Everyday Life Sensing by Living Lab approach

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***Abstract*— Effective, agile and trusted eServcies Co-creation needs to align the formalized business procedures with the need for innovating business genuinely on the spot, or ad-hoc, namely understanding the real needs of users. An emerging innovation approach called "Living Lab" is such a 'in-vivo' and 'in-situ' approach, which emphasizes understanding users' needs in their real life contexts. Living Lab is a combination of user-centric and context-centric innovation paradigm. In this paper, we present a study of everyday lives of Chinese University students by mobile sensing based Living Lab approach. Finally, we discuss the implications of Living Lab approach and our future work.**

***Index Terms*— Living Lab, eServices, mobile sensing, Co-creation, ambient intelligence**

I. INTRODUCTION

TRADITIONAL innovation forces include the technology push and market pull [1]. Later, user has been recognized as important innovation force by researchers [2], [3]. Numerous user-centric approaches (e.g. user-centric design) have sprung up during the years [4]. However, involving users in the innovation processes is still considered to be complex [5]–[7]. Many reasons concerned for this are related with the lacking of structure and governance for user involvement and the understanding their needs (especially the hidden ones) in the real life contexts [8], [9]. For example, effective, agile and trusted eServcies Co-creation needs to align the formalized business procedures with the need for innovating business genuinely on the spot, or ad-hoc, namely understanding the real needs of users in their real life contexts. With the development of ICT technologies such as smartphones, ubiquitous computing and ambient intelligence, users' everyday living contexts and activities have been increasingly digitalized. An emerging innovation approach called "Living Lab" (LL) is such a 'in-vivo' and 'in-situ' approach, which emphasizes understanding users' needs in their real life contexts by ICT technologies.

The initial concept of LL was introduced in 1995 by Prof. William Mitchell from MIT MediaLab and School of Architecture and city planning [10]. The original idea of LL was to construct a home-like living environment by ambient intelligence and ubiquitous computing technologies such as wireless and sensor technologies to sense, prototype and validate complex ICT solutions [4]. Examples of this kind of LLs include the Aware Home at Georgia Institute of Technology [11] and PlaceLab at MIT [12]. Later, LL has been defined as an environment [13], as a methodology [14], and as an ecosystem [15]. Different definitions see LL from different perspectives. In this paper, we see LL from the methodology's perspective. LL is defined as as a human-centric and context-centric research and development approach whereby ICT innovations are co-created, tested, and evaluated in open, collaborative, multi-contextual real-world settings [16].

From methodology's perspective, LL is a mixed or multi-disciplinary approach, which combines the traditional research methods and emerging research methods as shown in Figure 1 [17]. The horizontal axis is the two components of LL, namely the laboratory part (more control) and the living part (less control). The vertical axis is the mediation, by ICT or by experts . In earlier LL projects, mostly, traditional methods have been used within the LLs [14]. The characteristics of LL is to gain insights in unexpected ICT uses and new service opportunities that emerge from users' daily life activities and experiences [18]. These traditional methods may be well suited for some LL studies, but does not represent important methodological advances [13]. There is an emerging trend for ICT-embedded real context methods (e.g. the smart homes and mobile handset-based sensing and measurement methods).

Table I shows the comparison between the four types of LL methods in Figure 1. Compared to the other three types of LL methods in Figure 1, the ICT-embedded real context methods offer many benefits and advantages such as automatic, real time and non-intrusive data collection.

In this paper, we present an experiment on Chinese students' every lives by emerging mobile handset-based measurement and traditional user research methods. In Section II, we review some related works in the literature; Section III shortly introduces the experiment case in study; Section IV presents the experiment results; Section V discusses and concludes the paper.

