A Systematic Review on Mobile Health Care

Luis C. Jersak , Adriana C. da Costa, Daniel A. Callegari

Tecnical Report Series

Number 073

May, 2013

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Luis Carlos Jersak, Adriana Cássia da Costa, and Daniel Antonio Callegari
{luis.jersak,adriana.cassia}@acad.pucrs.br
daniel.callegari@pucrs.br

Pontificia Universidade Catolica do Rio Grande do Sul
Av. Ipiranga, 6681 - Porto Alegre/RS, Brasil

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 ongoing trends and technical hallenges on the subject. The application areas include: patient monitoring, infrastructure, software architecture, modeling, framework, security, fications, multimedia, mobile cloud computing, and literature reviews on the topic. The most relevant challenges include the low battery life of devices, ultiplatform development, data transmission and security. Our paper consolidates ecent findings in the field and serves as a resourceful guide for future research planning and development.

Key words: Mobile, health, systematic review, trends, challenges

1 Introduction

In the 90s the popularity of mobile devices such as PDAs (Personal Digital Assistants), cell phones and laptops started to grow [26]. The use of these technologies in daily life increased the adoption of such technologies in work environments. Today, one area that deserves attention in mobile technology is the area of health care. This area has experienced changes in treatment, exam manipulation and also in the development of studies in regions of difficult access.

This evolution led to the development of a new area called Mobile Health (often shortened to mHealth) which, according to the World Health Organization (WHO), is the medical practice with support of mobile devices, like cell phones, patient monitoring devices, PDAs and other wireless devices, including the use of cell phones functions like audio, messages, Bluetooth and other services [39]. According to Wu et al. [40], the use of mobile devices is becoming more frequent in medical area as such devices help doctors in a safe and efficient way, for example, with patient data records and life signs monitoring.

The present work focuses on identifying the state of the art on mobile health in terms of application areas, current characteristics and challenges. This re-

search is performed by means of a systematic review on the available literature.

2 General Scope of Research

According to Oates [29], there are several ways for conducting a scientific research. Among those there is a form called Systematic Review, a way of assessing and interpreting all available researches on a particular topic in a given area, using a reliable and rigorous method. In a systematic review, a focus question is chosen to be answered with the results obtained from the research. In the present work, the objective is to answer the following questions:

a) what is the current state-of-the-art in mobile healthcare?
b) what are the current trends and technical challenges in mobile health?

3 Systematic Review Details

This systematic review follows the protocol proposed by Kitchenham [19]. In the following sections, we assume that the reader is familiar with such research method. The details are presented as follows:

Question Formulation: The objective of this research is to better understand the application areas of mobile health, characterizing the concepts proposed in the literature, the results and adopted research methods.

Search String: We obtained a grand total of 1,482 research papers in four libraries using the following string: ("m-health" OR "mHealth" OR "m health" OR "mobile health" OR "mobile medicine")

Population: The searches were performed between the months of March and April 2012 and complemented with a new search iteration in january 2013, in libraries that contained articles from journals and conferences related to mobile devices and health care (details follow).

Libraries: The libraries were chosen by the research group considering access, visualization and full paper download availability. Four libraries were selected: Springer Link, Science Direct, IEEExplore and ACM Digital Library.

Selection of studies: The criteria for inclusion and exclusion of papers in this research were:

a) key areas: computer science, information systems and medical informatics;
b) only papers that focused on the IT area were considered;
c) publication years ranging from 2010 to 2013;
d) papers that did not have focus on health care or mobile health were discarded;
e) all types of studies were analyzed;

f) only papers published in journals and conferences were analyzed;
g) areas: computer science, information technology and mobile health.

In the initial search, 1,482 papers were returned. After reading the titles and abstracts, 59 papers were selected for full reading. After full reading, 40 articles were selected for detailed analysis (2.69% of the overall search engines results), which represents an adequate sample according to our references [6] [19].

Overview of the selected sources: The papers were classified in the following non-exclusive areas : Infrastructure, Patient Monitoring, Software architecture, Modeling, Framework, Security, Multimedia, Literature review, Notifications and Mobile Cloud Computing (these areas are a consequence of the systematic review itself).

From the initial result analysis we identified some characteristics the papers have in common, as well as some interesting findings that will be reported in the next sections.

4 Early Classification of Studies

Regarding to the research methodology adopted in the studies, the papers were classified in 10 different methodologies according to the classification presented in Oates [29]. The methodology containing the majority of the papers was design and creation, in 21 of the 40 papers (52.5%). Seven papers were classified as experiments, five papers as proof of concept, three as bibliographic 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 these studies, half of them (13) focused on patient monitoring [1], [9], [11], [15], [17], [21], [28], [30], [32], [34], [36], [37], [45].

Also, works focusing on vital signs such as blood pressure and heart rate were found, as well as studies about daily life monitoring and transmission of this kind of data. Its worth noting that, in general, monitoring applications require specific hardware to collect the patients vital signs, such as ECG or blood pressure sensors.

5 mHealth Application Areas

This section presents characteristics of the solutions for mHealth. The objective of this section is to provide details about the solutions found in the areas of patient monitoring, infrastructure, software architecture, modeling, framework, security, notifications, multimedia and literature review.

