Technical Trends and Challenges in Mobile Health
A Systematic Review of Recent Available Literature

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Abstract: This paper presents the state of the art from the available literature on mobile health care. The study was performed by means of a systematic review, a way of assessing and interpreting all available research on a particular topic in a given area, using a reliable and rigorous method. From an initial amount of 1,482 papers, we extracted and analysed data via a full reading of 40 (2.69%) of the papers that matched our selection criteria. Our analysis since 2010 show current development in 10 application areas and present on-going trends and technical challenges on the subject. The application areas include patient monitoring, infrastructure, software architecture, modelling, framework, security, notifications, multimedia, mobile cloud computing, and literature reviews on the topic. The most relevant challenges include the low battery life of devices, multiplatform development, data transmission and security. Our study consolidates recent findings in the field and serves as a resourceful guide for future research planning and development.

1 INTRODUCTION

Today, one area that deserves attention in mobile technology is health care. In a broader sense, health care has experienced changes in treatment, exam manipulation and also on the development of studies in remote regions. The World Health Organization (2011) defines Mobile Health as the medical practice with support of mobile devices, such as cell phones, patient monitoring devices, PDAs and other wireless devices, including the use of cell phones' functions like audio, messages, Bluetooth and other services.

The present work focuses on identifying the state of the art on mobile health in terms of application areas, pointing out current trends and challenges. This research is performed by means of a systematic review on the more recent available literature. A total of 1,482 papers from January 2010 to January 2013 were analysed and 2.69% of the sample matched our research criteria – see (Biolchini et al., 2005). Our findings are intended as a resourceful guide for future research planning and development on the area. The systematic review follows the protocol proposed by Kitchenham (2004). In the following sections, we assume that the reader is familiar with such research method. Due to space reasons, we only present the most relevant aspects in this paper. Other details can be found in (Jersak et. al., 2013).

2 EARLY CLASSIFICATION OF STUDIES

Since each of the selected papers follow a different research methodology, we first grouped them in 10 different methodologies according to the classification presented in (Oates, 2006). The methodology that had the majority of the papers was "design and creation", containing 21 of the 40 papers (52.5%). Seven papers were classified as "experiments", five papers as "proof of concept", three as "literature review", two as "case-study", one as "survey", and one as "ethnography".

Most of the papers (26 in 40; i.e. 65%) used prototypes to test the solutions. Among those studies, half of them (13) focused on patient monitoring (Fernandes et al., 2011; Catarinucci et al., 2012; Chi et al., 2010; Heslop et al., 2010; Ivanov et al., 2010; Lara et al., 2012; Pandey et al., 2012; Masse et al., 2010; Pigadas et al., 2011; Siebra et al., 2011; Soomro and Schmitt, 2011; Al-Taee et al., 2011; O'Brien et al., 2010).

Works focusing on vital signs such as blood pressure and heart rate were also frequent, as well as studies about daily life monitoring and transmission

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of such data (see section 3). It is worth noting that monitoring applications very often require specific hardware to collect the patient's data, such as sensors for an ECG (electrocardiography) or blood pressure measurement (see section 3.1).

3 MOBILE HEALTH APPLICATION AREAS

This section presents our findings regarding mHealth solutions in the identified areas.

3.1 Patient Monitoring

Several of the analysed studies focus on solutions for monitoring bio-signals. Monitoring is usually done using external sensors. These sensors usually communicate with the mobile device via Wi-Fi or short-ranged protocols such as Bluetooth. We found that in most cases the mobile device acts as a gateway that gathers raw data from the sensors and then forwards it to a separate system that will process it and return data ready for visualization by doctors or the patient himself.

As a first example, Masse et al. (2010) use a smartphone as a gateway to collect bio-signal data from sensors and further present it to the doctor or patient. Other studies (Pigadas et al., 2011; Lara et al., 2012; Warren et al., 2011) and (Al-Taee et al., 2011) propose monitoring systems in which the sensor data is gathered by the smartphone and then sent to a remote server for processing and storage.

Similarly, the study from Pandey et al. (2012) presents a system in which the mobile device collects data and sends it for processing in the cloud. The mobile device can also retrieve data from the cloud and present it to the doctor or patient. Likewise, Fernandes et al. (2011) propose a solution where data gathered from external sensors by the mobile device is forwarded via a ZigBee link to a computer that acts as a ZigBee-to-Wi-Fi gateway. This computer also processes the data and then sends it to a remote server where it is stored and can be accessed using mobile devices or the web.

Blumrosen et al. (2011) present a solution that gathers sensor data via a ZigBee network using the smartphone at first as a gateway. The data is sent via MMS (Multimedia Messaging Service) to an e-mail box at a remote server for analysis and processing. The data is then sent back to the smartphone so the patient can visualize it.

