Pervasive Computing for Hospital, Chronic and Preventive Care

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Pervasive Computing for Hospital, Chronic, and Preventive Care

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Abstract

An emerging area of great impact and significance is the application of pervasive computing technologies in healthcare. Pervasive healthcare refers to the set of technologies designed to seamlessly integrate health education, interventions, and monitoring technology into our everyday lives, regardless of space and time. This approach can increase both the coverage and quality of care. Over the last decade, pervasive computing solutions for healthcare have become increasingly prevalent in both research and commercial efforts. This survey analyzes a variety of research projects and commercial solutions devoted to understanding, designing, and implementing pervasive healthcare applications in support of preventive care, hospital care, and chronic care.

Taking into account the working conditions of clinicians and the needs of patients, pervasive computing offers a variety of attractive solutions for many of the challenges to care delivery in these domains. The work of clinicians is intrinsically tied to the physical domain of

the patient, not to digital material available in computer systems; clinicians as well as other non-clinical caregivers continually switch between different caregiving contexts. Furthermore, their work is characterized by high mobility, *ad hoc* collaboration, and interruptions. At the same time, patients and family members frequently demonstrate poor adherence to both behavioral and pharmaceutical interventions and experience inadequate communication with those providing care. The use of health education to promote motivation, reinforcement, advice, and tools for capturing and tracking health information supporting self-monitoring can help patients to overcome these challenges. Pervasive computing offers solutions for clinicians, patients, and a variety of other caregivers to assist them with these problems including applications and mechanisms to:

- ease the recording, tracking, and monitoring of health information;
- allow communication, collaboration, and coordination among the varied stakeholders;
- encourage clinical adherence and disease prevention;
- support the nomadic work of clinicians and seamless integration of the physical and digital worlds; and
- enable the development of novel medical devices.

In this survey, we present an overview of the history of pervasive healthcare research as a human-centered vision driven by a healthcare model that includes preventive, hospital, and chronic care. We then summarize the research in this space, outlining research challenges, current approaches, results, and trends. Finally, we discuss future research directions as a springboard for new focus in pervasive healthcare. This survey is based on analysis of the literature as well as our own research experiences and those of many of our colleagues.

Contents

1

Introduction

The challenges of integrating more complex interventions into both hospital and home care are changing how healthcare is delivered. Many experts now advocate a move toward a more patient-centered approach. In this model, patients take greater responsibility and accountability for their own health with clinicians often acting more as expert consultants than the primary caregivers. A key feature of this patient-centered approach is that care is provided in a more distributed manner. As Bardram et al. argue:

> *"The [current] healthcare model needs to be transformed into a more distributed and highly responsive healthcare processing model, where locally available and distributed [tools] can help empower patients to manage their own health in the form of wellness management, preventive care and proactive intervention" [58].*

Mobile, pervasive, and ubiquitous computing technologies offer promising solutions to documenting progress, diagnosing conditions, and treating and managing care in this patient-centered approach. In this survey, we examine the role that novel mobile, pervasive, and

ubiquitous computing technologies can play in monitoring and analysis of health conditions to support preventive, hospital, and chronic care. Additionally, we examine the ways in which many of these technologies are reinventing the modern healthcare experience. This broad area of research and practice is often referred to as pervasive health, a term we use throughout this survey.

1.1 The Opportunity of Pervasive Healthcare

Pervasive computing, ubiquitous computing, and ambient intelligence are concepts evolving from the development and deployment of pervasive applications, frequently in the healthcare domain and are most of the time mentioned in the healthcare context [32]. Initial visions of pervasive and ubiquitous computing describe environments furnished with computational artifacts that remain in the background and have intelligent capabilities to support user-centered activities [201, 236, 237, 238]. Mark Weiser described a future of smart environments as:

> *"a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network [238]."*

The increasing availability of heterogeneous devices wirelessly interconnected, and advances in both hardware and software are gradually making Weiser's vision a reality.

The application of this vision to healthcare demands an interdisciplinary approach, borrowing methods and techniques from computing fields, such as Ubiquitous Computing, Context-aware Computing, Human–Computer Interaction (HCI) and Artificial Intelligence (AI) as well as medicine, nursing, public health, occupational therapy and health education. The complex healthcare environment requires a detailed understanding of user context. Additionally, these settings necessitate design that accounts for diverse and non-specialist users through simple and natural means of interaction. Finally, pervasive health systems need intelligent capabilities to be adaptive to users,

reactive to context, and capable of learning from user's behavior to provide high quality services based on user preferences.

