iShake: Mobile Phones as Seismic Sensors – User Study Findings

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ABSTRACT
The "iShake" system uses smartphones as seismic sensors to measure and deliver ground motion intensity parameters produced by earthquakes more rapidly and accurately than currently possible. Shaking table tests followed by field trial with approximately 30 iShake users were implemented to evaluate the reliability of the phones as seismic monitoring instruments and the functionality of the iShake system. In addition, user experiences were investigated with 59 iShake users, who provided feedback through a mobile questionnaire. Research included participative planning with a focus group to design and conceptualize how to improve iShake for future use. The shaking table tests demonstrated that cell phones may reliably measure the shaking produced by an earthquake. The performed user studies led to important guidelines for the future development and improvement of the iShake system. User studies also provided understanding of how iShake could best provide value to its users. The iShake system was shown to have great potential in providing critical information and added value for the public and emergency responders during earthquakes. Value creation for other users and first response through user-generated data was seen as a great source of motivation and commitment for active use of the system.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Evaluation/methodology, User-centered design.* J.2 [**Physical Sciences and Engineering**]: Earth and atmospheric sciences. K.4.1 [**Computers and Society**]: Public Policy Issues – *Human safety*. K.8 [**Personal Computing**]: Apple.

General Terms
Design, Experimentation, Security, Human Factors.

Keywords
Earthquake, seismic sensor, smartphone, Apple iPhone, post-earthquake notification, field trial, user experience, value creation, California.

1. INTRODUCTION
Most of the population takes the stability of the earth for granted. Human adjustment to earthquake hazard requires adaptation to phenomena that confuses people's senses and beliefs [20]. Earthquakes have been the cause of many of the most devastating natural catastrophes in the 20th century. Seismic zones are frequently subjected to earthquakes, which can cause a tremendous loss of lives and property. Unlike some other natural disasters, there is typically no or little warning, the impact is widespread, and the effects diverse. In the aftermath, fear of aftershocks and social and economic disturbances may last for years. Time and time again, studies have shown that populations subjected to large and frequent earthquakes suffer from on-going fear and anxiety [2]. Because earthquakes cannot be predicted, the only way to reduce damage and loss is through effective preparedness [29].

Dramatic changes in the features commonly available in cellular phones have produced a new breed of phones called smart phones that represent the convergence of sensing, computational power, and communication. While the smartphone is not technically designed to be a scientific sensor, the addition of inexpensive, lower-quality sensors into the device permits the exploitation of the device for such a use and allows one to treat the phone as a means of sensing ground motion data, along with the a means of transmitting the data to a central system. Thus, the iShake project sets out to utilize the Apple iPhone as a mobile sensor to measure seismic activity, permitting measurements to be taken wherever there is a network connection.

California is an earthquake prone area that has had several severe earthquakes in recent history, such as the magnitude (M) 6.9 Loma Prieta and M 6.7 Northridge earthquakes in 1989 and 1994, respectively. The Uniform California Earthquake Rupture Forecast (UCERF) report [34] used improvements in the earth sciences to predict that "California has a 99.7 percent chance of having a magnitude 6.7 or greater earthquake in the next 30 years, and a 46 percent chance of having a magnitude 7.5 or greater earthquake in the next 30 years". Regions subject to earthquakes have the benefit of having a population that is aware of the risks associated with earthquakes and potentially willing to utilize technology that can help them better manage the advent of a major earthquake.

Mobile phones are now referred as "a technology other than human observation itself that is as pervasively deployed out in the world" [22], and they offer powerful potential to enhance the role of the citizen observer, thus supporting advocacy and civic engagement [11,22]. With iShake, we make the assumption that if people are offered a free service on their phone, a sufficient number of users would voluntarily participate to make the system operational and capable of collecting large amounts of data. The collected data will aid first responders and will be invaluable to scientists.

The San Francisco Bay Area alone is home to over 10 million people. If only one-tenth of those individuals with capable phones participate, 100,000 sensors would come on line. If just one-tenth of these sensors measure accurate data during a major earthquake, the U.S. Geological Survey (USGS) and the California Geological Survey will have semi-quantitative ground motion data from 10,000 sensors. This is more than an order of magnitude more instruments than are currently available in the Bay Area through ANSS (the Advanced National Seismic System). In areas of the Nation where ground motion stations are more sparse, the increase in the number of sensors will enable higher-quality maps to be prepared with resolution previously not possible.

The iShake project proposes an innovative use of cell phones and information technology for rapid, post-earthquake analysis and visual representation of seismic data. A series of one-dimensional and three-dimensional shaking table tests were performed as a part of this study, and the results of these tests served as a proof of concept for the development of the iShake. A field trial was subsequently conducted to test the iShake system, where users simultaneously used the iShake application and shook their phones to simulate an earthquake (hence the term "virtual earthquake"). Through the field trial and related user study activities, guidelines and requirements for iShake's future development and improvement were developed. These tests also provided insight into how iShake could best provide value to its users and what kind of information and data visualization best serve the users during future earthquake events. Here, the purpose is not to validate the technical reliability and functionality of the iShake system, but to examine and analyze value parameters brought to users by iShake. Thus, the focus of this paper is on the qualitative findings of the iShake user study, and the shaking table tests and feasibility analysis of the system are not discussed at length in this paper, as they are detailed elsewhere [10].