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TABLE I.
COMPARISON OF DIFFERENT TYPES OF LIVING LAB METHODS

	traditional real context methods	traditional laboratory methods	ICT-adapted laboratory methods	ICT-embedded real context methods
scalability	low	low	high	high
authentic contexts	yes	no	no	yes
disruptiveness	high	high	middle	low
timespan	long	short	short	long
data richness	high	low	low	high
data dimensions	wide	narrow	narrow	wide
automatic data collection	no	no	partly	yes

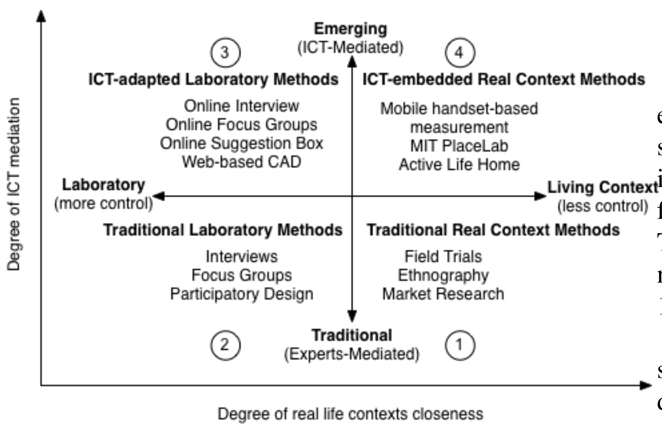

Figure 1. Taxonomy of Living Lab methods

II. RELATED WORKS

In earlier LL projects, mostly, traditional methods have been used [14]. With the further development of ICT technologies such as Internet of Things and ambient intelligence, LL type of smart environments such as smart homes [19], smart cities [20] and smart communities [21] become more popular. On the other hand, with the popularity of mobile phones, especially the smartphones, mobile phones have already become the most popular computing devices in people's everyday life. The smartphones nowadays are programmable and are usually embedded with a set of powerful sensors such as location sensors (e.g. GPS), social activity sensors (e.g. Call Logs) and environment sensors (e.g. temperature). For the diverse categories of sensing capabilities, mobile handsets have become popular research tools for different domains such as social domain [22]–[24], psychology [25], environment measurement [26], movement pattern recognition [27] and healthcare domain [28].

LL methodology has been widely used in different domains of innovation such as senior design [29], aging care [19], rural development [30] and mobile services [31]. However, there is a remarkable lack of in-depth descriptions and discussions of LL processes and methods in current LL literature [13]. Therefore, more empirical experiences are needed in the LL processes and methods aspects [10], [13]. There is a call for more empirical research on the application of LL methods.

III. EVERYDAY LIFE SENSING CASE STUDY BY LIVING LAB APPROACH

We conducted an experiment to understand the everyday lives of Chinese University students by mobile sensing based LL approach. The mobile sensing tool is the MIT open source Android-based mobile sensing framework "Funf" (`http://www.funf.org/`) [32]. The experiment was conducted in a laboratory of the Chinese University of Posts and Telecommunications from 16.10.2012 to 25.11.2012 (six weeks).

Funf provides abundant of built-in sensors or probes such as positioning, social, motion, environment and device interaction [32]. The Funf mobile sensing client used in the experiment is "Funf in a box" (http://www.funf.org/inabox). By using Funf in a box, each experiment participant will have the same Funf probe configuration (e.g. the number of the enabled probes and their sampling frequencies). Table II shows the configuration parameters for some Funf probes. For the detail meanings of the configuration parameters, please refer to the wiki pages of the Funf Developers website (`https://code.google.com/p/funf-open-sensing-framework/`). The collected data will first store at the local storages of participants' mobile devices and periodically upload to a configured Dropbox account storage. The data are stored in SQLite database format. The data are protected by passwords and are anonymized. All the privacy parts of data (such as Call Logs and browsing URLs) are hash encrypted.

IV. RESULTS

A. Demographic statistics

In the experiment, 19 participants (11 females and 8 males) were recruited as shown in Table III.

B. Application usage

Funf application probes can measure what applications are installed on the device, what applications are uninstalled and what applications are currently running.

