

A Survey on Smartphone Features Relevant for Reality Mining

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Abstract: The acquisition of data for Reality Mining applications is a critical factor, since many mobile devices, e.g. smartphones, must be capable of capturing the required data. Otherwise, only a small target group would be able to use the Reality Mining application. In the course of a survey, we have identified smartphone features which might be relevant for various Reality Mining applications. The survey classifies these features and shows how the support of each feature has changed over the years by analyzing 143 smartphones released between 2004 and 2015. All analyzed devices can be ranked by their number of provided features. Furthermore, this paper deals with quality issues which have occurred during carrying out the survey.

Keywords: Reality Mining, big data smartphone applications, smartphone features, mobile sensory hardware, wearable sensors

1 Motivation

Creating a benefit by analyzing and predicting the behavior of an individual or a group of users is one of the main objectives of a modern Reality Mining application. The acquisition of Reality Mining data could be a critical factor ruling the success or failure of the Reality Mining application due to two issues: Depending on the use case of the application, various kinds of data must be acquired, which requires a special “monitoring system” that is carried by the end user and has appropriate sensors for recording. Furthermore, those “monitoring systems” must be less expensive and available for a large group of potential users, otherwise the application would only be used by a small group of users which restricts the capability of predicting the behavior of a group due to a lack of users and data records.

Smartphones and other mobile devices like smartwatches are typical “monitoring systems” for Reality Mining since they provide a huge bandwidth of sensory hardware. They are widespread, affordable and automatically carried by many users. To be more specific, for the purpose of this research, a smartphone is defined as a telephone with cellular capabilities that includes features associated with traditional computers – such as an operating system (OS), being able to run software packages, so called apps (short for applications) or combinations of sensors, input devices and connectivity means.

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In 2004, Nathan Eagle and Alex Pentland [EP06] have shown which Reality Mining data can be captured with 100 Nokia 6600 smartphones having, considering today's conditions, only primitive features, namely Bluetooth and Global System for Mobile Communications (GSM) [Gs15], which can be used for Reality Mining. Astonishingly, much information could be extracted out of these few captured data sets and used for describing the behavior of the smartphone users and the whole group of test users.

Today, more than ten years later, the term “smartphone” has been redefined by many pioneering technologies and products like the release of the first iPhone or the Android operating system. The smartphones of today have much more features compared to those in 2004, which will be shown in the course of this paper. Especially, the increased feature set benefits the Reality Mining aspect.

This paper aims to provide an overview of smartphone features enabling Reality Mining applications to acquire relevant data. Especially, the evolution of those features from 2004 until 2015 should be shown. To capture this in more detail, the following research questions are posed:

RQ1: Which features relevant for Reality Mining are available in smartphones in 2015?

RQ2: How can these identified features be classified?

RQ3: How has the support of those features evolved over the last twelve years (2004-2015)?

For answering the research questions, a survey has been carried out in which the specifications of 143 selected smartphones released between January 2004 and May 2015 have been analyzed regarding their capability for Reality Mining applications. This capability is measured by the number of Reality Mining-relevant features a device might have. The support of a feature in a smartphone is rated with a Boolean value, i.e. yes or no. Finally, each analyzed smartphone has a feature counter reflecting the number of features. This way the smartphones can be ranked regarding their overall capability and support for Reality Mining applications. However, this does not automatically mean that a smartphone with a higher ranking is more suitable for a specific Reality Mining application than a smartphone with a lower ranking, since the application might rely on features not provided by all smartphones.

First of all, the feature set has to be identified and classified regarding its relevance for Reality Mining applications. This procedure and especially the results as well as **RQ1** and **RQ2** are described and answered in chapter 3. In a second step, smartphones released between January 2004 and May 2015 are selected and analyzed regarding their support for the identified features. All the results are collected in a spreadsheet. Chapter 4 deals with acquisition and analysis of this data and explains issues which have occurred during this process. Finally, the results of this survey are transformed into graphical representations and interpreted such that **RQ3** can be answered. Chapter 5 shows the results of the survey.