This paper is organized as follows: Related work is described first, followed by justification of the iShake system development together with the results obtained from system feasibility testing and a description of the iShake system. This is followed by an overview of the iShake user study introducing the methodology used in user experience data collection as well as the field trial procedures used for system testing and evaluation. The paper continues by representing and analyzing the user study findings. The paper finishes with discussion and conclusions, proposing topics for future research.

2. RELATED WORK

Through pre-event earthquake mitigation measures, the risks from earthquakes can be reduced [12]. In addition, it is critical to assess rapidly the post-event situation and effectively marshal emergency responders to areas hardest hit by an earthquake. The U.S. Geological Survey (USGS) has made a major commitment to deliver post-earthquake information for these purposes. ShakeMap and "Did You Feel It?" are examples of some of the products that are currently being used [4,31,32]. Although they enjoy some success, there is the need for advancements and refinements to improve the speed and accuracy of post-earthquake information.

ShakeMap [31] provides rapid, quantitative assessment of the level of shaking produced by a major earthquake. It works best in regions that contain a sufficient number of ground motion instruments to "capture" the event. While it does contain algorithms for estimating ground motions in areas of sparse station coverage, its reliability is hampered by the limited number of strong motion stations in a given area.

"Did You Feel It?" (DYFI) [4], on the other hand, uses human observations voluntarily submitted through the Internet after an earthquake. The mapping is based on the Modified Mercalli Intensity (MMI) scale [28,33], with individuals asked to respond to questions that lead to a value that best represents the local shaking at their location. A single MMI is assigned to each zip code and zip codes that have no response are shown as grey. The result is a Community Internet Intensity Map (CIIM) [32] summarizing the responses. However, the observations of untrained humans are a rough qualitative indicator of the effects of the earthquake. In addition, DYFI reliability is greatly hampered by the speed at which this information can be collected and disseminated. In turn system response is dependent on how fast people are able to access the Internet, which might be quite problematic depending on damage levels.

Another project for measuring and delivering post-earthquake information is the Quake-Catcher Network (QCN) [7] developed and run by Stanford University and the University of California, Riverside, which uses inexpensive accelerometers attached to personal computers and laptops to measure and detect earthquakes. The work done by iShake complements this project well, as it takes advantage of a resource not considered by Quake Catchers, and provides directional compass data that personal computers cannot measure, allowing the measurements to capture direction of first motion. Modern smartphones almost always come equipped with advanced geo-location services, which not only allow for a higher degree of accuracy for location in contrast to QCN sensors, but also allow the device to use the iShake application in any environment with a network connection.

3. RESEARCH SETTING

The following subsections present the technical innovation explored in the iShake user study.

3.1 Motivation for iShake

Emergency responders must "see" the effects of an earthquake clearly and rapidly so that they can effectively take steps to ameliorate the damage it has produced. When communicating the intensity of shaking with the public and emergency responders, on one side of the spectrum we have the high quality, but sparse, ground motion instrument data that are used to help develop ShakeMap, and on the other side of the spectrum we have the low quality, but sometimes larger quantity, human observational data collected to construct a "Did You Feel It?"-based map.

The primary objective of the iShake project is to use people's smartphones to bridge this gap and occupy a third space, as phones can provide immediate post-earthquake information with a potentially large number of relatively good quality sensors (see Figure 1). Rather than solely relying on individuals' feedback as measurement "devices", the iShake project uses a ubiquitous instrument that most people already possess to measure ground motion intensity parameters in a semi-quantitative manner. Participatory-sensing systems leveraging mobile phones have been acknowledged to offer unprecedented observational capacity [11].

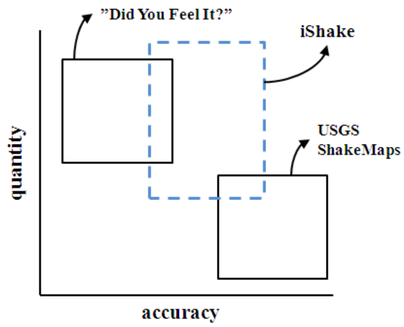

Figure 1. Bridging the gap with iShake.

The current iShake system uses accelerometer-enabled iPhones to measure the shaking produced by an earthquake. The seismic data is immediately sent after the earthquake occurs to a server that analyzes and interprets the data. A key point of the iShake system is the immediacy with which the data is relayed to emergency response centers, as the cellular network will rapidly become overloaded. The initial minute is sufficient time to automatically broadcast earthquake data providing users with basic information such as magnitude of the earthquake, location of the epicenter, and potential areas with the most damage. The future scenario is the collection of relatively high quality shaking data from thousands of cellular phones, enabling the USGS to produce ground shaking maps more rapidly and accurately than can be generated with current tools.

3.2 System Feasibility Testing

The Apple iPhone can best be modeled as an intelligent sensor that has the ability to transmit its data. Thus, we propose the use of the iPhone as a new ad-hoc sensor array based on participatory sensing. The nodes in the sensor array are cell phones voluntarily provided by participants, used to monitor vibrations when they are in a rest position.

