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Enabling ubiquitous patient monitoring: Model, decision protocols, opportunities and challenges

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ABSTRACT

Healthcare costs in the US are approximately 15% of GNP and are anticipated to reach 17% of GNP in the near future. Management of chronic diseases via technology based ubiquitous patient monitoring services has been widely proposed as a viable option for economizing healthcare resources, and providing efficient, quality healthcare. The process of ubiquitous patient monitoring is information intensive, the information generated is not only fragmented but also spans multiple processes, artifacts, parameters, and decision criteria. The current study explores the complexities associated with the process of ubiquitous patient monitoring and the enabling technologies. The key contribution is a framework that captures the complex processes, the parameters involved, and the decision criteria for ubiquitous patient monitoring. The decision protocols and enabling technologies supporting the processes are detailed in the study along with the opportunities and challenges of ubiquitous patient monitoring. A conceptual model of ubiquitous patient monitoring is developed by leveraging the proposed framework and is validated by a usage scenario. Finally, the implications of future research and contributions of the current research are discussed.

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1. Introduction

Healthcare forms an indispensable constituent of the modern society, representing a large percentage of Gross National Product (GNP) and sustaining a high political profile and strong public interest [5]. In the wake of the 21st century, healthcare systems around the globe are faced with an exponential rise in expenses, heavy utilization of services associated with a steep rise in aging population, and limited financial as well as human resources to manage the growing healthcare needs [13,48]. The current healthcare expenses in the US are approximately 15% of the GNP [25] and projected to reach 17% of the GNP by 2011 [6]. Another trend observed parallel to the rising healthcare costs is the "graying of the globe" — the worldwide population of adults over 65 years of age is on the rise and is expected to reach 761 million by 2025 [46,63]. Fig. 1 depicts the changing global demographics, the resultant increase in the number of aging *patients*, and the corresponding strain on both the human as well as financial resources of the healthcare sector.

Multiple studies in the past have noted the prevalence of chronic diseases in the aging population — seven of the most prevalent chronic illnesses in the US (and their associated in-patient expenses) include: coronary artery diseases ($25.6 billion), heart failure ($15.2 billion), chronic obstructive pulmonary diseases ($6.2 billion), mental health disorders ($3.9 billion), diabetes ($3.8 billion), hypertension ($3.2 billion) and asthma ($1 billion) [6]. Medicare's high-risk patients, approximately 8 million currently, with five or more chronic diseases account for approximately 78% of all health care spending — well over a trillion dollar per year and/or over two-thirds of Medicare's annual spending [3,6,17]. Many healthcare experts agree that current Medicare expense patterns are a reflection of *chronic illnesses managed unsuccessfully* [6]. A large percentage of chronic diseases deteriorate to the point where a crisis is reached resulting in unnecessary long-term hospitalization at massive cost to the healthcare sector. A critical inference drawn from epidemiological data and past studies is that preventing occurrences of *acute episodes* holds the key to providing *quality healthcare*, reducing incidences of *prolonged hospitalizations* and resultant *healthcare expenses* [43]. In order to reduce preventable acute episodes from occurring, it is critical to focus on preclusion of crisis/complications, proactive management of chronic illnesses, and timely detection of anomalies such that patients can lead a normal, healthy lifestyle *outside of the hospitals*.

Innovative strategies are needed to tackle the spiraling healthcare expenses and to cater to the healthcare needs of an aging population in addition to sustaining the trend towards an independent lifestyle focusing on personalized non-hospital based care [46,60]. One strategy is deployment of a large number of trained healthcare professionals to handle the current healthcare scenario involving chronic illnesses. However, there are two key constraints associated with heavy utilization of human resources towards timely detection of anomalies, prevention of complications, disease management, education/guidance with respect to medications, exercise, and diet (within the context of chronic illnesses): (1) healthcare professionals are limited and over-worked; (2) human resources constitute the most

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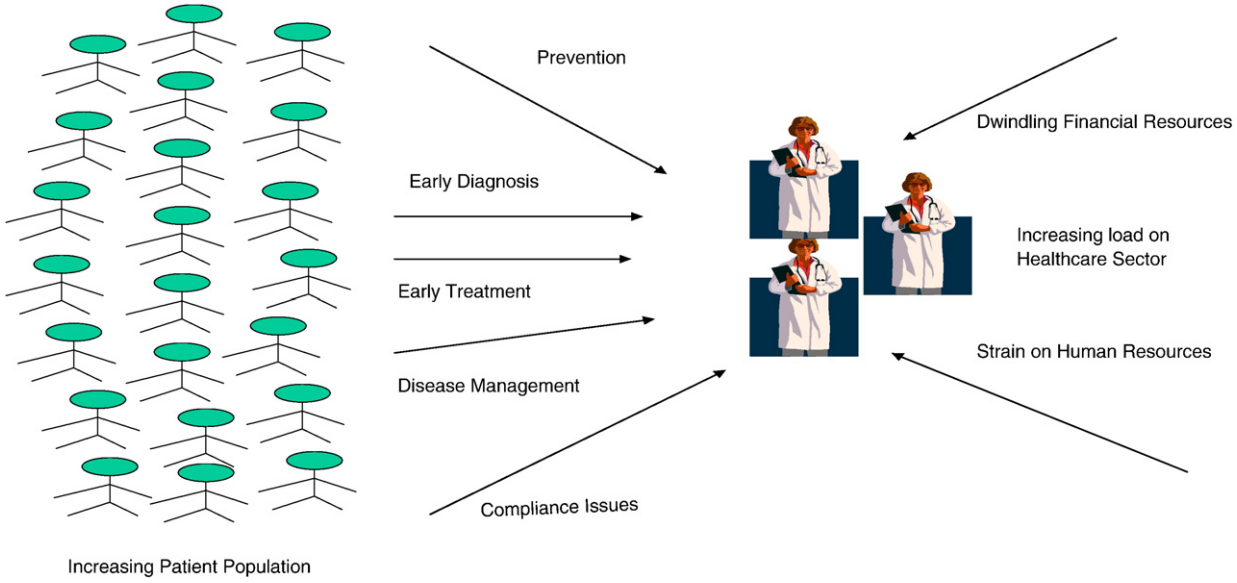