Pervasive health applications range from wearable and embedded sensors that assist in self-care (e.g., [39, 78, 87, 88, 102, 144]) to hospital environments enhanced with pervasive computing technology (e.g., [13, 14, 15, 16, 21]). Pervasive health includes a variety of definitions, often emphasizing different aspects of the research agenda in this domain [58]; but all emphasize the primary goal of supporting the patient, the caregiver, and the clinician through the use of mobile, pervasive, and ubiquitous computing technologies.

> *"...the use of mobile/wearable/environmental technologies that have come out of the ubicomp/pervasive research communities that is targeted at some challenge associated to health. The health part of it could be addressing issues of diagnosis or treatment that leads to increased medical knowledge(what we would consider medical or biomedical research) or it could be related to work that is contributing to the science or engineering of healthcare delivery." (Gregory Abowd)*[1] [58]

> *"...research on ubiquitous technologies both for supporting clinicians working in a hospital or other health institutions,as well as patients — and more generally citizens — themselves.The goal in the former case is to create technologies that help clinicians better treat and care for patients; in the latter case that patients become more capable and resourceful in their own disease management. Pervasive healthcare technologies can of course also be a hybrid of these two types of systems — that is,having systems that help patients manage health-related issues inclose cooperation with clinical staff at a hospital" (Jakob Bardram) [58]*

[1] *Discussed definitions were presented in the first pervasive health column of IEEE Pervasive Computing [58].*

> *"A new wireless health research field and industry . . . at the convergence of personal mobile wireless devices, networked sensing, and new embedded computing systems directed to advancing the quality and accessibility of healthcare" (Bill Kaiser) [58]*

As the quotes highlight, healthcare is a promising research area for pervasive computing, and likewise, pervasive computing is a promising new direction for health research. Pervasive computing capabilities can be used not only to support hospital work [13, 21] but also to shift care toward the home, thereby enhancing patient self-care and independent living. *"Anywhere and anytime"* are becoming keywords that are often associated with pervasive health. Due to the emphasis thus far on the design and development of pervasive health technologies, there has been less focus on understanding the impact of pervasive health applications on important healthcare issues such as medical errors and users' concerns such as privacy and security. The social, economic and ethical concerns regarding the use of pervasive computing [31, 219] are also extremely relevant in this domain and open new areas of research for scholars to pursue.

In this survey paper, we briefly note the origins of pervasive health and relevant projects that describe key areas of interest, providing an overview of the extensive literature in pervasive technologies that support patients, clinicians, and other stakeholders. In this survey, we highlight design issues and the impact of using these technologies in everyday practices. We primarily draw on the research literature in relevant conferences, such as CHI,[2] Ubicomp,[3] PervasiveHealth,[4] and Pervasive,[5] as well as relevant journals, such as Personal and Ubiquitous Computing[6] and IEEE Pervasive Computing,[7] as well as our own research experiences and those of many of our colleagues. However, readers should be aware that there is a great deal of related literature

[2] *http://www.chi2011.org/*
[3] *http://www.ubicomp.org/*
[4] *http://www.pervasivehealth.org/*
[5] *http://pervasiveconference.org/*
[6] *http://www.springerlink.com/content/106503/*
[7] *http://www.computer.org/portal/web/pervasive/home*

in the medical informatics domain primarily focused on tools, devices, and methods required to optimize the acquisition, storage, retrieval and use of information in healthcare. Additionally, relevant literature can be found scattered amongst public health, nursing, medical, gerontology, mental health, and other journals. Our aim, here, is not to provide a comprehensive review of all of the relevant literature in this vast interdisciplinary space. Instead, this survey describes the field of pervasive healthcare in a way that prepares newcomers to tackle some of the most important issues and that identifies upcoming trends in this important research space. The general inclusion criteria for the projects discussed in this paper included, papers discussing issues related to:

- mobile devices (e.g., laptops, PDAs, tablet PCs, mobile phones),
- wearable and on-body sensors (computer-enhanced textiles or medical sensors),
- natural interfaces,
- stationary devices embedded in "everyday objects" or infrastructure, such as buildings, furniture, etc.
- systems and context-aware services with elements of "intelligence,"
- pilot studies and case studies conducted in health care settings for understanding healthcare needs and the use of pervasive applications

1.2 The Healthcare Model and Contemporary Computer Technology in Healthcare

Pervasive computing entered health care in a variety of settings, making it difficult to frame a paradigmatic vision of a pervasive health system. The relevant settings that the pervasive computing literature has tended to examine can generally be divided across two axes (Table 1.1): system users and system purposes. System users include health care professionals (i.e., nurses, psychologists, and clinicians), caregivers (i.e., family, friends) and patients. Even though, in most cases, several stakeholders are involved in the use of a system (e.g., a *patient* captures