In the first development phase, iShake was set out to utilize the iPhone as a mobile sensor for seismic data. While the iPhone is not technically designed to be a sensor platform, a variety of sensors in the device permit its use in this fashion. The iPhone uses the STMicroelectronics LIS302DL "piccolo" accelerometer. The dynamic range of the accelerometer may be adjusted by Apple to a 2 or 8 g range. To evaluate the performance of the accelerometers used in the iPhones, a series of 1-D and 3-D shaking table tests were performed at UC San Diego and UC Berkeley, respectively. Detailed findings from these shaking table tests are reported in technical report [10]. In these tests, four iPhone 3GS and three iPod Touch devices were mounted at different orientations and subjected to 124 earthquake ground motions at various intensities to characterize their response and reliability as seismic sensors. Also attached to the base platform were three orthogonal, relatively high-quality miniature accelerometers that were used as a reference for the phone measurements. The testing also provided insight into the seismic response of unsecured and falling instruments [10].

The devices and reference accelerometers captured the shaking events in a series of trials. For each trial, the reference accelerometer signals were compared to the mobile device-measured signals to study the reliability of phone measurements as seismic monitoring instruments. The recorded cell phone data were used to calculate seismic parameters such as peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), and 5% damped spectral accelerations [10]. The mean acceleration response spectrum of the seven iPhones compared well with that of the reference accelerometers, and slightly over-estimated the ground motion energy and hence, Arias Intensity (I_a). The error in the recorded intensity parameters was dependent on the characteristics of the input ground motion, particularly its PGA and I_a, and decreased slightly for stronger motions with a higher signal to noise ratio. While mobile devices are not well-equipped to handle lower-intensity shaking events, as the intensity (and PGA) increases, the devices perform better.

Figure 2 shows representative velocity and displacement time-series recorded by the high-fidelity reference accelerometers, as well as those recorded by an iPhone device. The records were calculated by successive integration of the original accelerometer signal. It is obvious from Figure 2 that the peaks from the two sources are very similar and occur at the same time. PGA, PGV, and PGD statistics help in determining where the most severe shaking occurred during an earthquake. Particularly, the ground velocity is a good measure of damage to engineered facilities, which is valuable to emergency responders.

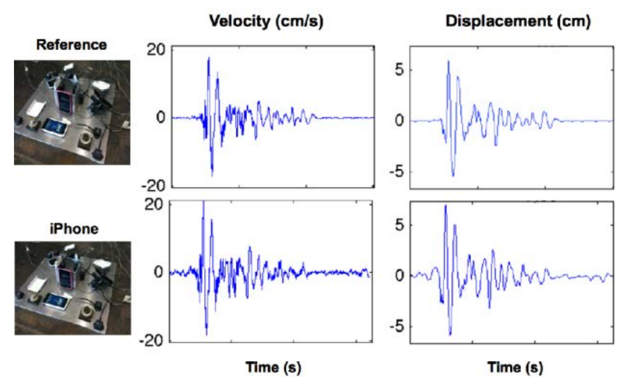

Figure 2. The accelerometer records of the reference and mobile devices.

An additional set of tests was run to evaluate whether meaningful data could be obtained from a phone not rigidly fixed to a table. The use of a high-friction device cover (e.g., rubber iPhone covers) on two unsecured phones yielded substantially improved data by minimizing independent phone movement [10].

The testing sequence showed that the iShake system was able to successfully deliver acceleration readings from the phone to the database on the server, at which point the data could be plotted for instant verification. The iPhones were proved to be successful in capturing key intensity parameters during shaking table tests. It was discovered that the iPhones are much more capable of measuring high-intensity events due to the limited resolution of the iPhone accelerometer. The results of the tests served as a proof of concept for the development of the iShake system introduced in the next section.

3.3 iShake System Description

Figure 3 provides an overview of the iShake system architecture.

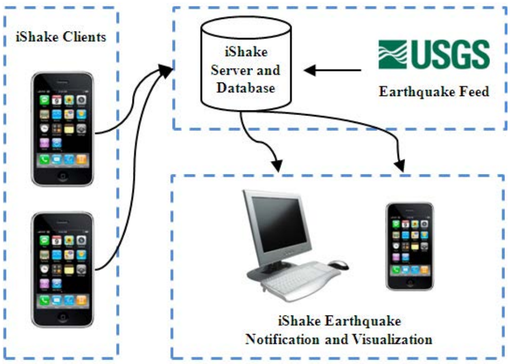

Figure 3. Overview of the iShake system.

3.3.1 iShake Client

In addition to the accelerometer, the iPhone includes a 3-axis magnetometer, which acts as a compass in common use, and a GPS unit for geo-location and navigation. For a traditional seismic recording, the orientation and location of the seismograph are constant and known. These parameters are dynamic for the phone and must be determined and associated with any data that the accelerometer reports. Using the accelerometer, magnetometer, and GPS readings, the orientation and location of the phone can be estimated (Figure 4).

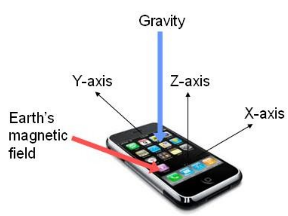

Figure 4. Mobile phone as seismic sensor.

