MobileSens: A Ubiquitous Psychological Laboratory based on Mobile Device

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ABSTRACT

In psychological research, it is difficult to acquire unintrusive, real-time and objective data under real-life non-experimental scenario. This article proposes a system (MobileSens) for automatically recording user behavior on Android mobile device (e.g., turning on device, sending messages, and web surfing), and uploading data to web server through General Packet Radio Service (GPRS) for subsequent analysis. During testing, MobileSens runs smoothly and efficiently on both the smartphone and tablet computer. It indicates that, in the future, this method of data acquisition can improve the performance of conducting psychological research.

Keywords: *Android, Behavior Logger, General Packet Radio Service (GPRS), Mobile Device, MobileSens, Psychological Research*

INTRODUCTION

Psychology refers to the study of human mental function and consequential behavioral outcome. Since mental function is invisible, external behavior indicator (i.e., behavioral sample) is perceived as its appropriate metric (Anastasi & Urbina, 1997). To some extent, the credibility of psychological measurement relies on the selected method for gathering behavioral data.

In psychology, self-report (e.g., paper-and-pencil survey) is the commonly used method for measuring human behavior (Domino & Domino, 2006). As it is difficult to acquire real-time, objective and non-biased behavioral data in non-experimental situation, self-report tends to increase respondent error, decrease ecological validity and make psychological measurement insensitive to the changing patterns of behavior over time (Buchanan & Smith, 1999; Carlbring et al., 2007). This reflects the long-standing dilemma in psychological research, that is, psychology attempts to examine human behavior directly, but psychologists have

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to use indirect measuring method. Therefore, quite a few psychologists advocate "a renewed commitment to including direct observation of behavior whenever possible" (Baumeister, Vohs, & Funder, 2007, pp.396-403) and propose "repeated sampling of subjects' current behaviors and experiences in real time, in subjects' natural environments" (Shiffman, Stone, & Hufford, 2008, pp. 1-32). It requires psychologists to work out an alternative method for gathering precise, objective, sustained behavioral data in real-life situation.

The emergence of mobile device gives an opportunity to contribute to the improvement of psychological research, because it is ubiquitous, unobtrusive, sensor-rich, and remotely accessible (Dufau, Dunabeitia, Moret-Tatay, et al., 2011; Kwok, 2009). With mobile device, it is convenient and efficient to gather behavioral data in non-experimental situation precisely, objectively, and sustainedly (Rachuri & Mascolo, 2011; Heron & Smith, 2010; Miller, 2012). During the past few years, mobile device (e.g., a smartphone or a tablet computer) becomes more and more popular. According to recent surveys by Pew Research Center's Internet & American Life Project in 2012, 25% of American adults own tablet computers (Rainie, 2012a) and 45% of American adults have smartphones (Rainie, 2012b). In China, the number of smartphone users in December 2012 is up to 420 million, which is 31% of national population (China Internet Network Information Center, 2013). Moreover, with the development of information technology, mobile device is also increasingly multifunctional. Take smartphone for example, it not only provides the basic communication function through calling or text-messaging, but also supplies with other service functions (e.g., web surfing, gaming, e-commercing, news and multimedia entertainment). In terms of its technological merits, popularization and diverse intelligent functions, mobile device seems to be an alternative method of gathering behavioral data in psychological research.

Because mobile device offers huge potential to improve conventional research method in psychology, the relationship between user's mental function and his/her behavior on mobile device is supposed to be examined. According to Brunswik's "Lens Model" (1956), mental function could be manifested on behavioral indicators in a variety of situations, including virtual environment (Gosling, Ko, Mannarelli, & Morriss, 2002; Yee, Harris, Jabon, & Bailenson, 2011). It proposes that virtual behavior could be used to indicate user's invisible mental function (Gosling, Augustine, Vazire, Holtzman, & Gaddis, 2011). Some empirical studies have demonstrated that user's mental function (trait or state variable) associate with his/her behavior on mobile device. Phillips, Butt and Blaszczynski (2006) found that people with low score on Agreeableness tends to play games with a mobile phone. Lane and Manner (2011) reported that extravert is more likely to be a smartphone user and prefers texting, while people high on Agreeableness would like to make phone calls directly. Chittaranjan, Blom, and Gatica-Perez (2011) used data mining method to build gender-specific models for detecting user's personality traits based on smartphone usage. Mundt, Vogel, Feltner and Lenderking (2012) gathered human voice acoustical data through telephone transmission for detecting user's depression severity and treatment response. Thus, as a new component of human behavior, user's behavior on mobile device could also be used to indicate mental function.