1) Installed applications: The total unique application packages are 182 (around 10 applications per person). We categorize all these installed applications to 19 categories. We first search the applications from the respective app stores such as Google Play and Qihoo App Store by their

TABLE II.
FUNF SENSING CONFIGURATION

Category	Probe name	sensing frequency
Device	Android info	604800 seconds
	Battery Info	600 seconds
	Hardware Info	604800 seconds
	Mobile Network Info	604800 seconds
Device Interaction	Applications	36000 seconds
	Running Applications	30 seconds
Motion	Accelerometer	300 seconds for 30 seconds
	Activity	300 seconds for 15 seconds
	Orientation	180 seconds for 15 seconds
Positioning	Location	1200 seconds for 120 seconds
	Cell Towers	600 seconds for 30 seconds
	Bluetooth	600 seconds for 30 seconds
	Wifi devices	600 seconds for 30 seconds
Social	Call Logs	36000 seconds
	Contacts	36000 seconds
	SMS Logs	36000 seconds

TABLE III.
DEMOGRAPHIC INFORMATION OF THE PARTICIPANTS

ID	Gender	Mobile Device	Android version
1	male	Samsung GT-19100G	4.0.4
2	female	HTC Villec	4.0.3
3	female	ZTE U930	4.0.3
4	male	HTC Vivow	4.0.3
5	femae	Samsung GT-19108	2.3.6
6	male	HTC Espresso	4.0.3
7	female	HTC Marvel	2.3.5
8	female	Meizu M9	4.0.3
9	male	XiaoMi M1	2.3.5
10	female	ZTE V880	2.2.2
11	female	HTC Vivo	2.3.5
12	female	Samsung S5830	2.3.4
13	female	Samsung GT-19300	4.0.4
14	male	XiaoMi M1	4.0.4
15	female	Huawei iT9200	4.0.3
16	female	Vtion Vpad V7	2.2.2
17	male	XiaoMi M1	2.3.5
18	male	Motorola Titianium	2.1
19	male	Xiaomi M1	2.3.5

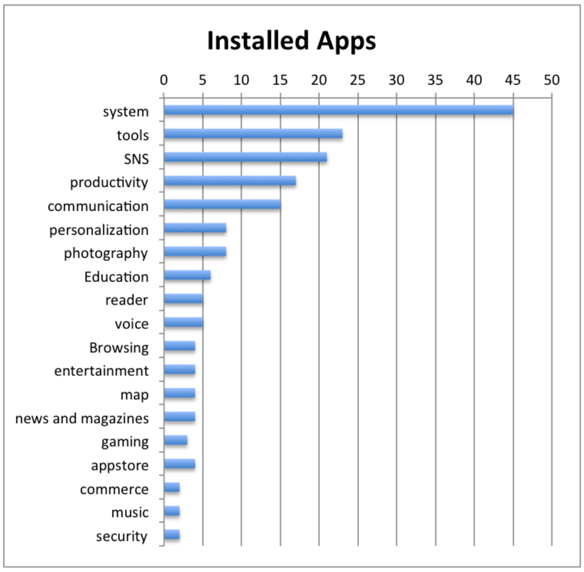

Figure 2. Installed applications

names. We then use the categories identified in the respective app stores. For the applications which we cannot figure them out, we will verify them by discussing with the participants. The application categories are shown in Table IV. The numbers of applications in each category are shown in Figure 2.

2) Uninstalled applications: 74% participants (all the 8 male participants and 6 female participants) didn't delete any applications during the experiment time span, while 5 female participants have deleted 45 applications. Figure 3 shows the numbers of uninstalled applications.

3) Running applications: From Funf's Running applications probe data, we get all the running applications in each sampling session. The sampling frequency in this study is half minute. From all the running applications, we separate the top running applications (the applications which participants interact with) and background running applications (the applications running on the background). Figure 4 shows the top running applications by their frequencies. Many applications are shared among participants such as Mobile QQ and Sina Weibo.

From all the top running applications data, we visualize the average activities of different categories of application usages in Figure 5. We also visualize the percentages of face times of each category of applications, their average used days per week and their percentage of usages in Figure 6 and Figure 7 respectively.

C. Mobility

Funf positioning probes use surrounding wireless signals to gather information about a device's absolute location and relative location to other devices by GPS, Cell ID, Bluetooth and Wifi.