To begin determination of earthquake events, the mobile device must be stationary for a period of time prior to recording. The reasons for this are twofold. First, to determine orientation of the device, the gravity vector must be determined, and this can only be accomplished if the device is not experiencing other forces. Second, the iShake project is only analyzing recordings from stationary devices. Thus, devices carried on a moving person or experiencing a great deal of movement unrelated to seismic events should not transmit their data to the server. Device movement is characterized by a change in the accelerometer reading.

Cellular phones are used by their owners only part of the time. In particular, when phones are being charged, they are not being used, and are in a rest or static position. This situation offers interesting opportunities for reliably sensing earthquakes, since during the charging time, phones have essentially unlimited power (and are therefore able to use all their sensing and communication equipment regardless of battery life), and can be stabilized. Thus, the phones are able to capture features from the environment uncontaminated by human motion, such as when they are being carried. In consequence, iShake users are asked to simply turn on the application when they plug in their phone, for example at night when they go to sleep. Then any possible earthquake triggers measured by the phone will instantly be streamed back to iShake servers for further processing and shake map generation.

Multi-tasking is not supported on iPhone models older than version 4.0. Hence, an alarm, text message, or a phone call may interrupt the successful and continuous running of the application. This problem is largely addressed in recent iPhone and iPod touch models. With the introduction of iPhone Operating System 4.0, all compatible iPhones have background activity capabilities. Receiving alerts such as text messages or phone calls will no longer disturb the application.

3.3.2 iShake Server

The server for iShake acts as the administrator for the possibly large number of events being sent from the iShake clients. Although any data transmitted from the iPhone is considered a shake event, we may reasonably assume that most events sent by the phone will not actually correlate to a real earthquake. When shaking events are first received by the server, the event is classified as "unverified". All unverified events are compared against a database of recent earthquake events reported by the USGS through an online xml feed. Since the iShake system is currently designed for California earthquakes, this verification process is considered to be acceptable. If our server receives multiple simultaneous accelerometer readings within the same region, it is likely an earthquake. Filtering algorithms are used to detect falling or loosely-attached devices, as well as device-specific responses to the event. Signals produced by devices experiencing sudden or unrelated forces should be removed.

3.3.3 Earthquake Notification and Visualization

Once the server has validated and processed the transmitted data from the iShake clients, the summarized information will be visualized on the users' phones. In a presentation similar to the ShakeMaps by USGS, iShake can produce a geospatially-varying intensity map from the filtered and processed accelerometer recordings of the iShake clients. For testing purposes the iShake client was given an additional functionality called the "Shake Monitor" where the users could generate their own shake events by giving the phone a trigger, e.g. by tilting the phone. These live "iShake Maps" of users' shakes are made instantly available for viewing on the application as well as on the iShake website. Figure 5 shows the user views of the Shake Monitor interface and an example of iShake Map generated on client application from users' individual shake events. This map visualized locations of anonymous iShake users around the "earthquake" area with a rough shaking intensity map showing the magnitude and duration of the earthquake in the user's zone of interest. iShake users could select to view the information obtained from their own phone only or alternatively also those obtained from other users.

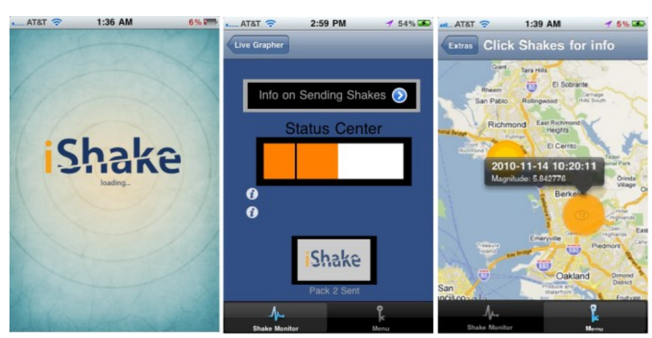

Figure 5. "Shake Monitor" interface and "iShake Map" generated on client application.

When the user first downloads the application, s/he is asked to register (this step is voluntary) to have the opportunity to access and view their own data and contributions also online at the iShake website. The information requested during the registration process does not inherently reveal or become associated with the user's real-world identity. On the Shake Monitor, the user is able to view "Live Grapher" displays of the forces his/her phone is currently feeling from the environment (see Figure 6). Registered users can view accelerograms sent from their iPhones as well as the time and location of each record through the "iShake Signal Grapher" link on the website.

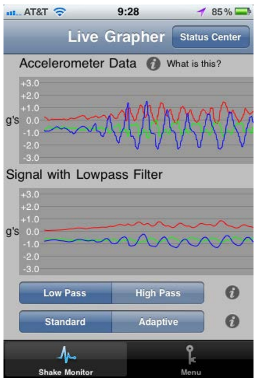

Figure 6. "Live Grapher" interface.

