Mobile Phone Sensing: Current Trends and Challenges

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Abstract. The efforts to improve user experience and expand the services offered through mobile phones over the past few years have led to new ways of recollecting data and inferring knowledge about people and their surroundings. This emerging area is known as mobile phone sensing and has been supported by a plethora of devices and sensors. Mobile phone sensing has enabled researchers to migrate from presumably bias-prone surveys and large observational teams to accurate, timely, and in-situ data collection about subjects of research. In doing so, this area has been experiencing different waves of technological development. In this paper, we analyze and discuss three waves of development and present a review of related literature in the area.

Keywords: Mobile phone sensing · Opportunistic sensing · Participatory sensing

1 Introduction

In social and behavioral sciences, and related fields, several research methods rely on direct observation of the subjects or on their memories. In this regard, mobile phone sensing is an emerging area that has been helping researchers obtain data from large groups of persons with lower costs and more advantages at the time of analyzing data for it can be collected when it happens, where it happens, and stored in remote repositories for detailed scrutiny.

In this work, we present the results of a literature review in the area and discuss different trends that have been pervading mobile phone sensing. In the following sections, we discuss how technology has provided a large range of types of sensors and how researchers have started to use them. We first discuss how these have been implemented in custom-built devices. Then we discuss how researchers have taken advantage of mobile phone that incorporate sensors (Sect. 2). In Sect. 3, we present the methodology used for literature review. After that, we present results about the usage of the different types of sensors. In Sect. 5, we describe some trends and challenges that are to be addressed in this emerging field. Finally, in Sect. 6, we present some concluding remarks.

2 Mobile Phone Sensing: Three Waves of Development

Mobile phone sensing is a relatively new research area that has been developing during the last few years, which can be split into three different waves that have been gaining attention as the area unfolds: (1) the creation of custom-built sensing devices, (2) the use of on-device built-in sensors, and (3) the use of commercial sensors.

2.1 The Creation of Custom-Built Sensing Devices

The first wave of mobile sensing used several devices that were built to meet a particular research need. These sensing devices were mainly crafted when technology was mature enough to combine sensors that would fit in a box that subjects could carry with them in an unobtrusive way. In some studies, they used sensing devices with self-storage methods and analyzed the information as soon as they downloaded it from these devices, like in [1].

As soon as the capabilities of feature phones increased, they became the companion to their custom-built sensing devices. Advanced feature phones could store a considerable amount of information, could communicate with external sensors and remote servers, and had an acceptable processing power. While the custom-built device sensed the environment (or the subject), feature phones usually communicated with this device via Bluetooth to collect and save the data in their storage or send it through the network to remote servers for further analysis. Also, feature phones enabled researchers to inform subjects of their status (with a glance to the phone's screen background [2]) as well as correct sensor bad readings.

2.2 The Use of Built-in Sensors

The second major wave in mobile phone sensing started with the emergence of smartphones. By 2007, mobile phones began embedding sensors for a better user experience (e.g., accelerometer and gyroscope) and for novel types of services that involved knowing user location and orientation (e.g., GPS and compass).

Recent papers have shown that researchers are able to infer several aspects of persons, like the quality of their sleep [3], their level of stress [4], their wellbeing [3], their surroundings [5], and even personality traits [6]. Beyond that, the usefulness of mobile phones with built-in sensors does not end at a personal level, but they have contributions at the social level where researchers look for ways to infer social behavior and interactions patterns [7], or at community level where they help map and identify urban situations, like noise pollution in a city [8], or predicting bus arrival [9].

2.3 The Use of Commercial Sensors

In the literature, two main uses for commercial sensors along mobile phones were found: (1) as a tool to get the ground truth (i.e., they are used to compare with the

results of a study with an alternate method), and (2) as a companion to the mobile phone.

To illustrate the first usage, in [10] they developed an algorithm that uses built-in mobile phone sensors to infer when a person is sleeping and the amount of time they slept. Then, they compared the results with proven-to-work commercial applications that can get that information: (a) Jawbone Up that uses a wrist band, and (b) the Zeo Sleep Manager Pro that uses a head band. For the second goal, in [11], they used the Emotiv Epoc Electroencephalography (EEG) headset to control the address book dialing app of the smartphone with the mind of the subject.

3 Research Procedure

In this section, we describe the research procedure used for searching the papers presented in this work. The search is by no means exhaustive.

1. *Google Scholar*. First we used the search phrase mobile sensing and selected papers from the first five result pages whose title and abstract were relevant for our purposes. Secondly, we used the search phrase mobile phone sensing and again selected from the first five result pages of the search engine papers whose title and abstract were relevant for our purposes. Thirdly, we used again the search phrase mobile phone sensing but this time we applied a filter, to obtain papers that were published between 2013 and 2015, and, as previously stated, selected from the first five result pages whose titles were relevant for our purposes.
2. *References on downloaded papers*. We analyzed the references from the papers, and selected the ones that included the following keywords: mobile, phone, smartphone and sensing in their title, or a composite phrase using two or more of those words. The selected items from the references were looked up on Google Scholar and filter out the ones that were not relevant for our goals.

4 Results

We next describe the aggregated papers grouped and classified, by the types of sensors used by year of publication. Using the previous procedure, we found 43 papers that we considered relevant to the purpose of this work. It is important to mention that some papers include more than one type of sensor, therefore they were counted more than once. Due to space constraints, not all papers were discussed in the text.

