Citisense: Mobile Air Quality Sensing for Individuals and Communities

Design and deployment of the Citisense mobile air-quality system.

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Abstract— **Individual and community health can be greatly impacted by poor air quality. Unfortunately air quality metrics are hard for individuals to obtain and are often not precise enough for people to make the inferences they need to construct positive personal health choices. Through the Citisense mobile air quality system we enable users to track their personal air quality exposure for discovery, self-reflection, and sharing within their local communities and online social networks.**

Keywords-ubicomp; sensors; air quality; participatory sensing

I. INTRODUCTION

Air quality is an important topic that often is ignored by individuals. Personal exposure is hard to track and for many individuals the negative health effects are often not seen until after many years of cumulative exposure have passed. Additionally, the lack of fine grain sensing adds a level of complexity to the issue as large urban areas are often monitored by a small number of sensors (6 sample sites for the 400 square mile city where we conducted our study). These sparse stationary sensors can provide a baseline for individual exposure, but as users learned in our study, are often not representative of the air experienced at street level.

To help individuals gain a better understanding of their personal exposure we designed the Citisense mobile air quality sensor. This sensor is designed to pair with any android device to allow users to view real time air quality data of their surroundings. Users can view their current air quality through our custom android application. To allow for simple understanding of the sensor reading we display the current air quality using a variation of the United States Environmental Protection Agency's Air Quality Index (AQI), a color-coded system for displaying air quality numbers for public consumption [2,3]. For the more involved user we also provide hourly peaks in exposure, the raw sensor numbers, and a full-scale web interface that can be explored in greater depth using a desktop computer.

We hypothesized that users of our system would be interested in sharing their finding with others in their communities, so we built social network sharing features into both the mobile and computer based applications. Through our system, users can post current readings as well as detailed maps of their sample data. In this paper we report on the design of the Citisense system and present initial results from a one month pilot study.

II. RELATED WORK

Others have studied the topic of enabling individuals to conduct participatory sensing [6] in the area of air quality. Willetts common sense community used a controlled single day deployment study to explore how individuals with different backgrounds might use a mobile air quality sensor[5] with the particular goal of inspiring data analysis of the sensor data. Aoki et al. explored how mobile air quality sensing fits into the ecology of stakeholders, and discovered barriers that might be faced by mobile sensor networks, such as the credibility, viability, and relevance of the data [4]. We attempted to address these concerns in our system by focusing the design at the individual and friend-group level rather than try and include large-scale government and policy in our design. In the future these may become concerns that will need to be addressed with additional thought and design.

III. SYSTEM DESIGN

The Citisense system is comprised of three main parts. The sensor and phone are mobile and can be carried with an individual throughout their day and specifically during their commute. The sensor and phone provide instantaneous access to the current air conditions and are meant for "in the moment" observations. The third aspect of the Citisense project consists of a web interface accessible from a desktop or laptop computer. The website provides historical data and trends which users can explore to reflect on their overall exposure to pollutants.

A. Sensor

We created a mobile sensor designed to be light and wearable. The custom board is designed to house three electrochemical gas sensors with the current configuration consisting of NO2, O3 and CO sensors [**Figure 1**]. The board also contains sensors for temperature, humidity, and barometric pressure. We choose to use electrochemical gas sensors because of their low energy consumption when compared with

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Semiconductor Metal Oxide (SMO) sensors that require heat to produce readings. Our sensor board connects via Bluetooth with the phone to provide maximum flexibility for users regarding where they carry the sensor board and where they carry the phone.

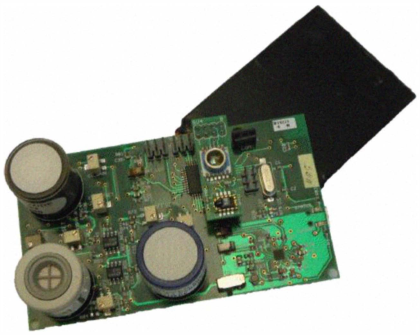

Figure 1. Internal view of the custom board. Sensors for NO2, O3, and CO are shown.

The sensors were each calibrated before being attached to the board using gasses of known concentrations to ensure accurate readings. The sensor board was then encased in a hard plastic shell with Velcro straps attached to the casing. The straps are designed so that the sensor could be easily attached to backpack straps and bicycle frames [**Figure 2**]. The battery life of the sensor board is roughly 5 days per charge.

Figure 2. For the study these boards were encased within protective plastic cases. Holes in sides and top of the plastic case allow for airflow to reach the sensors on the board.

B. Mobile Phone Application

The phone interface provides a way for users to gain instant access to their current air quality using the data collected from the sensor board. The phone interface is divided into two screens; the home screen supplies glanceable information regarding the current air quality, while the details screen provides the current reading reported by each sensor along with a graph showing the historical readings from that day.

