Automated Mobile Health: Designing a Social Reasoning Platform for Remote Health Management

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Abstract. With the drastic expansion of mobile technologies, mobile health has become ubiquitous and versatile to revolutionize healthcare for improved health outcomes. This study takes initiatives to investigate a new paradigm of automated mobile health as the process automation of mobile-enabled health interventions. Through the realisation of the paradigm, a novel social reasoning platform with a comprehensive set of design guidelines are proposed for efficient and effective remote health management. The study considerably contributes to the cumulative theoretical development of mobile health and health decision making. It also provides a number of implications for academic bodies, healthcare practitioners, and developers of mobile health.

Keywords: Automated · mhealth · Health management · Decision · Reasoning · Screening · Treatment · Social support

1 Introduction

Mobile health is going through a massive growth spurt that would promisingly extend the reach of healthcare to 1.7 billion patients, by 2018 [1]. Its technologies such as wireless sensing devices, and computation and memory resources have constantly been advanced to meet the worldwide escalating public expectations on healthcare [2]. By removing both spatial and time constraints, it is promisingly transforming healthcare services for improved health outcomes, higher quality of care, and reduced costs of healthcare delivery.

Today, mobile health has been evolved beyond classic data collection and reporting functions to provide better decision support capabilities [3, 4]. Therefore, this research takes an evolutionary approach in investigating the literature of mobile health and health decision making to propose a new paradigm of automated mobile health. It enables highly personalised health interventions for patients in managing their conditions by automating certain healthcare processes. Integration of reasoning processes on mobile devices unveils new capabilities of providing suitable and timely clinical alerts, action plans, and recommendations [5–8]. This study aims to address major boundaries of mobile computing resources [6], utilization of patient's information [9], and data

G. Meiselwitz (Ed.): SCSM 2016, LNCS 9742, pp. 34–46, 2016.
DOI: 10.1007/978-3-319-39910-2_4

privacy [10] by introducing a social mobile reasoning platform with a comprehensive set of design guidelines for remote health management.

Based on theoretical foundations, the study contributes to the cumulative theoretical development of mobile health and health decision making. It has drawn out many implications for academic theorists and healthcare practitioners.

The structure of the paper is as follows. Firstly, we review the literature background of our study in Sect. 2. Secondly, we introduce the paradigm of automated mobile health in Sect. 3. Section 4 presents our social reasoning platform with the design concepts of our mobile platform. Lastly, we conclude our paper with findings and contributions in the final section.

2 Literature Background

2.1 Mobile Health

The firm development of mobile technologies leading to a digital revolution in healthcare has started the path for a new health management model, "mobile health" or "mHealth" [11]. It is broadly defined as "healthcare to anyone, anytime, and anywhere by removing locational and temporal constraints while increasing both the coverage and the quality of healthcare" [12, 13]. With the prevalence of over 6 billion smartphone users [14], mobile health is moving away from typical hospital settings depending solely on clinicians to transform healthcare within existing resource constraints such as infrastructure, healthcare workforce, or financial limitations [15]. The applications of mobile health encompass a variety of activities such as disease management and prevention [4, 16, 17], care surveillance [18–20] and decision support [4, 21].

With the significant advantages of usability and mobility [22, 23], it is imperative to note that mobile health has been progressed beyond simple data collection and displaying functions [4] to link health observations with clinical knowledge to influence decisions for improved health outcome [3].

2.2 Health Decision Making

Making health decisions typically involves a number of parameters, factors and outcome possibilities; thus, it is always complex to both patients and healthcare professionals [24, 25]. The problem of decision conflict may arise when there are two or more clinically reasonable options in screening, treatments, or major life transitions for patients with preference-sensitive conditions (e.g., diabetes mellitus, back pain, early breast/prostate cancer…) [26]. Studies have shown that involvement of both patients and healthcare practitioners in considering various options, benefits, and risks of these health management processes reduces decision conflict, and improves adherence to treatment protocols and outcomes [27, 28].

