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A model for improving quality of decisions in mobile health

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ABSTRACT

The rapid and wide-scale introduction of mobile technologies in healthcare is resulting in an emerging area of mobile health. m-Health has major implications for patients, healthcare professionals, developers, infrastructure providers and regulators in both developed and developing countries. Mobile technologies can not only support instant and ubiquitous access to information, healthcare professionals and patients, but can also create many interesting challenges, including additional complexity and potential for various errors. In this paper, we address how mobile health can be more effectively supported by mobile technologies. More specifically, we present two sets of enhancements: (a) context-awareness and processing and (b) improved presentation of information to healthcare professionals. These enhancements are then applied in the conceptual design of a mobile health alert generation and processing system. To evaluate the effectiveness of the proposed enhancements, we develop and utilize an analytical model. Using multiple metrics, including the number of alerts generated and probability of error in alert-response, we show that the proposed enhancements can improve the quality of mobile health. We hope that other researchers design, implement and evaluate additional enhancements in mobile technologies for m-health. While we do not present any prototypes of the systems, the work presented in the paper can lead to prototypes and testing of systems in the future for mobile health.

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1. Introduction

Mobile technologies are changing the way healthcare services are being designed, implemented, delivered and received. This is resulting in a new area of mobile health (or m-health) and has major implications for individuals, groups, and societies both in developed and developing countries. Mobile health can be simply defined as delivery of healthcare services using mobile technologies [8]. Mobile technologies can facilitate instant communications and access to healthcare professionals, and with access to multiple wireless networks, it can increase the speed of decision making, especially for emergency cases. There is a significant potential for utilizing numerous advances of mobile computing in healthcare [24]. m-Health includes multiple applications and several wireless networks including cellular, wireless LANs, and satellites [8]. We envision that other networks such as Bluetooth, ad hoc networks and Zigbee will also play a major role with sensors and RFID in mobile health.

There is a need to study how mobile technologies may affect the quality of healthcare in different scenarios of preventive care, urgent care, emergency care, home health, and long-term care. Mobile devices in healthcare are likely to be diverse, ranging from sensors, RFID, small screen smartphones to larger screen handheld devices [8]. Some work in mobile health include graphical information visualization [9], clinical decision support system for major lung disease (Chronic Obstructive Pulmonary Disease (COPD)) patients [10], alerts generation for brain activity changes [11], coordination system for emergency medical care [12], management of health conditions of hypertensive patients [13], clinical decision support system for pediatric intensive care [14], and the ontology driven system for chest pain risk assessment [15].

Almost all of the above work focus on designing and developing systems for specific health conditions. However, how mobile technologies can be enhanced to improve mobile health has not been studied. Mobile health is likely to involve multiple sources of information. Many decisions, including some by automated devices and then followed by healthcare professionals, need to be made in identifying the needs of patients and providing them with best possible healthcare services. There are numerous challenges in how to support mobile health. In this paper, we address how mobile health can be better supported by enhancements in mobile devices and networks. More specifically, we present two sets of enhancements, namely (a) context-awareness and (b) improved presentation of information to healthcare professionals. The first enhancement is likely to reduce the amount of traffic generated, transmitted over networks, and presented to healthcare professionals without sacrificing the quality of information. The second enhancement is designed to improve the presentation of information to healthcare professional and could reduce the probability of error in alert-response among others.

In simple case, alerts can be generated by utilizing the absolute values of vital signs as shown in Fig. 1(a). However, such system could lead to many "false-positive" alerts, resulting in waste of healthcare resources. The proposed enhancements are applied in the design of a

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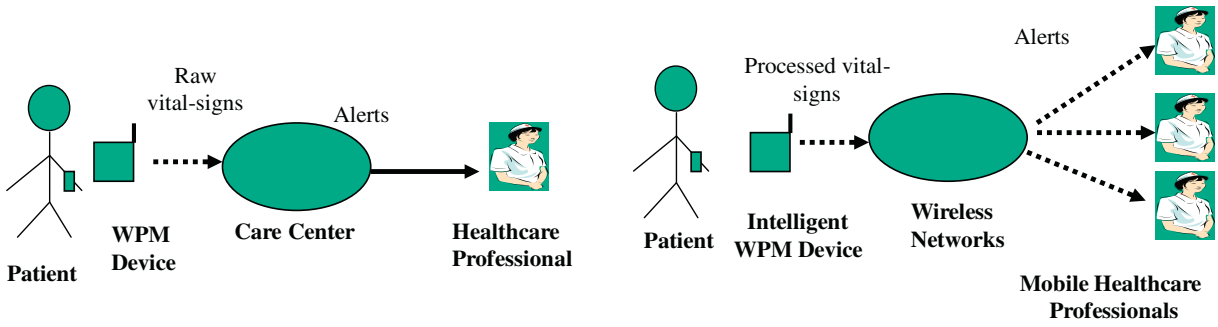