During the experiment, only one participant has enabled the GPS. For this reason, we use Cell ID probe as our positioning method. Although the accuracy of Cell ID positioning is not very high, however, it's enough to roughly show students' daily mobility activities. There are 347 unique Cell IDs in all the Cell ID probes dataset. The original Cell ID numbers differ each other very big. For example, one Cell ID is 7 and another Cell iD is

TABLE IV.
APPLICATION CATEGORIES

Category	Description
System	System related applications such as control panel, settings,clipboard, input methods etc.
Tools	Utilities for a wide range of tasks such as VPN client, FileTransferClient, Flashlight etc.
SNS	Social network services such as Sina Weibo, and Renren. etc.
Productivity	Applications that enhance productivity such as office, calendar, contacts, clocks etc.
Communication	Communication applications include Instant Messaging (e.g. WeChat), email,SMS (including Fetion and Youni SMS) etc.
Voice	Phone calls and other voice related applications
Personalization	Ringtones, wallpapers, desktop themes
Photography	Photos and videos, camera
Education	Study related applications such as dictionary
Reader	eBook readers, Adobe PDF reader
Browsing	browsers
Entertainment	Applications for amusement or enjoyment such as PPS, joke books, mediashub
Map	Maps, navigation
News and magazines	Sina news, diangping, radio news
Gaming	different types of games
Appstore	Google Play, Qihoo Appstore, Wandoujia, Samsung Apps
Commerce	Online shopping and ebusiness such as Taobao, tao800, dazhihui
Music	musics and music players
Security	Security applications such as Qihoo 360 mobile safe, Kingsoft mobile guard

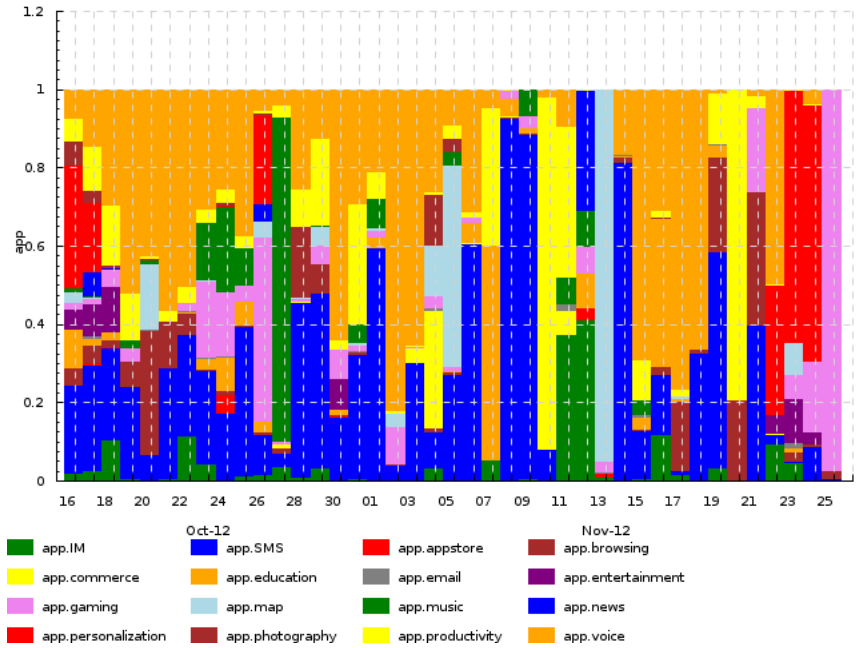

Figure 5. Average activities of running applications daily usage

33271. To simplify the visualization, we renumber all the unique Cell IDs from 1 to 347. Then, we separate all the Cell ID probes data into weekday data and weekend data. Finally, we visualize all the weekday and weekend Cell ID distribution data into one day time span (24 hours) as shown in Figure 8 and Figure 9 respectively. Namely, we condense six weeks data into one typical day time span.