2 Related Work

M. del Rosario, S. Redmond and N. Lovell [RRL15] analyze and classify several smartphone sensors which are capable of monitoring the human movement for ambulant monitoring applications. The paper gives an overview of the development and the evolution of related classification algorithms for human movement. Furthermore, they describe the utilization of these sensors and how they can be combined for obtaining the required data. There are many similarities in both, the underlying use case as well as the results in comparison with the conducted Smartphone Feature Survey. Especially the use case of monitoring a user for ambulant purposes can be seen as a special Reality Mining application.

3 Identified and Classified Smartphone Features

Modern Reality Mining includes both the acquisition and processing of data reflecting the behavior and the movement including all activities of an individual user throughout the day as well as data describing environmental conditions. Thus, a smartphone feature might be relevant for Reality Mining applications, if it can provide details about the behavior of the smartphone user or the user's environment and finally how different users or even static objects relate and interact with each other (e.g. a user is meeting another user every day at the coffee corner). Websites like Areamobile.de [Ar15], GSMArena.com [Gs15] and phoneArena.com [Ph15] have been used as a primary source for the specifications of the selected smartphones. Commonly, the specifications are listed in tables such that the pool of features and characteristics can be easily collected and evaluated regarding their relevance. Some "exotic" features, which are not widely spread under the state of the art smartphones but which might be relevant for Reality Mining applications, have been enlisted in the survey but excluded from the comparison. A couple of features have been identified while collecting the smartphone data, so the identification and classification resulted in an iterative process.

The following section provides a list of identified features being available in smartphones in 2015, grouped into categories for classification. This answers **RQ1** and **RQ2**:

- **User Input Category:** User input devices provide details about the usage of the phone, e.g. when the phone has been used. Identified feature: **Touchscreen**
- **Communication Category:** Besides the ability to communicate (which is also relevant for exchanging Reality Mining data) those features provide two further beneficial aspects which can be used by Reality Mining applications: On the one hand, communication features like GSM, Wi-Fi and Bluetooth (standards for wireless network connectivity) can be used for locating a user and the user's smartphone by scanning the environment for static devices (like N. Eagle and A. Pentland have already shown it [EP06]). On the other hand, short range

communication features like Infrared, Bluetooth or Near Field Communication (NFC) provide details about the social behavior of the user by answering the question who is communicating with whom or who is in range (e.g. by Bluetooth Discovery). Identified features: **Wi-Fi, Bluetooth, NFC, Infrared, GSM**

GSM has been excluded as a feature to be further evaluated due to differing standards, versioning and availability in different markets. What remains relevant for Reality Mining is the fact that every considered smartphone released between 2004 and 2015 is able to communicate via a technology comparable to GSM.

- **Localization and Movement Category:** Using communication features like GSM is one option, but targeted localization services like Global Positioning System (GPS) or Globalnaya Navigazionnaya Sputnikovaya Sistema (GLONASS) are more accurate for locating a user [WM10, Za09]. Furthermore, they can be used for tracking the speed of movement. Identified features: **GPS, GLONASS, BDS, Step Counter, Accelerometer and Gyroscope**

BDS, also called BeiDou (short for: BeiDou Navigation Satellite System), is the Chinese navigation system service [Be16] but it is only supported by few phones. Given that GPS and GLONASS are wide-spread and provide the same goal of accurate geo-localization, which is the relevant usage for Reality Mining, it has been excluded from the comparison. The dedicated step counter has been excluded as well, since the relevant use case for this feature is commonly implemented using the data of other sensors, e.g. the accelerometer [JAM13, Sc07, To12], which are already considered as Reality Mining features.