To gather user's behavioral data on mobile device in a large scale, many behavior logging systems have been developed (Karlson, Meyers, Jacobs, Johns, & Kane, 2009; Smura, 2008; Oliver, 2010). Reeder, Pirolli and Card (2001) build WebEyeMapper to record web user's online eye movements and a sequence of visited web pages. Pirolli, Fu, Reeder, and Card (2002) proposed a user-tracing architecture which can be used to record user's online behavior. He (2008) developed a web browser (SurfLogger) on Python for recording online behavior, but it needs to be initiated for a long time. Silva and Bernardino (2004) have designed another web logger hooked up with an event handler, which is able to record most browsing events. These above-mentioned web loggers could record user's browsing events, but the user's behavior on mobile device is diverse, not browsing behavior only (Falaki, Mahajan, & Kandula, 2010). So, in order to gather user's behavioral data comprehensively, subsequent logging systems are supposed to be much more sensor-rich. SystemSens (Falaki, Mahajan, & Estrin, 2011) is a logging system, which aims to record the performance of different system units on user's smartphone, such as operating status of CPU, memory, and network. LiveLab (Shepard, Rahmati, Tossell, Zhong, & Kortum, 2010) is designed to record user's smartphone usage (e.g., web history, currently running processes, available WiFi access points and GPS location) in daily life. Its aim is to analyze technological features of application usage, and operating environment of wireless network. MyExperience (Froehlich, Chen, Consolvo, Harrison, & Landy, 2007) is an open source tool for Windows mobile device (including PDAs and mobile phones), and it collects both quantitative and qualitative data about user's behavior to improve user experience or detect technological defect. Table 1 shows the main parameters of the above loggers. Although these loggers could collect user's usage data efficiently and comprehensively, they are mainly designed for tuning the system performance. Psychologist intends to examine user behavior on mobile device, rather than common system events. For this reason, existing behavior loggers are not suitable for conducting psychological research.

In this paper, we propose a behavior logger on Android platform, MobileSens, which examines user behavior on Android mobile devices comprehensively, and is suitable for psychological research.

ARCHITECTURE OF MOBILESENS

The proposed logging system, MobileSens, comprises of two components: client side and server side (see Figure 1). In general, the client side runs on the mobile device (i.e., a smartphone and a tablet computer) to record user's behavior. The server side runs on web server, to receive and save data from the client side.

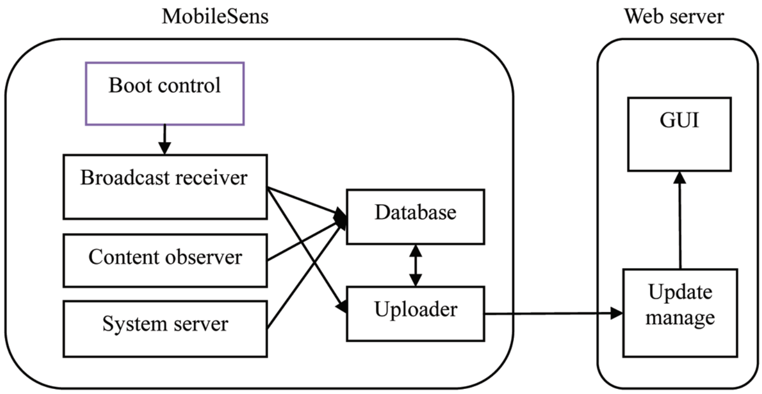
Specifically, the client side is running on the Android platform. It is a service application with no negative effect on user's normal operation and little system resource consumption. The client side acquires behavior data by Android API. To work properly, the client side should run on the Android 2.2 or later. To upload the data, the system also requires the mobile device with Internet access. To save the data storage, the client side sends data when it receives a signal indicating the screen is turned off. Once uploaded successfully, the data will be cleared from the local database (e.g., Sqlite) immediately.

The server side is mainly for storage. When the server receives JSON objects form the client side, the server side decodes received data at first, and then writes data into the local database (e.g., MySQL).

Table 1. Parameters of data collection tools based on mobile device

	Operating Environment	Data Recording	Subjective Data Collection	Data Storage
SystemSens	Android	performance of smartphone	no	web server
LiveLab	iPhone iOS	performance of smartphone, and wireless network environment	no	web server
MyExperience	Windows mobiles	user experience, and smartphone usage	yes	mobile device, and web server

Figure 1. The architecture of MobileSens



IMPLEMENTATION ISSUES

MobileSens is implemented on Java, and runs on Android 2.2 platform, and some of its implementation issues are discussed as follows.