4.1 Types of Sensors Used Per Year

From the papers found, different types of sensor were used, mainly form three sources: (a) from the smartphone itself (built-in), (b) from custom-built external devices, and (c) from commercial external devices. Generally, the sensors that fit in these three sources are called hard sensors. However, there is another type of sensor based on software, i.e., logs of the use of the mobile phone (e.g., call logs, SMS logs, internet

usage logs, calendar logs, social networks logs) [6, 12]. Usually, these sensors have been used to infer social, or personality traits of the user.

In our results, most of the sensors used are hard sensors, where the accelerometer, GPS, Bluetooth and microphone are the most commonly used (see Fig. 1). The built-in sensors are the most accessible and less obtrusive as no additional devices are needed. Whereas in soft sensors the application logs, SMS logs and call logs seem to be the most useful (see Fig. 1).

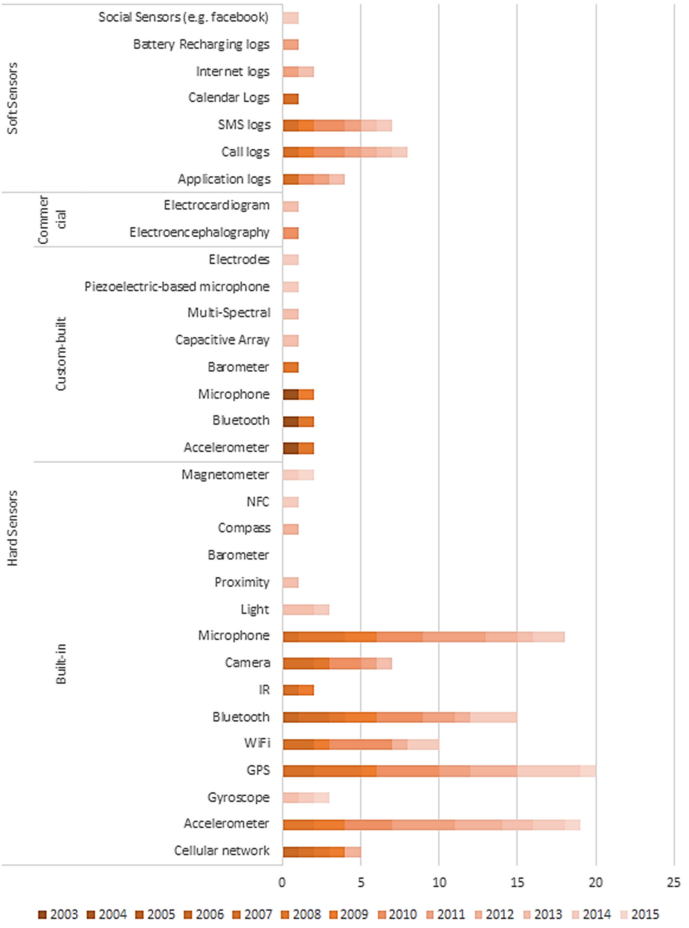

Fig. 1. The numbers of papers using each type of sensor per year

5 Current Trends and Challenges in Mobile Phone Sensing

Up until now, smartphones have played mainly two roles in mobile sensing. First, mobile phones are an augmented sensing device, capable of collecting raw data from its environment, processing them to give them some meaning or inferring situations about

users, their surroundings, or people they interact with. Still, there are some data analyses that require too much processing time and therefore a lot of power, thus smartphones may not be the most suitable devices to process the data. Secondly, mobile phones are devices used as a means to link to external sensing devices, with the capacity of storing and processing data, and communicating with remote repositories, thus becoming a platform for deploying specialized sensors in extensive campaigns.

Despite the fact that smartphones from different vendors share many features, they usually differ in their development platform. In general, this difference can result in an increase of costs for creating a sensing tool. Several projects have attempted to decrease the technical burden by creating tools that do not require programming experts [12, 13].

One of the most daunting challenges in mobile phone sensing is making sense of the data collected. In this task, the use of machine learning or pattern recognition algorithms is paramount. However, as of today, due to the data quality (i.e., bad sensor readings, noisy readings, and unlabeled data) and the restrictions of machine learning algorithms, this task is very challenging. Finally, another challenge is energy. Modern mobile phones, although with better batteries, consume even more power than their predecessors.

6 Conclusions

Mobile phone sensing is an area that is taking advantages of the mobile phones properties (e.g., ubiquitous) and has been used to help researchers gather data. Mobile phones have become generally more powerful, as they embed larger capacities (e.g., more memory, more processing power, improved data transmission, more sensors). In the transition from feature phones to smartphones, different techniques to exploit the potential of mobile phones have been applied. We found mainly three different waves of development, (1) when phones did not include sensors and researchers primarily created their own, (2) when phones did include sensors and researchers started using them, and (3) when commercial sensors appeared and researchers exploited them, since they are specialized, cheap, and accurate. We also found that during all the time during the development of mobile sensing, built-in hard sensors are the most used, where the accelerometer, Bluetooth, GPS, and microphones are the ones that have been used in almost all the years we looked upon.

There is still room for some improvements as different development platforms exist and technical knowledge is required in order to take advantage of the capabilities of modern mobile phones, but there is some work that might help to overcome these challenges. We hope that the results and discussion in this paper can be used to motivate technological developments or research in this emerging area.

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