In Figure 8 and Figure 9, the red dots represents female students' mobilities, while blue dots represents male students' mobilities. As in this experiment, we have more female students than male students, so there are more red dots than blue dots in both figures. The red and blue dot lines, which are in the two ends of Figure 8 and Figure 9 during the sleeping time (e.g. 10 PM to 6 AM, can be identified as students' sleeping places (e.g. dormitories). The distribution of the dots in Figure 8 and Figure 9 show students' daily mobility patterns. For example, during the working hours of weekdays (namely from 8 AM to 5PM), the top of Figure 8 shows the mix of red dots and blue dots. This is because our participants are recruited from the same laboratory. In the middle of Figure 9, where the red dots and blue dots mix, is the campus dining places. Through the Cell IDs, LACs (Location Area Code), MCCs (Mobile Country Code)

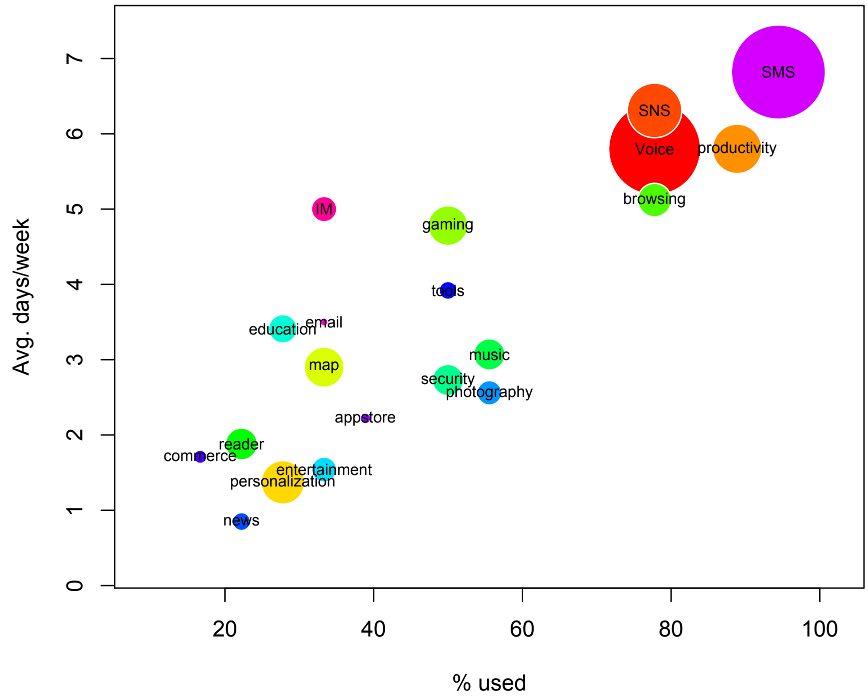

Figure 7. Running applications usage statistics

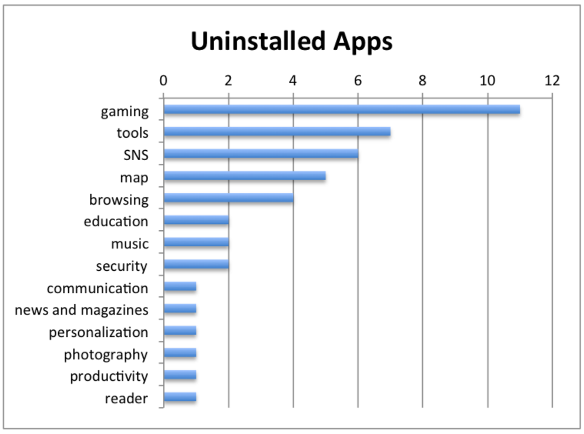

Figure 3. Uninstalled applications

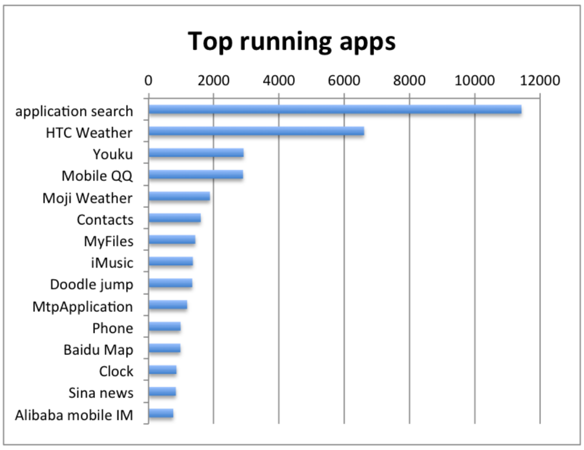

Figure 4. Top running applications by frequencies

and MNCs (Mobile Network Code),we calculate mobility locations (the latitudes and longitudes). We identify with participants that almost all the main activities such as sleeping, eating and studying take place in the campus areas. The overlapping of dots in Figure 8 and Figure 9 reflects the repeatability of everyday routine activities.