MobileSens Client

The client side consists of four modules: Boot Control, Sensor, Database and Update Module.

Boot Control Module comprises of two parts. One is to receive a signal indicating successful startup of mobile device to initiate MobileSens. The other part periodically records an alarm signal to activate MobileSens for recording.

Sensor Module acts as a virtual sensor, and it obtains both user behavior and system events by calling various Android API.

Database Module is responsible for the data storage. It writes the behavior data into the tables on local Sqlite database. Because MobileSens records user's heterogeneous behavioral information simultaneously, the data is encoded into a JSON object and formed as a universal data format. There are three important columns:

1. *id*: integer, primary key, auto-increment;
2. *time*: text, not null;
3. *msg*: text, not null.

Specifically, *time* is the time stamp of the behavior or event, and its type is text. In addition, the *msg* is a JSON object with the body of the information.

MobileSens is a system server application which needs to be triggered. When it receives the system boot-completed signal, the Boot Control Module creates a server *dalvik*, and registers many standard broadcast receivers, content observers, and system servers. Like standard service application, MobileSens runs on background. When it receives the ACTION_BATTERY_CHANGED signal, it will upload data to the web server. In the course of MobileSens operation, the Boot Control Module receives the alarm signal and drives sensors to record the system logging events automatically.

Logging

MobileSens provides four types of logging. The first one is to receive OS broadcast, such as new outgoing call, power connects or disconnects, screen open or close. The second one is to read system logger periodically, such as network traffic, activity application logger, and system server logger. In MobileSens, the length of interval is two minutes. The third one is to register a content observer. The content provided by Android can share data between difference applications. Sensor Module actually monitors any change on these data by using content observer. The fourth is to register the system server. There are many system services, such as power manager, alarm manager, location provider. For example, GPS information would be got through registering a location listener to interact with location providers. Table 2 summarizes the logging of MobileSens, and also lists each type of logging.

JSON is chosen as data-interchange format between the client side and server side, which provides the flexibility to add new types of sensors and data records without changing database schema. It is more efficient to handle JSON objects than XML on Android platform. In specific, each JSON object has four pairs of key-value: information record time, timestamp, information type, and IMEI of smartphone which is used to identify the user. In addition, the "msg" is the information body.

Uploading

In MobileSens, it is very energy consuming while uploading data to web server. SystemSens is designed to upload data when the smartphone is being charged. The benefit is to offer the application with enough opportunity for uploading data, because most smartphone users charge their smartphones overnight and don't have interaction with them (Falaki, Mahajan, & Estrin, 2011). But, this scheme would fail if the phone is turned off, or put into an area with a poor network connection.

MobileSens uploads data when the device is being charged, or the screen is closed. Once the screen is turned off, the system consumes

Table 2. List of the type, record content and method of logging in MobileSens

Type	Record Content	Method
activity application log	creating, starting, resuming, stopping, and exiting of activity application	read system logger
application package log	adding, changing, and removing package	broadcast receiver
calling log	state, number, contact, and direction of calling	broadcast receiver
camera button log	pressing of camera button	broadcast receiver
configuration log	configuration change information (e.g., font, screen size, and keyboard type)	broadcast receiver
contact log	adding, changing, and deleting of contacts	content observer
date changed log	changing of system date and time	broadcast receiver
gps log	user's locale, altitude, latitude, longitude and direction of movement	system server
headset log	plugging in headset or not	broadcast receiver
locale changed log	changing of locale (e.g., language, and state)	broadcast receiver
data transfer log	amount of data send or received by used application	read system logger
power connected log	connecting power or not	broadcast receiver
power log	powering on smartphone or not	broadcast receiver
screen log	state of the screen	broadcast receiver
service application log	creating, starting, and deleting service application	read system logger
sms log	state, content, and contacts of sms	broadcast receiver
wallpaper log	changing wallpaper	broadcast receiver
wifi log	wifi accessing point	broadcast receiver
Internet accessing log	Internet accessing (e.g., url, web title, visiting frequency, and bookmark)	content observer

minimum energy without any interaction, which is more convenient for uploading.