Table 1.1. Overview of the projects discussed in this survey[8]

Application themes by domain (total)/(%)	Healthcare Users		Care purpose		
	Caregivers	Patients	Preventive	Hospital	Chronic
Natural interfaces	4	14	1	4	13
Context-aware computing and pervasive monitoring	22	21	1	22	20
Capture and access tools and self-care management	17	25	15	6	11
Collaboration and coordination	10	22	15	6	11
Pervasive games		7	7		
Robots		6	1		5
Total (n = 148)	**53**	**95**	**39**	**39**	**70**

his/her heart rate that could be later reviewed by his/her *relatives* and *healthcare providers*), in most cases, we can still identify a primary user who benefits from using the system. For the purpose of this survey we define the user as the *"person who primarily interacts with and has benefited from the system."* The system's purpose can be divided into preventive, hospital, and chronic care. In this survey paper, we discuss close to 150 projects from the academic and commercial domains. Although we tried to balance the discussed projects according to each dimension (i.e., healthcare users and the purpose of care), the selected projects reflect the body of work we identified in each domain. Certainly, this discussion does not and cannot include every piece of technology related to healthcare. The field is moving quickly; new products reach the market and new research projects are launched each day. In this survey, we focus on those technologies that have been empirically validated in the literature and only highlight those commercial products that are particularly popular or relevant to the evidence-based solutions from research.

[8] *We did not include in the table projects discussing methods and tools in support of the research and Pervasive Healthcare, and studies conducted for understanding healthcare user needs because we wanted to reflect on the application themes available in this community.*

In this section, we discuss the different areas of health and wellness and current health technology to highlight how computing research in healthcare is evolving toward pervasive health.

1.2.1 Personal Informatics and Games for Preventive Care

Behavior and lifestyle choices (e.g., smoking, obesity, and inactivity) contribute to increased prevalence of chronic degenerative diseases and premature deaths [52]. For example, the worldwide obesity phenomenon and associated diabetes are "*becoming the main epidemic of the 21st century*" [223]. This growing phenomenon — largely as a result of changes in the modern lifestyle and food systems — placed a heavy burden on the hospital and healthcare sectors. Indeed, many chronic diseases and premature deaths are linked to common preventable risk factors (Figure 1.1).

Prolonged alcohol and tobacco use, unhealthy nutrition, and physical inactivity are some of the major causes of preventable chronic degenerative diseases [52]. Public health researchers and officials alike have argued heavily for strategies to enable and support behavior change in those with high risk factors. Thus, in recent years, a variety of governments have created preventive health programs targeting behavior

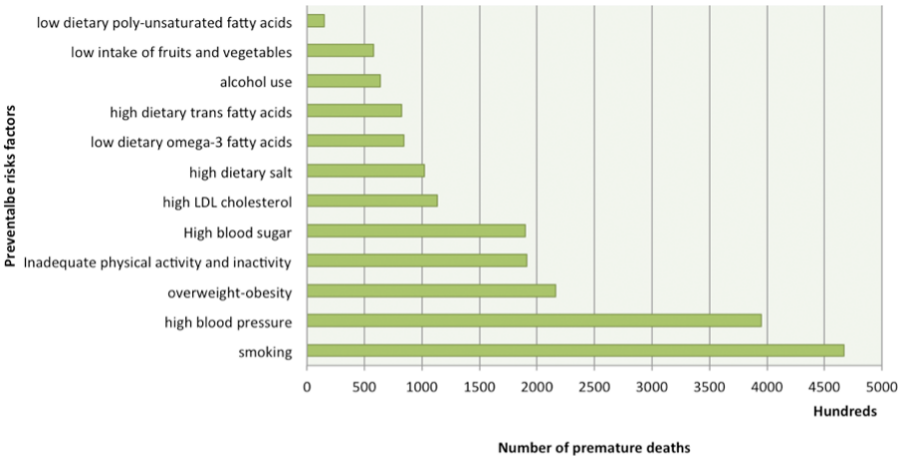

Fig. 1.1 Preventable risk factors for premature death in the United States [52].

change (e.g., obesity, food safety, and infectious disease prevention[9]) as an alternative method using health education to preventing diseases and encouraging people to take on the responsibility of self-care. Preventive *health care or preventive medicine* refers to measures taken to prevent diseases, or injuries, rather than curing or treating them [199]. It is about giving *"your body the best chance of remaining free from disease"* [199].