The application also provides users with other useful and interesting information related to earthquakes, and offers a detailed "handbook" of earthquake preparedness compiled from various reliable and official sources. The information bundle is intended to help the iShake users educate themselves and prepare in advance, as this is the key to surviving when natural disaster strikes [12]. This important educational preparedness information is presented in the form of text, video and images, and categorized under themes such as "before an earthquake", "during an earthquake", and "after an earthquake".

4. USER STUDY

To complete the shaking table experiments, the performance of the iShake system was also evaluated through field trial and related user study activities. Jurison [18] has concluded that applications which are perceived to offer high value from the start are adopted rapidly while those perceived to be of low value are adopted slowly and are unlikely to gain acceptance in the long run. Our aim is to have the users to adopt iShake in long-term use and use it as a critical information channel during earthquake. To achieve this, we need a deeper understanding on what kind of information and instructions users would like to receive from iShake in the event of an earthquake, and how to present this data to users.

Through the user study we wanted to obtain guidelines and requirements for iShake's future development and improvement. It was also essential to identify the individual value parameters brought to the user through iShake. Another side of the trial was to experiment the functionality and scalability of the iShake system, i.e., the sensing, transmission, and display capabilities of the iPhones.

4.1 Participants

Before the launch of the user testing, the free iShake application was released on Apple's own App Store. We hoped that enough value could be provided to iShake users through the application itself, thus giving users sufficient reasons to participate in the trial. The pool of potential iPhone users is large, but the number of trial participants was dependent on how many people eventually chose to install, and then use, the application. Our strategy was to exploit the large penetration of iPhones in the student body at University of California in Berkeley (UCB) as a starting point, and get volunteers to submit samples for the research data. The number of participants was limited because of the amount of time for which measurement data was collected, the incentive that users had to install the application, and the potential number of users who had the technical capabilities and belonged to the UCB community, which was used as a main recruiting pool for test participants and where the activities for finding test volunteers were centered.

In regards to data collection the users' identities were kept anonymous. When any user first launched the application, a unique identifier was generated that provided absolutely no information about the user. This unique identifier was used for all data collected for this particular user. No personally identifiable information existed which could link a user's data obtained from field tests to an actual person.

4.2 User Experience Data Collection

Given difficulties that need to be overcome for describing and understanding user experience, we decided to combine a variety of data collection methods that were complementary [35] in order to increase reliability and validity of the results. Data collection methods used during the field trial and related user study activities were as follows.

4.2.1 Observations

The potential users were encountered face-to-face when promoting the application on the UC Berkeley campus. In the same context, the initial expectations and thoughts of the users regarding the iShake service were preliminarily explored by informally communicating with the people during our recruitment activities.

4.2.2 Questionnaire

During the iShake field trial, we hoped to gather valuable user experience data with the data collection tool that could be used by subjects without supervision. We decided to create a real-time mobile questionnaire and make it available on the application in order to assess the phenomena at the time they occur as the people being observed are in natural settings. Thus, the users were asked to record on a mobile questionnaire various dimensions of their subjective experience evoked by the use of the iShake application.

4.2.3 Brainstorming

After the field trial with a small focus group comprising of three UCB students and two project team members a brainstorming session was arranged. Brainstorming participants were recruited among the iShake test users. The session included participative features, i.e. the purpose was to plan and vision together with the users how to improve iShake for future use. Jones and Marsden [17] have stated that in terms of new systems, focus-group session method is best used for brainstorming possibilities rather than critiquing concepts.

The objective was also to more profoundly explore users' initial experiences and feedback of the iShake system. We wanted to better understand how iShake could best provide value for its users and what kind of information and data visualizations users would like to receive via iShake during the future earthquake events; what iShake could provide to users immediately after the earthquake and what kind of information would be useful before the earthquake.

During the brainstorming session the participating students were directed to discuss and reflect on future usage scenarios of iShake. The scenarios described how iShake could act as a critical information channel during the earthquake, in addition to providing other valuable information and instructions before and after shakings. The agenda and the structure of the brainstorming session were intentionally kept informal. The participants were requested not to limit their creativity with the current technological restrictions, but they were instead asked to let their imagination fly and not be too critical on their ideas. Participants were asked to create as rich a variety of iShake future usage scenarios and possibilities as possible.

4.3 Field Trial Procedures

The iShake field trial was carried out in the beginning of 2011. This was the first phase in the iterative process of the iShake system testing and evaluation and a basis for the next steps in the system development.

Abowd et al. [1] have pointed out that controlled studies in usability laboratories cannot lead to deep, empirical evaluation results. What is needed is real use in an authentic setting. However, we could not count on “conveniently” having a noticeable earthquake in California during our limited time frame allocated for user testing, which would enable us to trial the system in real situation. We chose to approach this problem by developing an additional functionality in our application that allowed users to generate their own “earthquakes”, i.e. shake events. These live and real-time shake maps of users’ shakes were made instantly available for viewing on the application (see Figure 5) as well as on the iShake website. Through this measure, we hoped the users would get a better and more illustrative understanding of the future use of the iShake system, where the iShake application would provide critical information during earthquakes.

4.3.1 Pilot Testing

Prior the iShake field trial, a comprehensive two-day pilot test was implemented with a delimited “insider” group of five people before introducing the application to the wider audience and releasing the application for users to download. The objective was to assess the iShake system functionality by testing and evaluating the planned field trial procedures. We also wanted to ensure that the information and feedback (push notifications and live iShake Map) sent to the user by the iShake system perform correctly.