At times hardware evolve so quickly that it is hard to keep up-to-date knowledge in this regard. In Ivanov et al.'s work (2010) an example of a monitoring application is presented and tested in 11 different smartphones and PDAs. The objective was to check and compare the performance of each device for health care applications. The study from Pereira et al. (2011) shows a solution implemented in 4 different operating systems (Android, Symbian, iOS and Windows Mobile). This solution communicates with the sensors via Bluetooth and is capable of plotting graphs to better show the patients' vital signs.

By the analysis of the studies under the patient monitoring category, we found that 12 proposals use some sort of sensor to gather the patient's vital signs. It is important to note that the sensors built-in to the mobile devices are typically insufficient to cover the needs of this area.

The solutions presented in Masse et al. (2010) and in Chi et al. (2010) have even developed prototypes for those types of sensors. The sensors

Table 1: The use of sensors in each proposal.

Source / Sensor	ECG	EEG	BP	Temp	RR	HR	Accel*	GPS*	Lum*	Gyr*
Fernandes et al., 2011	X			X		X				
Altini et al., 2010	X					X				
Blumrosen et al., 2011***							X			
Catarinucci et al., 2012***			X	X						
Chi et al., 2010	X	X								
Lara et al., 2012				X	X	X	X			X
O'Brien et al., 2010***							X			X
Pandey et al., 2012	X									
Masse et al., 2010	X						X**			
Pereira et al., 2011***				X						
Pigadas et al., 2011							X	X	X	

* Mobile devices' native (built-in) sensors; ** In this case, the accelerometer is encapsulated in an external sensor; *** The number of sensors is small because this is only a demonstration of the application's features. In the case of real use, more sensors can be involved.

found in the studies were: Electrocardiogram (ECG); Electroencephalogram (EEG); Blood Pressure (BP); Skin Temperature (Temp); Respiratory Rate (RR); Heart Rate (HR); Accelerometer (Accel); GPS; Luminosity Sensor (Lum); Gyroscope (Gyr). We observe from Table 1 that most of the sensors used in those solutions are not built-in to the mobile devices.

From the 11 studies that do use sensors, only 3 did not use an external sensor. From those 3 studies, the solution shown in Pigadas et al. (2011) only keeps track of the patient’s location and corporal position, while in the works of Blumrosen et al. (2011) and O'Brien et al. (2010) the sensors are only used as a proof of concept for the proposed solutions of the respective studies, as those solutions focus on communication or data processing. Thus, it is important to note that applications that keep track of vital signs will typicaly have to depend on external sensors, as the available technology for mobile devices is not capable or reliable enough for measuring such important data.

3.2 Hardware Infrastructure

In mobile health applications, the low battery life of devices is a frequent complaint. In Heslop et al. (2010), for instance, the authors mention the benefits of tablets, such as the ease of use and good screen resolution that favours the visualization of certain exams, e.g. radiology images, but report an average battery life of only 2.5 hours. Smaller devices such as mobile phones contain even less battery capacity. In fact, despite technology advances, we found that in several cases batteries do not last long enough to cover an entire work day in such circumstances – e.g. Siebra et al. (2011), Warren et al. (2011), Pandey et al. (2012), Lagerspetz and Tarkoma (2011), Alamri (2012). The remote processing of data is a growing trend as we shall see later in section 3.10.

3.3 Software Architecture

A mobile network architecture for clinical use is proposed in (Rahbar, 2010). The health care unit receives the patient's location and sends help from the nearest location.

The study presented in (Siebra et al., 2011) focuses on monitoring systems that use SMS and agents which analyze information and make decisions. Also, it tries to address energy consumption and emergency alerts. Patient data is sent from the sensors to the smartphone via Bluetooth. Heart rate and blood pressure sensors were used for testing the solution.

Several studies on architectures were found, including solutions for monitoring specific areas such as (Blobel, 2011) and many address cloud computing solutions (section 3.10).

3.4 Modelling

Only one paper was classified under the modeling area (Gomes et al., 2012). It presents a modeling of their proposal for an mHealth software product line, leaving the implementation in a real environment for future work. A drawback of this kind of approach is that we can only estimate how the solution's behavior would be. In other words, real world situations would be more suitable for testing and analysis.

3.5 Software Development Frameworks

Ahmed and Ahamad (2012) propose a framework for mHealth data security on Android systems. It is possible to define which data will be monitored by the framework by configuring some parameters. When an application running on the patient’s smartphone tries to transfer monitored data to an unknown destination, the user is prompted if she really wants to complete the operation.