5.1 Patient Monitoring

Several of the analyzed studies focus on solutions for monitoring bio-signals. Monitoring is usually done using external sensors that are not built-in to the mobile device. These sensors usually communicate with the mobile device through

Wi-Fi or short-ranged protocols such as Bluetooth or ZigBee (IEEE 802.15.4 standard) [28]. 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, Penders et al. [32] use a smartphone as a gateway to collect bio-signal data from sensors and further presentation of this data to the doctor or patient. Other studies [34], [21], [38] and [18] 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. [30] present a system in which the mobile device collects data and sends it to processing in the cloud. Also, the mobile device can retrieve the data from the cloud and show it to the doctor or patient.

Likewise, Afonso et al. [1] propose a solution where the data gathered from external sensors by the mobile device is forwarded through 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. [8] presents a solution that gathers the sensor data through a ZigBee network, using the smartphone at first as a gateway. The data is sent via MMS (Multimedia Messaging Service) to an email box at a remote server for analysis and processing. The data is then sent back to the smartphone so the patient can visualize it.

In Ivanov et al. [17] an example of a monitoring application is presented and tested in 11 different smartphones and PDAs. The objective is to check and compare the performance of each device for healthcare applications. Because hardware evolve so quickly, it is hard to keep up-to-date knowledge in this regard.

The study from Pereira et al. [33] shows a solution implemented in 4 different operating systems (Android, Symbian, iOS and Windows Mobile). This solution communicates with the sensors via Bluetooth and it is capable of plotting graphs to better show the patients vital signs. Besides, if a vital sign exceeds a certain threshold, the application may do an emergency call to a pre-established number.

5.1.1 Closing Remarks on the Monitoring Area

In general, the proposed solutions are implemented for the operating systems Android, iOS and Symbian. Also, the most typical language used for developing mobile applications is Java (J2ME platform). One exception is the solution proposed by Pereira et al. [33], which used Python because it provides better control of the application, according to the authors.

5.1.2 Monitoring Using Sensors

After the analysis of the studies classified under the category of patient monitoring, we found that 12 solutions use some sort of sensor to gather the patients life signs. It is also important to notice that the sensors built-in to the mobile devices are insufficient to cover the needs of this area. This conclusion was found

Source / Sensor	ECG	EEG	BP	Temp	RR	HR	Accel*	GPS*	Lum*	Gyr*
Fernandes et al., 2011	X			X		X				
Altini et al., 2011	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	

Table 1. The use of sensors in each proposal.

due to the number of studies that required external sensors for data acquisition. The solutions presented in Penders et al.[32] and in Chi et al. [11] have even developed prototypes for this type of sensors. The sensors found in the analyzed studies were: Electrocardiogram (ECG); Electroencephalogram (EEG); Blood Pressure (BP); Skin Temperature (Tmp); Respiratory Rate (RR); Heart Rate (HR); Accelerometer (Accel); GPS; Luminosity Sensor (Lum); Gyroscope (Gyr). Table 1 shows the list of sensors found in the analyzed studies. It is possible to observe that most of the sensors used are not built-in to the mobile devices.

From the 11 studies that use sensors, only 3 did not use an external sensor. And from those 3, the solution shown in Pigadas et al. [34] only keeps track of the patients location and corporal position, while in the studies in Blumrosen et al. [8] and OBrien et al. [28] the sensors are only used as a proof of concept for the solutions proposed in those studies, as those solutions focus on communication or data processing. Hence, it is important to observe that applications that keep track of vital signs will have to depend on external sensors, as the available technology for mobile devices is not reliable enough for measuring such important data.

5.2 Infrastructure

Heslop et al. [15] presents some interesting findings but it has a downside: it was developed focusing on a restricted area, a specific hospital in Australia. As a consequence, a general implementation for hospitals would probably require adjustments, if feasible.

The authors also mention the benefits of tablets, such as the ease of use and good screen resolution that favors the visualization of certain exams, e.g.radiology images. But they also mention a disadvantage of these devices: the low battery life (about 2.5 hours). This kind of remark is frequent in works

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*Mobile devices native sensors

**In this case, the accelerometer is encapsulated in an external sensor

***The number of sensors is reduced because it is only a demonstration of the applications functionalities, in the case of real use more sensors can be used.

involving mobile devices, because, despite the technology advances in this area, in several cases the batteries do not last long enough to cover an entire work day in such circumstances.

5.3 Software Architecture

In Pawar et al. [31] a generic architecture for comparing patient monitoring applications is proposed. The study was used to compare six different monitoring applications, selected according to the following criteria: use of mobile communication technologies, test evidences and scientific publication availability. It was also used to define the features of real-time epilepsy monitoring systems.

A mobile network architecture for clinical use is proposed in [35]. The proposed network is split in five parts: health agencies, medical clinics, doctors, patients and the application. A scenario of usage of this application is when the patient activates the software in his smartphone and requests medical aid. The health care unit receives the patient's location and sends help from the nearest location.

The study presented in Siebra et al. [36] 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.