4.3.2 Field Trial

The iShake field trial began in the end of January 2011, with the focus on San Francisco Bay Area and especially on the UC Berkeley campus. The trial lasted two days. On the first testing day altogether 26 unique users around the U.S. and the world contributed in generating virtual shake events and transmitting phone sensor readings to the iShake system. On the second day, a total of 9 users participated in the shake event. Of the participating users the majority, about 20 people, were from the Bay Area.

Apple provides the Apple Push Notification Service (APNS), allowing applications to send alerts to their users. These appear on the phone's screen as pop-up alerts which must be dismissed before the user can continue using the device. We took advantage of this system to notify users of upcoming shake events and also provided a clear mechanism for users to opt out of further data collection if they wanted to do so.

4.3.2.1 Virtual Shake Events

During the field trial, we arranged two separate virtual shake events, during which the users simulated a virtual earthquake by all shaking their phones at the same, pre-notified time. The servers automatically collected and processed the measurement data from the users' iPhones during the test situation. A real-time iShake Map was generated showing the intensity of shake events obtained from the phones in the sensor network (see Figure 5). iShake Maps were instantly made available for viewing for the user on the application as well as on the iShake website. In addition, the user could view online the accelerograms sent from his/her iPhone as well as the time and location of each record.

The general form for the shake event was the following:

1) Early warning
2) Very late warning
3) Actual earthquake alert
4) Notification about new earthquake data
5) Request to fill out questionnaire

Both shake events followed the above five-point structure, in addition to:

6) Nightly reminder to turn on the application and leave it on

iShake users were asked to simply turn on the application when they plug in their phone at night. Then any possible earthquake triggers measured by the phone would instantly be streamed back to iShake servers for further processing and iShake Map generation.

4.3.2.2 Virtual “Fake” Earthquake Alerts

During the field trial, we also produced and delivered notifications about a “fake” earthquake event happening in user’s close proximity, and consequently showed an iShake Map visualizing this imaginary earthquake with 100 random points in “earthquake zone.”

The test users were naturally notified that the earthquake notification sent to them was not real, but they were asked to treat the information as it was authentic and to consider the received information and their corresponding user experience in the context as it happens. The aim was to get the user to better comprehend what kind of information and instructions iShake could send to the user in real situations in the future, and imagine oneself in the situation in which the earthquake occurs and iShake acts for the user as a critical information channel.

5. USER STUDY FINDINGS

In the following subsections are introduced and analyzed the experiences and findings of the iShake user study.

5.1 Observations

When promoting the iShake service concept to potential users our observations revealed that for the people living in the earthquake prone area the concept for receiving earthquake notifications on a mobile device is something they would readily welcome. However, the limitations on service adoption set by the required technical capabilities pointed out the need to expand the service to other types of smartphones as well in future phases of the project. In addition, people's spontaneous reactions and comments when introduced to the iShake service concept brought out a demand for an early warning system. It came out that not all the people fully internalized the actual functionality of the current iShake system at first sight, as some were expecting to be able to receive right away also detailed earthquake forecasts.

5.2 Pilot Testing

Pilot testing confirmed that the iShake system was able to successfully record and deliver acceleration readings, i.e. shake events generated by the users, from the iShake clients to the server, at which point the received measurement data was automatically processed and plotted for instant visualization on users' phones.

In addition, pilot test participants provided detailed comments and feedback from engineering-minded and user-minded backgrounds. They made very useful suggestions related for example to restructuring the application navigation and further clarifying the graph and data presentation. Based on achieved feedback, some modifications were made to the iShake system accordingly before proceeding to actual field trial phase, and also some ideas for iShake's development were reserved to be explored further and possibly implemented in the future product.

5.3 Questionnaire

We received a total of 59 responses to the iShake questionnaire, and among them were those who participated in producing virtual shake events. The age distribution of the respondents was quite diversified; however, the majority (~58%) of the users were under 35 year old. 64% of the users were male, and 81% were native English speakers. Many of the respondents had a technological background, as around 20 out of 59 users were studying in some UC Berkeley Engineering, Computer Science, or similar study program.

78% of respondents had some experience of earthquakes. On a scale of 1 to 5 (where 1=not scared at all and 5=very scared), the respondents reported that they were only moderately scared of earthquakes (avg. 2.79, sd. 1.01). In general, users rated themselves as intermediate experienced iPhone application users (avg. 3.40, sd. 0.95), where the scale was from 1 to 5 (1=no experience and 5=expert).

Unless stated otherwise, a six-point Likert scale [23] ranging from 1 (strongly disagree) to 6 (strongly agree) was used to measure the questionnaire variables discussed in the following.

The respondents agreed that the iShake application is straightforward and easy to use (avg. 4.61, sd. 1.14), and that they liked the iShake user interface (avg. 4.50, sd. 1.07). In addition, the majority reported that they considered iShake as very exciting and important mobile application (avg. 5.02, sd. 1.03), and thought the information and instructions provided on iShake on earthquake preparedness were useful (avg. 4.81, sd. 1.14) and interesting (avg. 5.07, sd. 1.04). Respondents agreed that in the event of future earthquakes, receiving similar kind of information as provided on the "iShake Map" would be valuable (avg. 5.28, sd. 0.77), and considered the received earthquake information also fascinating (avg. 5.02, sd. 1.05).