- **Human Sensor Category:** A state-of-the-art smartphone might provide many sensors revealing details about the users and their behavior (e.g. for classification) or even for identifying a user. Identified features: **Finger Print Sensor, Gesture Sensor, Heart Rate Sensor, Proximity Sensor and SpO2**

SpO2 in the sense of a feature is a sensor or a combination of sensors that can be used to estimate the level of oxygen saturation in blood. The Finger Print Sensor is commonly used as a security feature for unlocking the device. The gesture sensor recognizes gestures of the user for controlling the smartphone and its applications. Although both sensors, the Finger Print Sensor and the Gesture Sensor, are commonly used as input devices triggering a reaction of the smartphone (e.g. unlocking), they have not been classified as features of the User Input Category but as features of the Human Sensor Category since both sensors have the capability to classify or even identify the human (e.g. by a finger print or by experienced gestures) which might be more valuable for Reality Mining applications. Nevertheless, they can be used to provide details about the usage of the phone as well (as defined for the User Input Category).

- **Environmental Sensor Category:** Moreover, there are several sensors providing details about the environment (e.g. weather information) which can reveal details about the user's activity as well. A barometer is part of this classification, but can

also be used for determining the altitude of a user relative to the initial position of the smartphone by measuring the atmospheric pressure [RRL15]. Lu et al. [Lu09] describes methods and algorithms for specifying sound events by extracting sound frequencies over the microphone and Khan et al. [Kh14] describes a classification algorithm which is capable to identify fifteen physical movements by capturing data from the microphone, the barometer and the accelerometer. There are even approaches involving the camera of the smartphone as a sensor by taking pictures periodically [Gu13]. Identified features: **Microphone, Camera, Luxmeter, Ultraviolet (UV) Sensor, Magnetometer, Thermometer, Barometer and Humidity Sensor**

Even though several of the above features fit into multiple categories (e.g. the Gesture Sensor), the categories are disjoint. Thus, features have been assigned to the category in which they provide the most benefits with relation to Reality Mining. All in all, 22 smartphone features being relevant for Reality Mining have been identified (plus three excluded features) and classified in five categories.

With the 22 features grouped into five categories, details about the user behavior (User Input Category, Communication Category, Localization and Movement Category and Human Sensor Category) as well as details about the environment (Environmental Sensor Category) can be provided. Furthermore, features of the Communication Category as well as Localization and Movement Category are potentially able to uncover relations and interactions between users and environmental objects and locations (e.g. if a group of users meet at the same place). Therefore, **RQ1** and **RQ2** are answered.

4 Selection and Analyzation of Smartphones

The second step of this survey consists of two elementary sub steps: In the first step, a list of smartphones which should be analyzed in course of this survey has to be created. Then in the second step, the specifications of those smartphones have to be investigated and analyzed for answering the question whether each identified feature (see Chapter 3) is supported by the smartphone or not. Finally, the supported features are counted for each smartphone such that all devices can be ranked.

The survey should contain smartphones which have been released in the last twelve years, i.e. from January 2004 until May 2015. The survey has been finished in June 2015, therefore May had been chosen for the newest phones. The popularity of a smartphone has been the main objective for selecting a device for this survey. A high popularity seems to be an indicator that this phone is or has been used by many users which means that many users have or had access to the provided features. That fact is important for Reality Mining applications since they rely on a specific feature set which must be supported by many phones such that many users can be addressed. The second criterion has been the release date since every year should be represented by at least seven smartphones, otherwise the average feature counter might be distorted by

smartphones having abnormally many or less features for the corresponding year. The price of a smartphone has not been considered due to regional market dependencies like different currencies and time dependent price fluctuations. There might be regional dependencies for the release date since this date might differ from country to country (e.g. for the iPhone 6 [Ts14]). Also, the popularity of a smartphone is a subjective value and can only be measured by the amount of sold devices which is hard to investigate and regionally dependent. Hence, the survey focuses on the popularity in Germany. The list of selected smartphones relies on subjective smartphone rankings provided by different websites for each year (e.g. [He04]). Due to its subjectiveness, this can be seen as a weak point of this survey. All in all, 143 smartphones have been selected for the survey. The number of analyzed smartphones per year is shown in Fig. 1.