Figure 3. Phone interface. Left: Main screen shows current air quality in a large color coded cloud designed for easy glanceability. Buttons below allow for in-the-moment sharing of air quality with popular social networks. Right: The Pollutant Details screen gives curious users more fine grained information about the sensor readings. The graph at the bottom plots the maximum AQI recorded each hour.

Initial short-term deployments revealed that the AQI color code did not provide sufficient feedback for our curious users. Due to the ranges being relatively large, users reported that they wanted to know when they were in borderline situations (for example a high green, bordering on yellow). To address this user concern we added the color bar to the main screen that indicates where along the color scale the current AQI reading registers using a white arrow and line.

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air Quality is considered satisfactory, and air pollution poses little of no risk
Moderate	51 to 100	Air Quality is acceptable; however, for some pollutants there may be moderate health concerns for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

Figure 4. The air quality index color chart was designed by the EPA to provide non-expert users with a way to easily understand their pollution exposure. We use the same colors in our interface to provide glanceable information about individual exposure and air quality. A link to this chart is available from the home screen of the application to provide users with easily access the levels if they forget.

The phone application is also responsible for recording the geographical location of each sensor reading. To prolong battery life we only use the phone's GPS when the user is moving. The remainder of the time a user's location is determined at the network level using cell towers, a procedure that has a much smaller impact on battery life.

C. Web Interface

The web interface is designed for reflection and review of collected data over time. The central aspect is the interactive map screen where users can view their personal data overlaid on a Google map [**Figure 5**][1]. Each bubble on the map screen is numbered so that users can tell by glancing when each sample was collected. This allows for users to quickly identify samples from different trips that occupied the same physical location, such as driving to work, and driving back home; a process that will likely utilize the same roads but at different times. If users are interested in a specific sample point they can click on the bubble to gain additional information about the exact time the sample was taken, the pollutant which the AQI calculation was based on, and the raw sensor readings. Each bubble's color corresponds to the associate AQI reading [**Figure 4**] to allow users to quickly scan for problem regions.

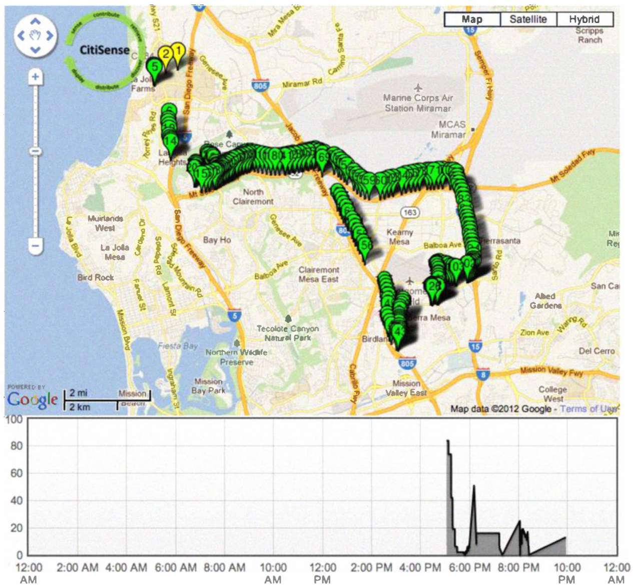

Figure 5. The interactive online map displays sample points from throughout the day. Each point is color-coded using the EPA's AQI color chart. Details for each sample can be explored by using the mouse to select the bubble. The graph below records each sample point collected to provide view of the data over time.

In addition to the interactive pollutant map, we also provide a timeline that tracks pollutant exposure throughout the day. This timeline show a more fine grain exposure than the graph on the phone as the additional space allows us to plot each sample collected rather than just the maximum sample per hour as we do on the phone.

IV. Study Design

To understand how users would make use of such a system in the wild we recruited 8 participants (5 men, 3 women) for a month long exploratory study. Recruitment criteria required that:

1. Participants commute each weekday for at least 20 minutes each direction.
2. Participants are regular users of an online social network. Particularly that the participants both visit a social network site multiple times per week, and post content to their social network multiple times per week.

Participants were recruited through an on-campus mailing list and included a librarian, a science writer, a programmer analyst, a public information officer, a fund manager, a student advisor, a senior budget analyst, and a student athlete.

The age of participants ranged from 20 to 45 (mean of 35 years of age) and the average commute distance ranged from 14 miles round trip to 65 miles round trip (mean of 40 miles round trip). To gain a broad span of results we selected our subjects to have a wide range of commuting methods as shown in Table 1.