The work by Lin et al. (2010) proposes a framework to facilitate the development of applications which communicate with external sensors. Authors claim that the framework simplifies the programming of sensors using what they call senselets – blocks that run in between the sensors and the application; they are platform independent and they abstract sensor calls. In the prototype, the authors manage to, in some cases, obtain a decrease of over 75% on the initial source code lines required for a solution (e.g. from 72 to 17 lines in the case of a fall detector application).

As noted before, mobile devices present a special issue regarding battery life. Warren et al. (2011) present a service oriented framework for monitoring applications that implements context-aware characteristics. As an example of this feature, the framework may change the current connection type for one that uses less battery (e.g. Wi-Fi to Bluetooth) when available.

In their study, Constantinescu and colleagues (2012) propose a framework for medical multimedia data. A daemon of the framework is attached to mHealth applications, collecting the multimedia data and adapting them to be viewed using different methods (web browser, mobile devices, etc.). Also, the daemons may communicate to each other, creating a data cloud that is transparent to the user.

3.6 Security

Security is an obligatory issue in health solutions. For example, Ahmed and Ahamad (2012) propose a framework to force security policies in mHealth applications for Android devices. This is done using a system that marks sensitive data. When this data is requested for another application or for transmission, the framework uses pre-established rules to manage these requests, granting or not access to the data.

In parallel, Mashima and Ahamad (2012) propose accountability techniques for eHealth data, with a patient-centric focus. The main concern assessed in this study is that the patient should know what is being done with his medical data and be informed about it. This study tries to reach three goals: (1) Accountable update: update the patient about changes made in his medical data stored in a repository; (2) Accountable usage: inform the patient when his data is used by an entity; (3) Protection of honest entities: this happens in the form of protocols that the entities must follow. This also makes the patient able to dispute requests from compromised or dishonest entities.

Another study, presented in (Le et al., 2010), proposes a cryptography scheme for networks for mobile devices in mHealth using public keys and elliptic curve cryptography. The network has special nodes which are responsible for generating and distributing the keys. After receiving the key, every time a device needs to transfer information to another device in the network, these devices exchange keys and the connection is encrypted.

Similarly to those two works, Barua and colleagues (2011) propose a cryptography system using public keys to control access to patients' data. The system is patient-centric, meaning that the patient decides how his information can be used.

The work by Barnickel et al. (2010) proposes a cryptography system using the user/password model to protect patient data. Every time data needs to be accessed, the user is prompted for his username and password, and then a session is started.

Along the same lines, Chen et al. (2012) propose a cloud based security system for sharing patients data among different institutions. When a record is accessed by an organization that does not own it, permission is requested to the owner (except in emergency cases).

As we can see, privacy and security of medical data is a very frequent issue in the analysed work. This concern is due to the fact that, if this data is intercepted by a malicious party, it may expose private and personal aspects of the patient's lives. Also, another concern goes around frauds involving medical data, such as false requests of insurance prizes. We did not get further into those issues here.

3.7 Notifications

We assume notifications simply as the exchange of information between parties of a health solution. The work presented in (Du et al., 2011) focuses on a system in which the user can send emergency alerts to family members and doctors. The main focus of the solution lies not on how the patient interacts with the system but on how the alerts are sent.

Despite the importance of emergency alerts, this kind of mechanism may not work properly if the patient is not in conditions to activate the alert.

3.8 Multimedia

The study presented in (Hewage et al., 2011) takes advantage of the increasing performance of the mobile devices and networks and proposes a medical 3D video transmission system over 4G networks. The study simulates 3D video streaming over a 4G network inside a hospital environment, and makes both objective and subjective evaluations. The objective evaluation was made by analyzing the left and right sides of an image separately. To do the subjective evaluation, two doctors were invited to analyze the quality of the video after the transmission under different packet sizes. Work from Constantinescu and colleagues (2012) was already mentioned in section 3.5. No other relevant papers were found in this specific area.

3.9 Literature Review

The rare studies classified under the Literature Review category make a compilation of other studies and highlight some characteristics and advantages of those studies. One example is presented in (Liu et al., 2011), where the authors list the characteristics of iOS devices from a developer's point of view. Yet in the study of (Kyriacou et al., 2011) the scope is reduced to specific applications for emergency situations, including monitoring systems, multimedia systems and communication protocols. Their findings corroborate our analysis.

3.10 Mobile Cloud Computing

A problem closely related to mobile devices in general is their low autonomy and limited storage. As the complexity of the data processed by the applications has increased, the amount of storage required to persist this data needs to increase too, as seen in Lagerspetz and Tarkoma's work (2011).

Also, despite the advances in the energetic efficiency of the devices' electronic components, battery duration remains an issue as not many devices can withstand long work periods without a recharge. One solution proposed to diminish such problems is Cloud Computing. Several solutions use this paradigm to expand the storage capabilities of mobile devices, to offload processing-intensive (and therefore, battery-intensive) tasks or simply to ease the sharing of data among different medical facilities. In this section we present some works that use mHealth and cloud computing together.