Over the recent decades, the development of tools and interventions for improving health decisions has progressively innovated. On the one hand, computerized clinical decision support systems (CCDS) are designed to assist and improve clinical decision making [29] which have been found to reduce prescription errors, to increase adherence to guidelines, to improve healthcare professionals' performance and to enrich health interventions for patients [29–31]. On the other hand, patient decision aids (PtDAs) are developed as evidence-based tools to enhance patient's knowledge, to educate risk perceptions, and to increase participation in decision making [32–34]. Patients are engaged to make health choices based on their own preferences and values towards better decision quality and outcomes [35]. For instance, patients with schizophrenia, those who participated in decision aid interventions, acquired better knowledge about their health conditions and had higher perceived involvement in health decisions [36]. Therefore, the evolution of technology-based interventions for health management is moving towards shared decision making for reduced clinical workloads, and economical healthcare services [37, 38].

3 Automated Mobile Health

In recent research, automation of healthcare practices supported by mobile and wearable technologies has paved the way for new types of interventions that are capable of providing highly personalised health monitoring, timely alerts and suitable recommendations [6–8]. With the integration of reasoning processes in mobile apps, automated mobile health has become a viable paradigm for a wider reach of interventions, population-based patient engagement, and cost savings [39]. It is useful in remote health management as a collective process of screening, monitoring and following treatment in which many sub-processes can be selectively automated by linking health observations such as medications, vital signs, and environmental factors with health knowledge towards better clinical outcomes [21]. For instance, rectifying the issue of non-adherence to existing treatments through the process automation of context-aware reminders [40, 41] would lead to more health benefits worldwide than developing any new medical treatments [42].

Automated mobile health is closely related to health informatics and mobile health analytics. Health-related insights can be discovered and operated by mobile health analytics which can trigger automatic health decisions that are parts of health informatics-enabled workflows. Sophisticated interventions of automated mobile health, therefore, can be designed to improve medication adherence, avoid adverse drug events, as well as, connect patients with their social networks and healthcare practitioners in real-time.

3.1 Key Challenges of Automated Mobile Health

In the early development, automated mobile health meets several barriers such as data collection issues, reliability issues, and constraints on mobile computation and memory capabilities. In addition, there are some well-known problems of mobile health interventions such as human involvement, as well as security and privacy concerns. The key challenges of automated mobile health are described as the following.

Heterogeneous Data. Mobile sensing data such as vital signs, medical streams and environmental measures are being captured and processed continuously from a variety of sensing devices [43–49]. In many scenarios, such data are high-speed, high-density, high-volume, and multi-dimensional [50]; for example, Electrocardiogram (ECG) has a high sampling rate of 128 Kbps [51]. For the data to be useful, aggregating and combining the data from multiple sensors in conjunction with medical and related data stored in dispersed locations are a grand challenge for automated mobile health.

Reliability. The reliability of automated mobile health is susceptible to some validity issues of mobile sensing technologies [52]. These include the problems of excessive thermal effects, bad signal failures, short battery life, or conflicts in packet/data delivery [53]. In some cases, the quality of data is prone to errors in usage or placement of mobile sensing devices. For instance, wearable devices could be slipped away or detached to a wrong position due to the patient's movements; thus, the measurement data might be interrupted or distorted. The validity of mobile sensing data might be unexpectedly degraded which might lead to inaccurate health recommendations.

Security and Privacy. Privacy, security and confidentiality concerns exist as highly personal information are subjected to data transmission wirelessly [54]. A study has shown that sensitive location information and physical movements of patients can be revealed by sophisticated reverse-engineering algorithms [55]. Hence, sharing certain privacy-sensitive data outside the mobile devices is not recommended. It is also critical to conceal personal identifiable information over one or multiple wireless communications.