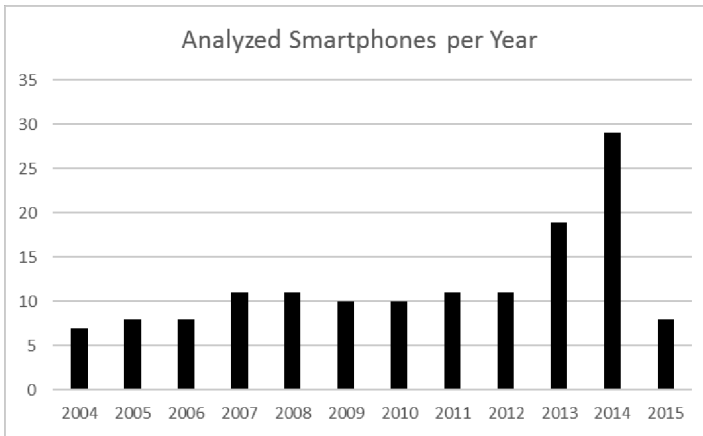


Fig. 1: Analyzed smartphones per year

Areamobile.de [Ar15], GSMarena.com [Gs15] and phonearena.com [Ph15] provide specification sheets for nearly every smartphone on the market and have been used for obtaining the specifications of the selected phones. However, data provided by those websites has to be treated with caution since the providers do not guarantee that the specifications are correct. During the investigation, a lot of contradictions regarding the specifications of a smartphone have been identified by consulting all three pages. The website of the vendor might help to solve this issue, but the specifications are often incomplete or the vendor has a different understanding of the support of a feature (e.g. if a feature is provided over a software mechanism or another feature instead of a hardware sensor, e.g. A-GPS via GSM instead of GPS). Moreover, there might be different models and versions of a specific smartphone (e.g. the Samsung Galaxy Ace 2 with “optional” NFC [Sa15]) having different features which has to be considered. Sometimes it is necessary to rely on statements of users who claim in blogs or on other websites that they have tested the phone and its features. The fuzziness of some specifications must be considered as the second weak point of this survey.

5 Survey Results

143 smartphones across 18 different vendors have been analyzed regarding their support of the identified features in the previous step of this survey. The information whether a feature is supported by the phone or not has been collected in a spreadsheet. Hence, graphical representations illustrating the results of the survey can be easily created, like bar charts showing the support for a feature for the corresponding years. Publishing a bar chart for each feature would go beyond the scope of this paper, but Fig. 2 gives an example how many smartphones analyzed in the survey and released in the corresponding year have been capable of GPS and GLONASS (e.g. 25% of the analyzed smartphones released in 2006 support the GPS feature).

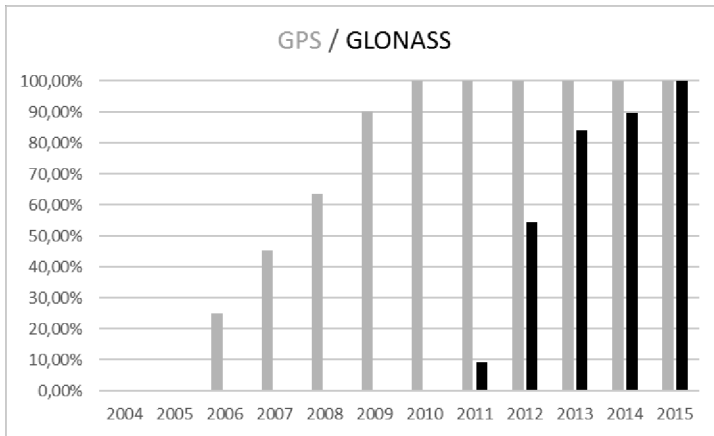


Fig. 2: Support of GPS and GLONASS

Concerning the support of a feature per year, the survey unveils an interesting fact which applies to nearly every feature observed in this survey: The support of an introduced feature is commonly growing over the next years after its first occurrence – which means that vendors would rather add new additional features to the smartphones instead of replacing the old features. Technologies which have been the state of the art, e.g. like Bluetooth, Wi-Fi or GPS in 2006, are still used in modern devices in 2015 (but the technology might have been revised, e.g. IEEE802.11g vs. IEEE802.11n, which is not considered in this survey).