One historical root of pervasive health applications derives from interest in this kind of preventive support as well as the general concepts of persuasive technology [45]. These applications have included technologies to support preventive health education (e.g., media for health education), personal self-reflection (e.g., personal health informatics and personal healthcare information management) and behavior change (e.g., games). Some of the available technologies in this space include multimedia educational videos and web-based portals, virtual communities (e.g., [215]) and games (e.g., BrainAge). Most of these solutions include a variety of print, graphic, audiovisual, and broadcast media programs intended to influence behavior change. For example, the Brain Age games from Nintendo DS *"help to stimulate your brain and give it the workout it needs through solving simple math problems, counting currency, drawing pictures on the Nintendo DS touch screen, and unscrambling letters."*[10] Educational health games facilitate learning through simulation of disease consequences or trivia-based designs [12].

Other available solutions for supporting preventive healthcare are tools for empowering users to collect *"the necessary personal information for insightful reflection"* [139]. As defined by Li et al. [139] personal informatics systems are those that

> "*help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge.*"

[9] *http://www.healthyamericans.org/*
[10] *http://brainage.com/launch/index.jsp*

In personal informatics, people participate in both the collection and analysis of behavioral information. Indeed, integrating personal health information helps people manage their lives and actively participate in their own health care [186]. For example, the Personal Healthcare Record (PHR) [1, 225], is a self-managed personal medical record where individuals update their own health data.[11] A PHR [225] is an:

> *"An electronic application through which individuals can access, manage and share their health information, and that of others for whom they are authorized, in a private, secure, and confidential environment."* [225]

The health data in a PHR might include family history, lab results, imaging reports, data gathered from medical devices, illnesses, and hospitalizations. Current implementations of PHR include electronic and web-based PHR(e.g., iHealthRecord[12] and IBM[13]). Some of the benefits of the PHR for patients include more knowledge about their health, increased participation in their medical care, and more knowledge about clinical decision-making [147]. Furthermore, pervasive health applications could be potentially connected to these PHRs and provide a variety of patient data to the record.

1.2.2 Information Technology for Hospital Care

Hospital environments are filled with increasingly complex technologies, and in these environments, highly mobile staff require greater coordination and collaboration among specialists for adequately and timely patient care delivery. Traditional computer technology in hospitals includes technology for managing and sharing health information and applications for support health provider's decision-making [213]. Electronic medical records (EMRs) aim to make hospital workflows more efficient, improve the quality of patient care and reduce costs [99, 216]. Likewise, the use of voice-over-IP (VoIP) systems has started to unify

[11] *The personal health record provides also a summary of the Electronic Medical Record (EMR) managed within health institutions.*
[12] *iHealthRecord. Available at: http://www.ihealthrecord.org. Accessed March 14, 2006.*
[13] *IBM breathes new life into healthcare. Available at: http://www.ibm.com/news/us/en/2005/11/2005_11_08.html. Accessed March 14, 2006.*

and streamline communications,[14] and the use of Picture Archiving and Communication Systems (PACS) offers faster access to diagnostic information, reduces the need for film and film storage, and increases radiologist and clinician satisfaction and productivity [226].

Clinical decision support systems (CDSS) are tools to assist clinician decision-making [213]. Although, these systems have mainly had a positive impact for drug dosing and other aspects of medical care, there are still open questions about whether these tools help in diagnosing [111]. The opportunity to integrate these devices, databases, and networking in the current hospital environment into a truly interconnected pervasive health experience represents that primary challenge for the branch of pervasive health applications focused on supporting the clinical experience.

1.2.3 Assisted Technologies for Chronic Care

As the population ages and acute care improves survival rates for a variety of illnesses affecting all age ranges, the prevalence of chronic diseases continues to grow. The increasing growth rate of individuals managing chronic conditions will increase the demands on healthcare workers, family members, the pharmaceutical industry, medical technology, and insurers to meet their needs. Consequently, many leading experts and policy advocates predict a severe strain on resources in trying to meet this demand.[15] According to the World Health Organization (WHO), between 1950 and 1980 the percentage of older adults of the world population was approximately 8%; after 2000 it was estimated that this figure will increase to 21.4%.