Energy and Resource Limitations. The power consumption of mobile sensing technologies has been known as a problem resulting in quick depletion of phone battery level. This issue leads to the usability and ecological issues of automated mobile health. D'Aquin and his team have reported that an elementary semantic data would take up to hundreds of KB in memory [56]; thus, direct processing over mobile sensing data would easily use up available memory resources on a mobile phone. The major challenge is to design a mobile companion of automated mobile health that is transparent to mobile users and other applications by consuming a low level of CPU and memory resources.

Complex Interventions. Many mobile health interventions require human involvement due to their nature and potential for harmful outcomes to the patient's health [24]. In these complex situations, the human interactions can be better utilized [12]; while some sub-processes with less chance of any risk to patients can be selectively supported by automated mobile health. It is intriguing to investigate the combination of automated and human-assisted care for highly personalized and improved remote health management.

3.2 Realisation of Automated Mobile Health

This study utilises Nguyen & Poo's framework for analysing automated mobile health interventions towards better remote health management [57]. Six core elements were assessed based on the Activity Theory [58], namely (1) subject, (2) objective, (3) tool, (4) control, (5) context, and (6) communication.

(1) **Subject.** Three key participants are identified in various scenarios of automated mobile health, namely: (i) patients, (ii) friends and family members, (iii) and healthcare practitioners. Patients are the centre and the most actionable subject of this paradigm; while their friends and family members, as well as their healthcare professionals, play a contributing role to support the patients in making health-related decisions.

(2) **Objective.** The primary objective is to automate certain healthcare processes in the direction of better decision efficiency and improved quality of outcomes. This can be achieved through mobile reasoning over sensing data and relevant knowledge to support decision automation of remote health management. It encompasses a number of scenarios such as providing suitable recommendations for improving adherence to treatment regimens, timely alerting for adverse events based on multiple sensors (e.g., accelerometers, ECG, pulse oximeter), and engaging patients and healthcare practitioners in shared decision making. The enabler of automated mobile health is a collection of patient's preferences and values which are integral parts of process automation and paths leading to proper health decisions [59].

(3) **Tool.** As a vital companion of remote health management [60, 61], mobile apps have excellent advantages of ubiquity, usability, and mobility [62, 63]. With the real-time connectivity between a mobile phone and multiple wireless-enabled medical devices, embedding a localized reasoning engine in mobile apps would unlock a full potential of automated mobile health without compromising the data security and privacy. As the result, a large number of healthcare workflows can be integrated and automated by reshaping the interactions amongst patients, their friends and family members, and healthcare practitioners.

(4) **Control.** There are boundaries in health practices such as regulations, policies, and cultural norms. It is critical to consider them as the guidelines for human-computer interaction design in which the user-friendly interface and the full control over information sharing are essential for automated mobile health interventions.

(5) **Context.** Both locational and temporal constraints have been removed in the environment of automated mobile health. Social connectivity amongst patients, their social networks, and their clinicians is strongly encouraged for shared understandings of healthcare processes including available options, benefits, risks, and outcomes. This provides opportunities for discovering and formulating decision rules in public communities over time.

(6) **Communication.** The use of mobile technologies empowers the participants with different forms of communication such as e-mail, short message service (SMS), and push notifications. One-to-one discussion and information sharing over a secured channel are essential for remote health management. Moreover, automated mobile health involves collaboration in automation of healthcare processes and automatic remote monitoring and alerts.

In summary, this section presents an analysis of the activity system of automated mobile health. It provides a ground for realising the process automation of mobile health as relevant interventions for improved health outcomes.

4 Designing a Social Reasoning Platform for Remote Health Management

Based on the realisation of automated mobile health interventions, this study takes an important step to propose a social mobile reasoning platform for remote health management. It utilizes a localized mobile reasoning engine where rules are implemented as the best choice and real-time sensing data collected become useful for health screening and management [10], even in the absence of network connectivity [64].

It aims to bring collaborative care to the next level where health knowledge is being exchanged, and social networks of patients are being involved in decision aid activities.

4.1 System Architecture

We architect the social reasoning platform for automating healthcare practices with two major components: (i) a cloud-based service platform, (ii) a mobile companion app. Figure 1 shows the overall architecture of the social reasoning platform.