V. Discussion and Conclusion

A. Findings

In this paper, we present a study of everyday lives of Chinese university students by mobile sensing based LL approach. The Funf tool used provides abundant of rich sensor data such as application usage, mobility, social and device. In this paper, we mainly present the results on application usages and mobility patterns of the experiment.

From the application usage study, we find that everyday used application numbers by students are small (averagely 10 applications per participant). For installed applications, different students share many common applications such as Sina Weibo, UCMobile and Youdao Dictionary. Besides the system applications, the top three categories of applications installed are tools, SNS and productivity. For uninstalled applications, majority of students didn't uninstall any applications during the study. So the everyday

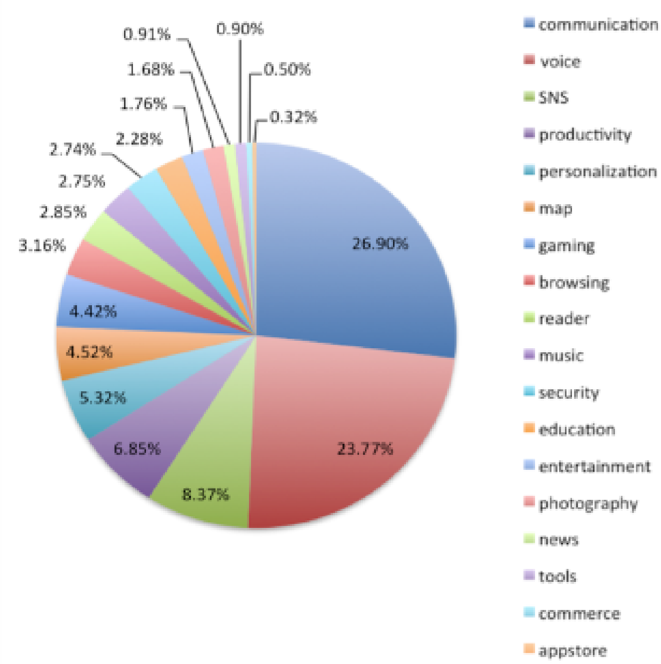

Figure 6. Running applications facetime statistics

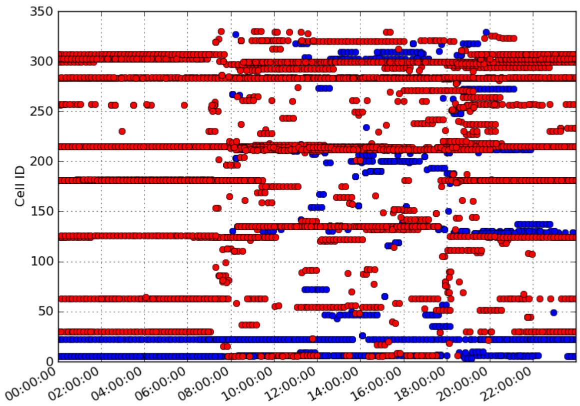

Figure 8. Mobility by Cell ID during weekdays

used applications by students are quite steady. Among the uninstalled applications, gaming is the top category of uninstalled applications.