The users to some extent thought that iShake would give them a better feeling of safety in the event of an earthquake (avg. 4.10, sd. 1.39). In addition, they highly valued the possibility of being able to receive critical information about future earthquakes on their mobile phone (avg. 5.36, sd. 0.92). In the event of an earthquake, users would like iShake to provide them information on their family's and friends' whereabouts (avg. 5.07, sd. 1.16). Users reported not being especially eager to share their own experiences and emotions after an earthquake with other iShake users via the application (avg. 3.84, sd. 1.44), but they were a slightly more interested in reading other iShake users' messages and experiences about earthquakes (avg. 4.03, sd. 1.38).

Users experienced the possibility of having iShake earthquake notifications personalized according to their location as very important (avg. 5.14, sd. 0.77), as well as stated that they would like to have the notifications personalized based on their individual preferences and needs (avg. 4.92, sd. 0.83). Users reported that they were going to take iShake into the long-term use (avg. 4.93, sd. 0.94), and believed that they would use iShake in the event of future earthquakes (avg. 5.05, sd. 1.00).

Users were also provided a free-word for iShake's future development, and they most of all expressed a need for earthquake forecasting and early warning system in order to help them to be safe from the future disasters.

5.4 Brainstorming

Three iShake test users participated to the brainstorming session, in addition to two project team members. None of the participants had previous experience of serious earthquakes, and according to participants' own estimation they were not particularly concerned with earthquakes.

In general, users preferred getting the information and instructions in the form of text and pictures instead of videos, as they experienced that videos are not so user-friendly and socially accepted since they could easily disturb other people. This has also come out in other user studies conducted earlier [e.g., 16] where users have expressed preference to other media formats over video in order to avoid embarrassing and socially disturbing situations caused by the loudness of the suddenly appearing sound. Regarding the earthquake data, graphs and illustrative and informative visualizations were preferred over text.

In Table 1 are introduced the themes that came most evident on the future iShake usage scenarios envisioned during the brainstorming session. Among the participants, these were considered the ways in which iShake has potential to create most value for its users and emergency responders.

Table 1. iShake value themes

Value theme	Description
Education of the public	Earthquake preparedness: knowledge on how to adequately prepare oneself for an earthquake
	List of essentials to keep in hand, i.e. how to prepare survival kit
Easily accessible earthquake information	Earthquake alerts on a device that is always at hand
	All the useful information in one place
	Available anytime and anywhere
Safety instructions immediately after the earthquake	Dos and don'ts, where to go, what areas to avoid, nearest safe places
	If in a car, how to get safe: fastest route to safe, risk factors along the route
Emergency service information	Hotline emergency number Shelter locations Missing persons' wall
Forecast and forewarn of aftershocks	After the first shake know to move to safer areas in time
Help search and rescue	If trapped below debris, press an 'emergency' button and send signal with GPS data
	Know high population density areas, and guide the first response accordingly
Ease the concern of close ones' well-being, and vice versa	Share location data within the pre-specified group of people
	Know close ones' whereabouts at the moment of earthquake, and damage level on that area
	Switch the map view based on different significant locations, e.g. own and parents' home
Recovery after the disaster	Connect with people affected by the same earthquake
	See other users' videos and photos on "iShake board"
Contribution of the nodes in the iShake network	How many users using the app at the moment
	How many users contributed on this particular region
	Compare own contribution with others
	Ranking system and competition between users
Value creation for first response and other users	"How am I using iShake and how I helped someone"
	Know that your data actually accomplished something
	Source of motivation and commitment

Brainstorming findings also revealed that if the users would get sufficient benefit from the system, they were respectively ready to provide some personal information for the application. This finding is also supported by Chellappa and Sin [6] who state that the consumers' value for personalization is almost two times more influential than the consumers' concern for privacy in determining usage of personalized services. But in exchange, the user would need to know where their data is used and why, and what would they get in return [21]. As a consequence, the user would then be able to make own educated judgments. In addition, the iShake users reported being willing to share their GPS data with the system, so the application could then keep track of user's location and update it automatically. Based on a combination of user manually provided and system automatically retrieved data, the system would be able to direct the user with the most relevant and valuable earthquake notifications and safety instructions.

6. DISCUSSION AND CONCLUSIONS

During this first phase of the iShake project, the objective was to create a prototype system on the UC Berkeley campus, which serves as a case study and proof of concept towards scaling the system up in the future. The eventual application of iShake would provide several benefits to the public and emergency responders and would help reduce losses from earthquakes in the U.S. and other countries. In September 2011, the iShake user base had increased to encompass around 1,900 users around the world.