Fig. 1. Changing global demographics and resultant healthcare needs.

expensive variable in the healthcare sector. Thus heavy utilization of human resources will not only increase the cognitive overload of the healthcare professionals, but will also increase healthcare costs.

This research explores *ubiquitous monitoring of chronic patients* as a potential solution that seeks to: (1) *leverage ubiquitous* biomedical sensing, computing, and communication *technologies* to *complement* and *assist* healthcare professionals in *efficiently* managing chronic illnesses 24×7, (2) *reduce* incidences of unnecessary *hospitalizations* due to undetected complications, (3) *provide timely detection* of anomalies before it snowballs into a crisis, and (4) *provide* pertinent *medical attention* utilizing the expertise of the healthcare professionals for handling anomalies "*just-in-time*" as and when needed without time and/or location dependency [5,14]. The population targeted for ubiquitous monitoring consists of Medicare's high-risk patients suffering from multiple chronic illnesses and incurring the lion's share (over a trillion dollar) in annual healthcare expenses. Ubiquitous patient monitoring does *not* intend to *replace* existing healthcare systems, practices, and personnel instead it seeks to *assist* and *complement* the functioning of the existing healthcare systems towards *efficient utilization* of *resources* and *reducing* unnecessary *expenses* incurred due to poorly managed chronic illnesses.

The market for patient monitoring services is a multi-billion dollar industry [61] that holds the potential to reducing unnecessary healthcare costs while providing quality care to an aging populace. Hence there is an imminent need to fully explore the domain of ubiquitous patient monitoring with respect to critical factors and enabling technologies. However, there is a dearth of research focusing on specific understanding of the role of technology based ubiquitous monitoring of patients in improving the practice and delivery of healthcare. Thus the goal of the current research is to:

- Explore the paradigm of ubiquitous patient monitoring within the context of chronic illnesses focusing specifically on successful disease management i.e., preventing incidences of unnecessary complications, prolonged hospitalizations, and corresponding expenses;
- Provide clear guidelines focusing on the process of patient monitoring, key parameters involved, decision logic, and an understanding of the technology enabling efficient and effective ubiquitous monitoring of chronic illnesses.

Active patient involvement within the ubiquitous patient monitoring paradigm seeks to reduce the mental as well as physical strain of the healthcare professionals, increase compliance to treatment, reduce unexpected hospitalization expenses and promote a better, healthier lifestyle of patients outside the hospital. The sole purpose of this research is to explore the utility of ubiquitous patient monitoring as a means of effective and efficient utilization of limited healthcare resources towards an efficient healthcare delivery within the context of chronic illnesses and corresponding expenses. The next section articulates the concept of ubiquitous patient monitoring, the associated requirements/challenges, and the enabling technologies.

2. Ubiquitous patient monitoring

Ubiquitous Patient Monitoring is a concept that has its roots in the vision of Mark Weiser — the father of ubiquitous computing. His vision of ubiquitous computing is captured beautifully in the following quote: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" [62]. Healthcare seems to be the most fertile ground for ubiquitous computing applications since there is no other domain where the importance of making correct decision based on obtaining the right information at the right time is more critical [39,62].

The promise of ubiquitous patient monitoring is an environment constituted flawlessly by enabling technologies that promote continuous, reliable monitoring of patient specific medical information without any dependence on time and location such that prompt medical intervention is provided as and when needed. The information obtained is analyzed via ubiquitous computing technologies for timely detection of anomalies and promoting compliance. Consequently, ubiquitous monitoring solutions, both short term and long term at patients' homes, nursing homes, and hospitals, are increasingly seen as a viable option for disease management, reduction in episodes of preventable hospitalizations, corresponding expenses, and provisioning of healthcare services "just in time" as and when needed [41].

The definition of ubiquitous patient monitoring involves two perspectives, one being the domain of application of the technologies enabling ubiquitous computing and the other being the concept that integrates healthcare more seamlessly to our everyday life [27]. Ubiquitous patient monitoring is not merely a technological innovation; it involves a paradigm shift in healthcare practice, delivery and view. This paradigm shift implies technical applications of consumer-operated