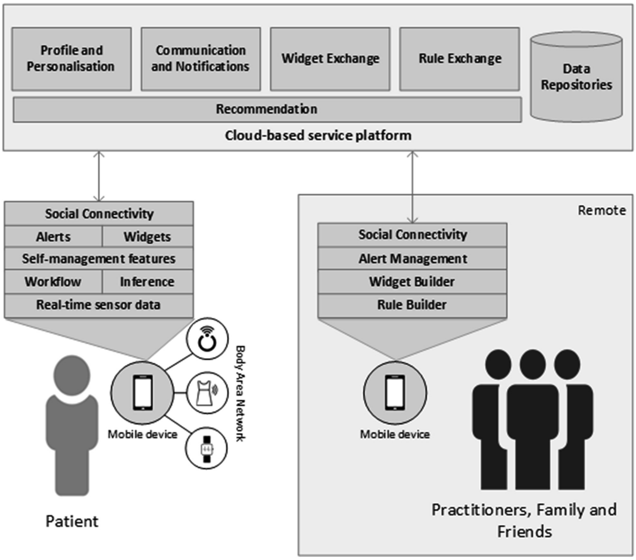

Fig. 1. Overall architecture

The cloud-based service platform employs an enterprise service architecture for modularity and extensibility [65]. It consists of five core services: profile and personalization, communication and notifications, monitoring widget exchange, rule exchange, and recommendation services. These services expose a RESTful interface for the mobile companion app to consume.

A minimal set of de-identified profile data, rules, widgets and alerts will be stored in the cloud-based data repositories. This practice ensures the data security and privacy in which privacy-sensitive data will not be transmitted outside mobile phones. In general, rules have no privacy issues, and rules exchange is introduced to empower patients with community standards. These data strategies minimize the network bandwidth between the server and the mobile companion app, thereby reducing the power consumption and computation resources on mobile phones.

The comprehensive feature set of the mobile companion app is described in the subsequent section for more details.

4.2 Design Concepts of the Mobile Companion App

In remote health management, while healthcare practitioners are expert about disease knowledge; patients are indeed experts about their own health observations [66]. Hence, constant cooperation between them plays a decisive role for effective health management [9]. Moreover, based on a strong theoretical foundation, the social support from those who are family members and friends involved in interventions helps to create persuasion power and generate sufficient motivation for patients to achieve better outcomes [61]. Therefore, the mobile companion app will be provided to patients, friends and family members, as well as healthcare practitioners for remote health management. The following highlights the key features of our proposed mobile companion app.

Profile Personalisation. The flow of automated mobile health interventions begins with a self-registration process which captures the essential profile data of a user. Once registered, the user proceeds to a personalisation process which encompasses the selection of role: (i) patients, (ii) friends and family members, and (iii) healthcare practitioners, as well as personal preferences. It is critical for users to indicate the types of health management: screening, treatment, and monitoring, and more importantly to select the categories of health conditions for control. High blood sugar (diabetes mellitus), coronary heart disease, chronic kidney disease, or baby monitoring are typical scenarios of automated mobile health. Furthermore, more preferences will be prompted for fine tuning decision automation once patient's health conditions are entered.

Social Connectivity. The mobile app allows patients to connect with friends and family members as well as healthcare practitioners via major social networking sites such as Facebook and Twitter (Fig. 2.). Once connected with appropriate permissions, the platform ensures the interactions and information exchange amongst the users in real-time. With the social support, the engagement between the users and the mobile app would strengthen the frequent usage leading to a healthier lifestyle.