The goal of this work was to create a system that moves beyond "DYFI" and USGS ShakeMaps by taking advantage of the accelerometers most people already have in their cell phones, so that a more accurate portrayal of the damage effects of an earthquake may be provided to government officials, emergency responders, and the public immediately after an event. The aim of this research was to expand the number of users beyond the largest number of sensors in a given seismic sensor array today. We believe that by using participatory sensing, the technology has the potential of providing real-time earthquake data at a significantly lower cost than dedicated infrastructure. Furthermore, the increased resolution will allow emergency responders to focus efforts at a more local (neighborhood) level. Due to the automated nature of the iShake system, the response time for post-earthquake rescue efforts could be reduced.

The results gained from the shaking table tests proved that iPhones (and soon other cellular phones and personal computers that contain accelerometers) can measure reliably the shaking produced by an earthquake. In addition, field trial procedures confirmed that the iShake system is able to reliably record and deliver acceleration readings from the clients to the server, at which point the received measurement data are automatically processed and disseminated. Through the field trial and related user studies we also gained great insights into iShake's future development and improvement. The user studies provided insight into: how to provide the desired earthquake-related information to the users in a meaningful way; how to effectively motivate and commit the users to take the iShake application in a long-term and active use as well as utilize iShake during emergencies.

Our findings revealed that users place most value on the possibility to receive critical earthquake information on a device that is always at hand. Users also expressed a need for information of their close ones' whereabouts and well-being after an earthquake. Hence, the users recognized that iShake has great potential to help ease the concern of other people's safety. In addition, users hoped to receive the most relevant earthquake information and notifications that are personalized according to their location and personal preferences and needs. When delivering earthquake data to users, other media formats should be used instead of video with sound, which is also supported by previous research [16]. Furthermore, graphs and illustrative data visualizations were preferred over text by the iShake users.

Akason et al. [2] have suggested that the first active mitigating action observed after an earthquake is the victims' own efforts to seek relief from each other. The most effective type of mutual seeking for emotional relief is to start talking about feelings and sharing own experience with others who have been through the same kind of ordeal [2]. However, this finding wasn't supported in our user studies, as the iShake users did not place much emphasis on this form of recovery from the earthquake-induced trauma. Instead, they expressed their somewhat indifferent point of view on sharing their experiences and communicating with other users through this application.

The surveys also pointed out that users would need incentives to turn on the application and leave it on at night or at other times when charging the phone. For engaging the user to voluntarily download and regularly turn on the iShake application, a kind of competition between users could be created. Users could also be given tangible feedback on how their phone's data was used to provide information and help other people during crises. Thus, value creation for other users and first response may be seen as a great source of motivation and commitment for active use of the system.

In his research, Loewenberg [24] discovered that after each earthquake, rumors and fears of upcoming aftershocks turn up immediately. Our findings revealed that users place emphasis on the value of an early warning system. Thus, the future iShake should be able to send up to minute warnings to users' phones that an earthquake is going to hit. We envision this feature to be available in the future of the iShake project. However, one needs to remember that earthquake early warning is not earthquake prediction. In fact, earthquake prediction is not something that most earth scientists think will be possible in the foreseeable future [3,15,19]. Rather, earthquake early warning involves rapid detection of the beginnings of an earthquake, assessment of the likely shaking, and then sending subsequent warnings to those in the zone likely affected [3].

7. LIMITATIONS AND FUTURE WORK

It can be assumed that since the iShake application downloading and utilization were purely based on volunteering, the field trial participant population was generally more aware of future earthquake risks, and also likely on a more affluent and technologically-savvy side. In addition, because the sample size was fairly small and cannot be seen to represent the general population, the user research findings cannot be reliably generalized to encompass the entire potential user population. However, our results serve as a valuable basis and provide important guidelines and information for the future development of iShake.

In the next phase of this project, additional shaking table tests will be conducted that will evaluate and address in more detail the detection of erroneous measurements when the phone is not in a stationary position (i.e., the response of falling and moving phones). Additional work is required to make the phone and server software more robust, and research is underway to better understand the response of other types of smartphones such as Androids. In addition, the technology will be re-tested in a field operational test that will then lead to deployment through a recruiting campaign with the goal of reaching several thousands of cell phones (and therefore sensors) from as diversified user population as possible.

The provision of information to citizens regarding environmental hazards is a central feature of emergency planning and management. Thus, also special needs population (i.e., individuals characterized by social vulnerability) need to have equal opportunities to use the same services and get access to the same information as the large population. However, special needs populations are disproportionately affected during disasters and, because of their invisibility in communities, mostly ignored during recovery [9]. The social science community has identified as some of the major factors that influence social vulnerability to include, among others, age, gender, ethnicity, socioeconomic status, social capital, beliefs and customs, language barriers, and educational level [5,8,9,14,27,30].

It has been discovered that special needs population might be more likely to perceive hazards as risky; less likely to prepare for hazards or buy insurance; less likely to respond to warnings or take them seriously; more likely to die, suffer injuries, and have proportionately higher material losses; have more psychological trauma; face more obstacles during the phases of response, recovery, and reconstruction; likely not to receive, understand, or believe earthquake warnings [9,13,14,25,26]. From this point of view, it would be highly beneficial to also test and evaluate iShake with the special needs population when continuing to the next steps in the system development and planning its future use. It would be crucial to know how different user groups differ in relation to receiving, understanding, and treating the emergency earthquake information.

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