In contrast, Infrared has shown that a feature or technology can leave the smartphone market immediately. However, it is more surprising that especially this technology has experienced a “rebirth” – not as a communication technology, but as a feature which extends smartphones with the functionality of a remote control (e.g. the LG G3 [Lg16]). Fig. 3 shows the evolution of this feature.

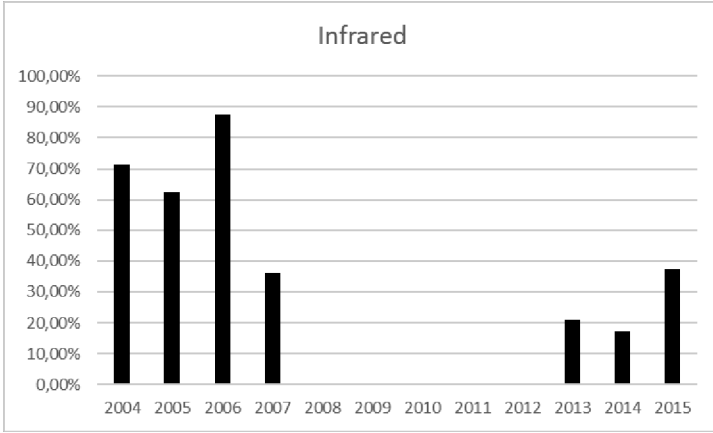


Fig. 3: Downfall and rebirth of Infrared

The fact that features are rather added then replaced is also reflected by the overall result of this survey showing the average number of features supported by a smartphone released in the corresponding year. This overall result is illustrated in Fig. 4 which answers **RQ3**.

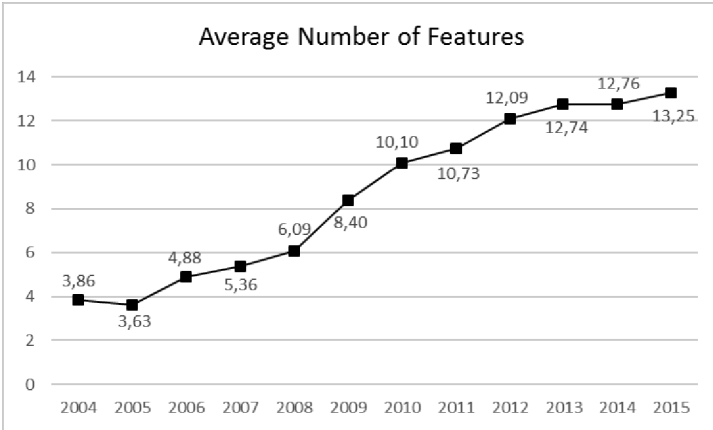


Fig. 4: Average number of features supported by a smartphone released in the corresponding year

6 Conclusion and Future Work

The support of a feature set required for a specific Reality Mining application among the smartphones of potential users is an important matter which cannot be neglected while planning such an application. If those features are not supported by many smartphones,

only a few users would have access to the application. This survey has analyzed 143 smartphones released between 2004 and 2015 regarding their support for 22 features which might be relevant for Reality Mining applications. Moreover, those features can be classified into five categories. The results of the survey show that the vendors of the smartphones would rather add new additional features to the phones instead of replacing old features by new ones. Hence the average number of Reality Mining related features in a smartphone has grown from 3.86 features in 2004 to 13.25 features in 2015. The subjectiveness of the popularity criterion for selecting a smartphone for this survey as well as the incompleteness, incorrectness and fuzziness of specifications provided in the internet are the two weak points which decrease the quality and tenability of this survey.

Future work might include more smartphones to compensate this fuzziness by more, correct data. Another approach would be the testing of each device which might be extremely expensive and time-consuming since every device has to be acquired and tested regarding the support of the features. Moreover, the survey can be extended by expanding the scope by further years of release (e.g. smartphones released in 2016). Additionally, it might be interesting to incorporate the price of each smartphone into the survey such that the devices can be ranked regarding their price-performance ratio for Reality Mining applications or for calculating a price-per-feature ratio. Including the pricing aspect might identify features which are not suitable for Reality Mining application since those features are too expensive for a large target user group.

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