The study presented by Berndt et al. (2012) shows a solution for monitoring several health aspects like bio-signals, fall detection, chronic diseases, etc. The whole system's infrastructure is cloud based, using the IaaS - Infrastructure as a Service model. The cloud is used to increase the storage of the system, interconnect web based and mobile based parts of the system, share data among several medical units and to interact with health care services and also for security reasons.

Alamri (2012) proposes a medical imaging and video encoding system. This solution uses cloud computing to encode the video streams and automatically process medical images at the correct rates/sizes for each device. Offloading the process of encoding to the cloud saves battery and also can improve the video streaming for devices in a network with lower bandwidth by identifying the connection's speed and adjusting the video rate accordingly.

The work by Hsieh and Hsu (2012) presents a mobile ECG service where cloud computing is used to deliver ECG exams to the doctor's mobile device for quick analysis. The ECG reports are exported in XML format by the ECG exam equipment interconnected with the cloud-based system and then sent with other patient's info, if required, to the doctor's mobile device for reading. The authors point that this speeds up the initial care process as the doctors can analyze the ECG even before the patient's arrival at the hospital.

4 TRENDS AND CHALLENGES FOR MOBILE HEALTH

In this section we summarize the identified challenges found during our literature review.

First, as mentioned earlier, several papers highlight how battery lifetime is a main concern. Batteries currently can not withstand a full work day (e.g. Heslop et al., 2010 among others). Secondly, multiplatform development is a concern for other authors such as Fernandes et al. (2011); iOS, Windows Phone, and Android being the most common choices. Third, delays in data transmission and their consequence on patient monitoring is another current challenge (e.g. Soomro and Schmitt, 2011).

Finally, a common factor listed among the studies of literature review is the struggle to implement the project or software architecture in real environments. For instance, (Gomes et al., 2012) presents a model for software development in the healthcare area, but the authors identify the need to validate the model in real environments. Despite health care solutions around the world demand for new technologies, the inherent diverse environments, security issues, and sometimes people's resistance to change remain important issues to be addressed.

5 RESEARCH SUMMARY AND FINAL REMARKS

In this systematic review we analyzed state-of-the-art research related to the Mobile Health subject area. Four search engines were used to collect primary and secondary data (see Kitchenham, 2004). The studies were classified into 10 categories. We then summarized trends and challenges that we expect to be addressed by new research on the field. The key findings are:

1. It remains clear that the mHealth area is in expansion, mostly due to the advances in mobile devices technology. Despite the need for external sensors in several applications, the devices aggregate some built-in resources which aid in the development of mHealth applications.

2. Patient monitoring was the most frequent area in this study. Most of the solutions in this category use some sort of external sensor to gather the patient's data and send it to the mobile device. From the 11 solutions in this category, only 3 did not use external hardware.

3. Native sensors built in the mobile devices are insufficient to fulfill the needs of the area. Several types of communication technologies were found, Bluetooth being the most used one.

4. Security was the second most frequent category (8 studies). Placing the patient in the center of the decision is a very important issue on data security.

5. The small number of papers in the categories of infrastructure, modeling, notifications and multimedia suggests opportunities for further research.

6. Mobile Cloud Computing appears as an alternative way to approach battery duration and storage issues on mobile devices and should also present opportunities for research, as both Cloud Computing and mHealth are relatively new paradigms.

This systematic review consolidates recent findings in the field and serves as a resourceful guide for future research planning and development on the field of mobile heath care. Based on such findings we now draw the lines for future research in our group.

The very idea of mobile health involves the acquisition and the processing of data via mobile appliances. Nevertheless we have seen that the batteries on such devices currently do not withstand too long for some real world mobile health solutions. Cloud computing appears as an emerging solution for the remote processing of data. But simply sending all data to the cloud is inviable because of security, network and cost issues. There should be a tradeoff between local and remote processing of data. Hence, an important issue to mobile health care solutions relies on developing a way to determine which sets of information can be processed locally by the device and which sets of information could be sent to the cloud for remote processing.

In order to address this tradeoff, we suggest the development of a model to decide whether some information is better processed localy or else by the cloud. The model could comprise a set of variables (such as data size and type) to tune it for each application as well as take into account important network issues, such as latency and cost for both the infrastructure (computational costs) and the final users (monetary costs). By monitoring battery autonomy, application performance, the size and the nature of the data to be processed and considering networking issues, one must be able to make this decision. In a first moment, a static (run-once) solution could make itself useful for application developers. Later, a self-learning and more autonomous solution can be envisioned. Our next research steps are going in this direction.

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