For the running applications, we find that the top three categories of running applications are SMS, voice and SNS (total accounts for 57% of face times). Therefore, we can say that students mainly use their smartphones for communication and social networking. SMS is the number one application used among students instead of phone call. This might relate with the cheap price of SMS and the increasing other means of voice communication such as the Wechat, an Instant Messaging tools which have voice function.

From the mobility study by Cell IDs, we find that almost all the main activities such as sleeping, eating and studying take place in the campus areas and the repeatability of students' everyday routine activities.

The ICT-embedded LL methods (e.g. the mobile sensing) provide automatic and non-intrusive way of data collection during long period compared with traditional user

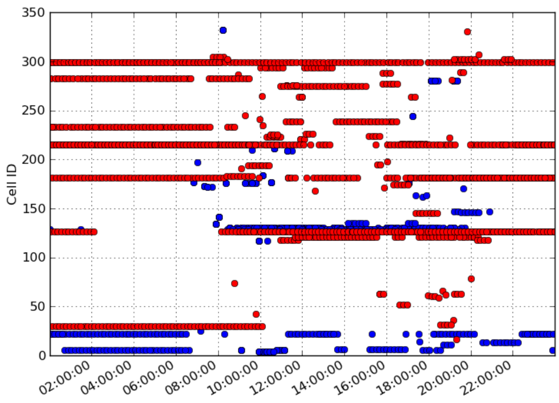

Figure 9. Mobility by Cell ID during weekends

study methods (e.g. interview). Through the combination of different LL methods (e.g. traditional LL methods and ICT-enabled methods), we can get a comprehensive picture of everyday lives of users.

B. Limitation and future work

We acknowledge some limitations in this study. First limitation is the limited numbers of experiment participants. Second limitation is the short time span of the experiment. Third limitation is that Funf in a box tool cannot provide user-inputted data. Therefore, in the future work, we plan to recruit more participants during longer time period. With more participants over longer time, we can study more detailed user behavior patterns and differences. For example, whether there are behavior differences between different genders or age groups. In future work, we will also analyze other sensor data collected by Funf such as social activities (e.g. SMS Logs and Call Logs) and Accelerometer sensor, which can detect the means of users' transportation (e.g. by walk or by car).

To cope with the third limitation, we have also developed a new mobile sensing tool called "ContextLogger" based on the Funf framework (`https://github.com/apps8os/contextlogger3`). The ContextLogger not only has all the Funf sensing capabilities but also provides an interface to let users to mark or log an event such ash shopping or driving etc. For example, users can start or stop activities by clicking different activity buttons. ContextLogger provides a list of common activities such as "at home" and "eating". Users can also add their own customized activities. Currently, ContextLogger also has the NFC (Near Field Communication) capability. Users can swipe their smartphones near the different NFC tags which represent different activities. In the future, we plan to add context-trigger functionality to ContextLogger. For example, questionnaires can be sent to users when they are at specific contexts (e.g. time or places). With these kinds of real time users' feedbacks in specific contexts, researchers can interpret the meanings of contexts more easily.

In this study, we use the default sensing configurations for different sensors. However, we find that some sensors such as Accelerometer sensor and Orientation sensor will generate more data than other sensors, which will drain the storage rooms and batteries. However, when users are at home or in the office, some sensors can stop sensing such as Accelerometer and Cell sensors. Therefore, it's important to have more intelligent or smart configurations for different sensors (e.g. sampling frequencies) in different contexts.

As users' daily life activities include both in-door activities (e.g. cooking and sleeping) and mobile activities (e.g. traveling), it's reasonable to combine the in-door sensing (e.g. Smart homes) and the mobile sensing. By using these mixed LL methods, we would have a more comprehensive picture of people's daily life in real-world settings over long periods of time, providing a key element of the LL approach, i.e. better understanding of user and user community needs, even beyond what they themselves have been able to explicitly identify as many of these needs and "service touch-points" are unnoticed parts of daily life patterns and practices. In the future, we also plan use the smart home solutions, mobile sensing and traditional user research methods in an elderly caring project for better understanding the everyday lives of elderly people.

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