Chronic health conditions typically include all impairments or deviations from the norm [195] that last three or more months [182]. Chronic care refers to medical care that addresses preexisting or long-term illness, as opposed to hospital care, which is concerned with short-term or severe illnesses of brief duration. Although chronic care is more

[14] *Why VoIP is the Becoming the Telephone System Choice For Hospitals in the UK. http://EzineArticles.com/?Why-VoIP-is-the-Becoming-the-Telephone-System-Choice-For-Hospitals-in-the-UK&id=2110277*

[15] *American Productivity and Quality Center. Available at: http://www.apqc.org/portal/apqc/site/generic2?path=/site/industry_focus/industryfocus_healthcare.jhtml*

common in the elderly, children, teenagers, and young adults also have to deal with chronic issues as well.

Assistive technologies help people with chronic and debilitating illnesses to live with greater independence, safety, and community integration. Assistive Technologies [133] is an umbrella term for defining:

> *"devices and other solutions that assist people with deficits in physical, mental or emotional functioning to perform actions, tasks and activities."*

Available assistive technologies for chronic care include applications for rehabilitation or compensation, health monitoring and community informatics.

Most traditionally available assistive technologies include systems and special devices for rehabilitation and/or the compensation of a lost skill. Examples of these technologies include electronic wheelchairs, visual and hearing aids, cognitive support systems, and augmentative and alternative communication technology. For example, patients with verbal impairments can use paper and electronic-based pictures, choice boards [159, 160], or text-to-speech software [207] to communicate their needs (e.g., requesting food).

The long-lasting nature of chronic illness makes record-keeping and long-term analysis of diagnostic and evaluative measures both extremely important and also very challenging. Not only must symptoms, interventions, and progress be documented over very long periods, but they must also often be recorded in the midst of daily activity. Thus, technologies in support of chronic care include applications for facilitating health data capturing. For example, health monitoring systems include biometric devices for the monitoring of patients, physiological parameters, and biological measurements (e.g., ECG, arterial oxygen saturation, and blood pressure). There is also increased interest in telemedicine and surveillance systems for monitoring patients' activities and behavior [56, 125]. The main goal of health monitoring is to allow caregivers and health providers to detect potential problems reducing unnecessary hospitalizations and health emergencies. As conditions grow in complexity and care moves from a centralized clinic setting to being distributed throughout homes and other environments,

health records management will require equally complex, distributed, and integrated solutions. Pervasive health not only offers a variety of opportunities in this kind of connectivity and multi-device platforms but also represents a kind of paradigm shift from a model of manual clinician-directed documentation to one that includes system automated and patient-initiated documentation.

Finally, applications for social support can be particularly important to help people with chronic conditions meet people with the same needs, exchange experiences, and find the needed social support for coping with their diseases. In the domain of community informatics [90], traditional information and communications technology is being used to enable users share experiences and gain social support empowering community process. In the medical area, virtual communities have been successfully used in the care of patients [107, 215]. Their benefits include the reduction of stress, social satisfaction, opportunistic access to information relevant to their disease, and increased communication between patients and clinicians [211]. For example, PatientsLikeMe is a virtual community through which people with chronic diseases have an online community for both resources and support [7]. Pervasive health offers a compliment to these current solutions in terms of supporting socialization and support through a variety of mobile, location-aware, and networked systems.

1.3 Conclusion

As seen through this brief examination of current technologies that support health and wellness, pervasive health has a diverse set of origins addressing a variety of challenges. Current IT solutions, while beneficial in many ways, do not provide the natural affordances that enable access to healthcare *"anywhere and anytime."* For example, when hospital information systems are evaluated, about three quarters of these systems are said to have failed [10, 239] and there is no evidence that they improve health professionals' productivity [82]. In the modern hospital environment, workers spend only a fraction of their work shift in front of a computer and more than twice of their time "on the move" [22, 23, 164, 196, 197]. Consequently, pervasive

computing may be very useful in supporting preventive, hospital, and chronic care.

There are many ways to organize and discuss the literature in pervasive healthcare: across domains, across diseases or across users' roles. In this survey, we describe the literature in light of the paradigm shift currently occurring as healthcare is more decentralized geographically and administratively but connected technologically, following the patient-centered model of care. Specifically, we first describe the use of highly networked innovative services in the hospital and clinical setting. We then describe the ways in which some of these technologies as well as new ones not seen in clinics are making their way into home care and assistive technologies for the chronically ill. We then describe a vision for the future that involves some of the most recent trends toward preventive health and wellness applications. Finally, we close with a discussion of the pervasive health design space in light of common methods and application areas in ubiquitous and pervasive computing. This organization enables the reader to follow how specific problems in contemporary healthcare have motivated and driven many researchers to design, develop, and deploy pervasive health applications as well as to understand the potential future trends and open research questions in the community.

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