Deployment and Evaluation

MobileSens could be launched on Google Android's SDK (Android 2.2), Motorola MT-016 (Android 2.1) and Samsung GT-I5508 (Android2.2). We tested the performance of the MobileSens on a smartphone (Huawei U8818) and a tablet computer (SAMSUNG P3110) respectively, both of which were brand new. The U8818's battery capacity is 1350 mAh and the P3110's battery capacity is 4000 mAh. Specifically, an Android App which is designed for cognition training was installed on both U8818 and P3110. Two male participants were recruited to play the training app in a limited 30 minutes with the system of MobileSens running, while another two male participants did the same tasks without MobileSens. The type of use that was being tested included "contact log", "Internet accessing log", "activity application log", "service application log", and "screen log". During the whole process of testing, except for the cognition training app, no other apps run in the background. Finally, the impact of running MobileSens on the battery consumption and the amount of data that MobileSens generates are evaluated.

Results showed that, for smartphone, the battery consumption with MobileSens running is almost the same as the case of without MobileSens (as shown in Table 3), and so did tablet computer (as shown in Table 4). MobileSens totally acquired 8432 bytes data (49 records) from the smartphone user, and 48295 bytes data (77 records) from the tablet computer user. On average, MobileSens generates 172 bytes (smartphone) or 627 bytes (tablet computer) for each user per record.

CONCLUSION

To psychologist, it is very important to acquire behavioral data on mobile device precisely, objectively, and sustainably in non-experimental situation, thus to understand the user's mental function. This paper introduces a logging system, MobileSens, which could record user behavior comprehensively to help conduct psychological research more efficiently.

During testing, MobileSens runs smoothly and efficiently on both the smartphone and tablet computer. With Internet access, MobileSens is able to upload recorded data to the web server. The behavior data could be accessed by any researcher directly.

It is worthy to note that, on Android 2.1 or earlier, some events cannot be recorded, such

Table 3. The impact of MobileSens on the rate of the reduction in battery life of smartphone

	With MobileSens Running			Without MobileSens Running		
Testing Point	Battery Level	Volts	Temperature	Battery Level	Volts	Temperature
1	77%	3.97V	31°	80%	3.98V	27°
2	76%	3.97V	31°	79%	3.99V	27°
3	75%	3.95V	31°	78%	3.98V	27°
4	75%	3.96V	30°	78%	3.98V	28°
5	75%	3.95V	31°	78%	3.97V	29°
6	75%	3.95V	30°	78%	3.96V	30°
7	74%	3.94V	30°	77%	3.97V	30°
8	74%	3.95V	31°	77%	3.97V	29°
9	74%	3.95V	30°	77%	3.97V	28°
10	74%	3.94V	31°	76%	3.97V	28°
11	73%	3.94V	31°	75%	3.96V	28°
12	72%	3.94V	31°	75%	3.96V	28°

Table 4. The impact of MobileSens on the rate of the reduction in battery life of tablet computer

	With MobileSens Running			Without MobileSens Running		
Testing Point	Battery Level	Volts	Temperature	Battery Level	Volts	Temperature
1	96%	4.02V	30°	65%	3.78V	28°
2	95%	4.01V	30°	65%	3.78V	28°
3	94%	3.95V	30°	64%	3.78V	28°
4	93%	3.99V	31°	63%	3.75V	29°
5	92%	3.98V	31°	62%	3.76V	29°
6	91%	3.98V	31°	61%	3.76V	29°
7	90%	3.96V	31°	60%	3.76V	29°
8	89%	3.97V	30°	59%	3.75V	29°
9	88%	3.91V	30°	58%	3.74V	29°
10	87%	3.94V	29°	57%	3.74V	29°
11	86%	3.94V	30°	56%	3.74V	30°
12	86%	3.94V	30°	56%	3.74V	30°

as active program log, service program log, and outgoing call. That is because the broadcast information of these events are not available on Android 2.1 or earlier.

For deployment, there are also several issues which should be paid attention in practice.

Workload

In general, the amount of behavior data relies on the interaction between user and mobile device. MobileSens is able to acquire 19 types of user's behavior data (as shown in Table 2), which may cause heavy data traffic. The data-intensive operation may reduce the performance of mobile device. It is expected to do much more computation locally, to reduce the burden of data transfer.

Privacy

Since MobileSens is designed for acquiring user's behavior as much as possible, such as incoming and outgoing calls, GPS information, and text messages. It implies a potential risk of privacy invasion. In the future, MobileSens would enable a user to choose which information would be allowed for logging. It is also planned to add feedback signal in the process of data uploading to ensure information integrity and protect user's privacy.

Security

In MobileSens, POST may have a potential security problem, and a more secured method for data transmission would be developed in the future.

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