Rule Management. This features the process of rule management where rules and action plans (e.g., alerts, reports) are being synchronized with the cloud-based service platform. Mobile users are allowed to create their rules with the antecedent (IF) clauses and the consequence (THEN) clauses from different data sensing sources. In Fig. 3 –

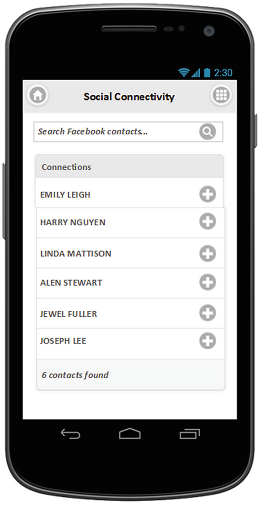

Fig. 2. Social connectivity

screen 1, the mobile is capable of establishing real-time connectivity with wearable devices such as a Bluetooth-enabled blood glucose meter or a temperature sensor to infer whether an adverse event of Hypoglycaemia is detected. Action plans such as alerting healthcare professionals are fully customisable and automated. Furthermore, the mobile app permits users to deposit their rules to the cloud-based repositories which can be flagged as private for personal use, shared for individual social networks, or public for the community. These rules can be exchanged and applied across users of the platform for remote health management as shown in Fig. 3 – screen 2.

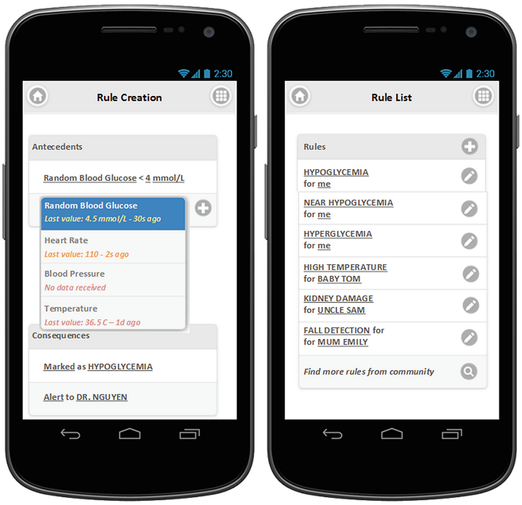

Fig. 3. Rule management

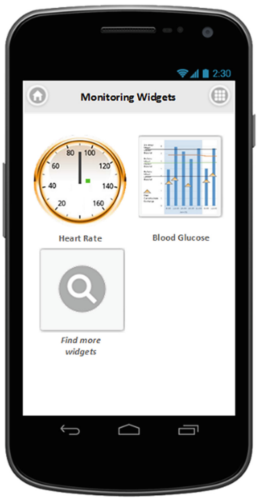

Fig. 4. Monitoring widgets

Monitoring Widgets. The mobile app is capable of enriching the interactions between patients and their smartphone using widgets for real-time and continuous health surveillance. Figure 4 shows two monitoring widgets based on the user profile personalisation: (i) the heat rates being read (as a green dot) from a heart rate sensor in an intuitive meter, and (ii) the blood glucose readings are being reported in real-time for diabetes self-management. For more community widgets, users can search for relevant widgets from the cloud-based repositories.

Alerts and Notifications. This facilities effective interventions for health management over messaging, social networking sites, and SMS. Based on event triggers of decision rules, alert and notifications will be sent to families, friends, or healthcare practitioners timely.

5 Conclusion

Our study has several implications for theoretical literature and practice of mobile health. First, we propose a new paradigm of automated mobile health as the automation of healthcare processes supported by mobile technologies. Second, we elaborate this paradigm to propose a novel social reasoning platform to empower patients with more affordable medical information and less dependent on healthcare practitioners. Last but not least, we designed and prototyped a mobile platform which is capable of reshaping the current generation of mobile health interventions towards a more supportive and automatic direction. It unveils the capability of building knowledge repositories for effective health management using ubiquitous mobile and wearable devices.

This paper is not an end, but rather a beginning of future research. We are looking into ways of further refining our mobile platform through the process of knowledge discovery in mobile health analytics. Decision rules, therefore, can be dynamic and highly personalised towards more efficient and effective personal health management. Furthermore, we are in the process of evaluating automated mobile health interventions to figure out their effects on behavioural change and improvements in health outcomes.

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