5.3.1 Closing Remarks on the Software Architecture Area

In many aspects, the architecture and framework areas overlap each other. Some authors classify their works as architecture with characteristics of framework, but we decided to maintain the author's explicit classification when present. Several studies on architectures were found, including solutions for monitoring specific areas [7].

5.4 Modeling

Only one paper was classified under the modeling area. Gomes et al. [14] only presents a modeling of their proposal for a mHealth software product line, leaving the implementation in a real environment for future work. A drawback of this kind of approach is that it is only possible to estimate how the solution's behavior would be. In other words, real world situations would be more suitable for testing and analysis.

5.5 Software Development Frameworks

The study presented in Ahmed et al. [2] proposes 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 patients smartphone tries to transfer monitored data to an

unknown destination, the user is prompted if she really wants to complete the operation.

Lin et al. [23] propose a framework to facilitate the development of applications which communicate with external sensors. The presented framework simplifies the programming of sensors using what the authors call senselets. Senselets are blocks that run in between the sensors and the application, they are platform independent and they abstract sensor calls. In the presented prototype, the authors manage to, in some cases, obtain a reduction of over 75% on the initial source code lines required (from 72 to 17 lines in the case of a fall detector application).

Mobile devices present a special issue regarding battery use. Warren et al. [38] presents a service oriented framework for monitoring applications. The framework is composed of three software components: 1.The device service, which runs on the smartphone and is responsible for the management of data and communication; 2.The surrogate, which runs in a server and serves as an interface between the mobile device and the other services and its clients; and 3.The surrogate-host, which acts as a surrogate container.

Furthermore, the framework 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 the study of Constantinescu et al. [12], a framework for medical multimedia data is proposed. A daemon of the framework is attached to mHealth applications, collects the multimedia data and adapts them to be viewed using different methods (web browser, mobile devices, etc.). Also, these daemons may communicate to each other, cre- ating a data cloud that is transparent to the user.

5.5.1 Closing Remarks on the Framework Area

The proposed frameworks focus on different aspects, nevertheless, it is easy to identify a common finding among these studies: all of them try to make the development of mHealth applications an easier task. In Ahmed et al. [2], the authors state that a big advantage of mHealth is that it is a convenient way for the user to access his medical information. It also makes the communication between patients and doctors easier.

5.6 Security

Ahmed et al. [2] proposes a framework to force security policies in mHealth applications for Android devices. This is done using a system that marks the sensitive data. The framework taints the data when it is stored and then monitors the data flows in the device. When tainted 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. Also, the authors state that the framework can intercept the actions of malicious scripts, as it runs in a layer above the layer these scripts usually run. As an example of this functionality,

the authors state that the framework can intercept false script-generated screen touches.

On the other hand, Mashima et al. [25] proposes 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 is 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 in Le et al[22] proposes a cryptography scheme for networks for mobile devices in mHealth using public keys and elliptic curve cryptography. The network has special nodes called Key Distribution Centers 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 the works presented in [25] and [22], Barua et al. [5] proposes 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.

Barnickel et al. [4] 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. The session is automatically terminated if the application stays idle for a configured amount of time, forcing the user to authenticate again.

Along the same lines, Chen et al. [10] propose a cloud based security system for sharing patient's 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).

5.6.1 Closing remarks on the security area

We observed that privacy and security of medical data is often mentioned in the papers analyzed. 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 patients 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.

5.7 Notifications

The solution presented in Du et al. [13] focuses on a system in which the user can send emergency alerts to family members and doctors. We observed that the main focus of the solution lies not on how the patient interacts with the system but on how the alerts are sent. The authors did not take in consideration whether the patient will have physical conditions to use the system or not, or if the patient

has enough knowledge to identify the symptoms of a serious condition, like the example of a heart attack mentioned in the original paper.

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. In the study, it was only tested if the alert would be transmitted from an area of difficult access.

5.8 Multimedia

The study presented by Hewage et al. [16] 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 the 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. No other relevant papers were found in this specific area.

5.9 Literature review

The 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. [24], where the authors talk about the characteristics of iOS devices from a developer's point of view. Yet in the study of Kyriacou et al. [20] the scope is reduced to specific applications for emergency situations, including monitoring systems, multimedia systems and communication protocols. Also, according to the authors, advances in 3G and 4G technologies benefited the transmission of images and videos in those cases.

5.10 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 et al. [41].

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. [42] 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 [43] 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 [44] 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.

6 Challenges for the mHealth Area

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.

7 Research Sumary 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 [19]). 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.

8 How to Reference this Technical Report

When referencing this technical report please cite both of the following works:

Technical Report:
    Jersak, L. C., Costa, A. C., Callegari, D. A., 2013. A systematic review on mobile health care. PUCRS Tecnical Report TR 073. Available at:
http://www3.pucrs.br/pucrs/files/uni/poa/facin/pos/relatoriostec/TR073.pdf

Article:
    Jersak, L. C., Costa, A. C., Callegari, D. A., 2013. Technical Trends and Challenges in Mobile Health: A Systematic Review of Recent Available Literature. 15th International Conference on Enterprise Information Systems - ICEIS 2013.

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