIT Press, Cambridge, MA 2000.

[2] http://la-bike.org/