TABLE I. Commute Methods & Distance (round trip)

Participants self-reported commute data	
Method	***Miles***
Cycle	27
Halfway car, halfway bus	40
Train and bus. Occasionally train and car.	60
Car	65
Bus and trolley	54
Cycle	20
Car	58
Motorized Scooter	14

To participate in the study, individuals agreed to carry the sensor daily for 4 weeks. They also completed an online pre-study questionnaire, a mid-study questionnaire, an end of study questionnaire, and an open-ended interview upon completion of the study. Compensation for time and travel costs was $75 for the month long study.

Results and Discussion

In this section we provide the initial results from our study interleaved with a brief discussion of the implications of our findings. As this first deployment was a small scale exploratory one designed to explore the breadth of possible responses, our discussion centers mainly on qualitative results, which illuminate how users may respond to having such systems available.

A. Discovering

For most participants this was the first time they had regular access to local air quality data. Participants related delighted surprise in finding better air quality than they expected "*I'm pleasantly surprised that the quality of air around my work and home environments is generally high*" <Participant 4>, concern in discovering unexpected poor quality air "*It never occurred to me how bad the air is as cars drive by while I'm waiting for the bus*" <Participant 5>, and curiosity in discovering that air quality behaved differently than they had imagined "*I've become more aware of how things like freeways, power plants, etc. affect the surrounding area. I guess I always just thought of the atmosphere as being evenly mixed but it is not*" <Participant 6>. The act of learning patterns in air quality was also positively reflected on with participant 2 saying "*I liked seeing how the air quality changed as I moved from place to place*."

In addition to the discoveries about outdoor air quality, participants also sampled indoor air in their homes and workplaces. This is especially important because indoor air quality information is something that will likely never be provided at the city level, and is an argument for why personal sensors like these can be beneficial to users. Using these sensors indoor enabled participants to discover previously unknown situations and practices that contributed to poor air quality. For Participant 6 this manifested her statement that "*It seems like my gas stove kicks out carbon monoxide and it isn't vented. That concerns me.*" In contrast, another participant related how a practice they had previously considered healthy was actually damaging their health "*Burning incense is terrible for my health!*" <Participant 1>.

In general using the sensors encourages participants to be more conscious of their surroundings and how their choices and environments could negatively or positively affect their exposure. With participants saying that before "*Most people, including me, generally have no idea about when air quality changes for the worse*" <Participant 4> but that using the system made them more aware "*I'm more conscious of leaving my car idling and keeping the windows closed on the freeway*" <Participant 6>.

B. Sharing

We expected participants to share content through online social networks but through the interviews we also found many cases of in-person sharing of data. Even more surprisingly several used their carrying of the sensor as an opportunity to share pollutant data with strangers. Four of the eight participants related a story about interactions with a stranger related to the system. Participant 6 shared their reflections saying "*I share the readings with the people I ride the train with and anyone else I interact with and they are usually interested. They seem pleased to see that it is pretty good and like me, surprised at the difference near the freeways.*" It is possible that because ambient air is a shared resource even among strangers, that barriers that would otherwise exist were easier to ignore in these interactions, and has similarities to how weak acquaintances might discuss the weather.

Posting to social networks was another way in which people shared the data they collected. However this also often served as a gateway to in person interaction with participant 2 saying "*A friend saw my posts to Facebook and asked many questions about the readings*". It may be that these in person interactions were common because local air quality may be an issue of particular interest to local friends. In additional studies we hope to look more at the geographical location of respondents to air quality postings on social networks.

C. Acceptance and Change

One of our chief concerns with enabling individuals to track their exposure to poor quality air was fear that participants might feel helpless to change their situation. We were surprised however to see how participants take steps to improve their situations based on the data they received from the system. It should also be noted that, in general, people in our study had relatively good air quality in their homes, and different results might be expected if more study subjects had experienced prolonged poor indoor air quality.

One of the ways in which we say people taking proactive steps to decrease their exposure to pollutants was through mindfulness of where they traveled. One participant reported they chose to avoid busy street when walking, and also avoided walking past the engine of a train which the perceived to be negatively impacting the air quality. Others took more long-term action by convincing their employer to buy new air filters for their building after they repeatedly recorded poor air quality readings inside.

Improved awareness also inspired interest in larger scale change. Participant 8 stated "*I try to keep abreast of environmental issues and this has definitely opened my eyes. The potential to bring awareness to the public is always key*." Participant 6 echoed with a similar sentiment: "*I'm more inclined to support regulations to improve air quality. It's made me aware that polluting our air is like fish pooping in their tank.*" These types of responses suggest that there may also be potential for these systems to motivate people to advocate for change. The Citisense system makes the previously invisible problem of poor air quality both visible and quantifiable which may be the cause of this sudden motivation.

Conclusion and Future Work

In this paper we present the design and initial deployment of the Citisense mobile air quality sensing system. In future work we plan to explore how users with existing relationships can leverage this type of data collection with a focus on selecting groups that are sensitive to poor air quality.

Acknowledgments

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