(a) Alert Generation in Wireless Patient Monitoring **(b)** Alert Generation in Context-aware Monitoring

Fig. 1. Different possibilities of monitoring and alert generation.

health alert generation and processing system, where decisions are made by healthcare professionals using mobile technologies as shown in Fig. 1(b). The use of context-awareness can reduce the information traffic, in terms of number of alerts to healthcare professionals, while improved presentation can reduce the information overload and thus improve the quality of decision making. We show the value of proposed enhancements by improving the ways alerts are more effectively generated by the alert generation system and processed by healthcare professionals in Fig. 1(b). The transmission of alerts through a variety of wireless networks has been addressed in [25]; here we focus on alert generation and processing by healthcare professionals.

We then evaluate these enhancements using an analytical model. The analytical model is designed to compute the number of alerts generated, delays in alerts and probability of error in alert-response. The use of context-awareness reduces the number of "false-positive" alerts and the probability of error in alert-response is shown to decrease with improved presentation of information. We are not focusing on complex and broad decision making using mobile devices, but rather focusing only on enhancements for mobile technologies to improve mobile health. Much more work is needed in addressing different challenges in decision making for mobile healthcare, including the complexity, quality, speed and effectiveness and the role of infrastructure. Also, the future research should address implementation and prototyping issues in decision making in mobile health using the proposed and other enhancements.

The paper is formatted as follows. We present two enhancements for mobile health in Section 2 and Section 3, and performance evaluation in Section 4. Some discussion is presented in Section 5. Finally some concluding remarks are made in Section 6.

2. Context-awareness for mobile health

In this section, we focus on adding context-awareness in mobile health. Other enhancements can be designed to improve mobile health, and we expect that many more enhancements will be presented in subsequent papers. In general, context-aware alert generation can

- reduce the amount of information in an alert message by focusing on "changed" values
- reduce the number of alerts by considering the rich context of patients (essentially reducing some false-positives)
- reduce the load for healthcare professionals, which can improve the quality of decision making.

2.1. Context-awareness

The context is any information that can be used to characterize the situation of an entity, which is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves [26]. By including the context, richness of communications can be increased and more useful services can be designed. The context can be sensed, derived or explicitly provided [27]. The context information can be acquired from multiple sources: sensors (ambient, location, health), information sources (preferences, information on applications and usage, user history, patient's history) and miscellaneous (current network traffic, special conditions in user's surroundings, closest place of interest, distance to a hospital). A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task [26]. The context includes who (identity), what (activity), where (location), when (temporal) and why (reasoning for behavior and actions). Fig. 2(a) shows the steps in context-awareness, where it is broken into three phases of information, context and adaptation [8]. The first step involves collecting the necessary and relevant information from multiple sources. Then using the "programmed" context protocols, information is integrated and the current context is generated. The final step involves adapting to the new context in providing services to the users. After discussing the basics of context-awareness, we now focus on how it can improve alert generation in mobile health. More specifically, context-awareness can help in (a) reducing the amount of information, (b) making sense of important information, and (c) improving the quality of decisions by healthcare professionals. The use of context in alert generation is shown in Fig. 2(b). A range of information about the patients must be obtained, amplified, and digitized before transmission. For personalized monitoring, patient's nominal vital signs are defined with multiple thresholds, set of actions, undesirable patterns, and inter-relationships. The level of context-awareness could involve health history, activities, and information on missing doses, recent labs, known handicaps, food and diets, and unusual conditions [23]. Some of these factors are used in deriving alerts in Fig. 2(b).

The wearable sensors on patient's body are shown in Fig. 3. In some cases, additional sensors may be used, while in some other cases, fewer sensors may be required. These sensors collect vital signs and other necessary biomedical parameters, which will then be processed by monitoring devices for generating "alerts". So this is part of information collection necessary for deriving the patient's context.

Context-generation protocols, utilizing weighted probabilities and prediction, derive possible contexts of patient's healthcare needs by integrating and processing information from multiple sources. The context-generation protocols can work with incomplete information in deriving the patient's context and healthcare needs. The context-generation protocols *assist* and do *not replace* the decision making by healthcare professionals, who make decisions using multiple informational items including the context. There is enough flexibility to allow different alarm logics to be implemented with requirement changes. The future work must address data analysis and alarm logic for complex monitoring scenarios and patients' conditions.

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