Pervasive Computing in Healthcare

Pervasive Computing in Healthcare

Edited by

Jakob E. Bardram
Alex Mihailidis
Dadong Wan

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an informa business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 0-8493-3621-X (Hardcover)
International Standard Book Number-13: 978-0-8493-3621-8 (Hardcover)

Library of Congress Cataloging-in-Publication Data

Pervasive computing in healthcare / edited by Jakob E. Bardram, Alex Mihailidis, and Dadong Wan.
p. ; cm.
Includes bibliographical references and index.
ISBN-13: 978-0-8493-3621-8 (hardcover : alk. paper)
ISBN-10: 0-8493-3621-X (hardcover : alk. paper)
1. Medical informatics. 2. Ubiquitous computing. 3. Medical telematics. 4. Patient self-monitoring. 5. Biosensors. I. Bardram, Jakob E. II. Mihailidis, Alex. III. Wan, Dadong.
[DNLM: 1. Biomedical Technology--instrumentation. 2. Computers. 3. Biosensing Techniques--instrumentation. 4. Delivery of Health Care--organization & administration. 5. Information Systems--instrumentation. 6. Telemedicine--instrumentation. W 26.55.C7 P471 2007]

R859.7.U27P47 2007
610.28--dc22 2006020620

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Foreword

Pervasive computing has become a very fashionable area for computer science, and many researchers are making much progress in the field. The size of the healthcare sector in the developed world in particular means that there are potentially vast markets for new technologies. It is almost inevitable that researchers, developers, and manufacturers will investigate the potential of pervasive computing in healthcare. There are, however, some dangers when computer scientists and engineers blindly jump on this particular bandwagon. The major danger—which has sadly been seen all too often—is that of technology being the driving force with little or no consideration of the healthcare sector's real needs and wants. Technological push can work in some sectors (personal computers and mobile telephones are two examples), but the healthcare sector has substantially different characteristics from more traditional business and domestic marketplaces.

For example, users of healthcare technology fall into two groups: patients or clients, and healthcare professionals. The former are very likely to be ill, disabled, or old, whereas professionals may have to use equipment in busy situations, in addition to being under significant stress. Both groups may have to operate equipment in hostile or unusual environments such as operating theaters, intensive care wards, and car accident sites. Even domestic environments, which have been modified to cope with an ill or disabled person, provide nonstandard situations. Similarly, a greater range of clothing (hospital gowns, nightwear, and protective clothing) may be worn than in more traditional situations. Further challenges include the need to protect equipment from a range of bodily fluids and chemicals while not compromising the requirement for a sterile environment.

Thus, in healthcare, neither the users nor the environments will be ordinary. As part of my research into design for computer systems to support older and disabled people, I have suggested the concept of "ordinary and extraordinary human computer interaction." This draws parallels between the computing challenges of ordinary (able-bodied) people operating in an extraordinary (high work load, stress, environmentally extreme) situation and extraordinary (disabled) people operating in an ordinary (office) environment.[1] The healthcare situation, however, also includes extraordinary people operating in an extraordinary environment. It thus provides very substantial challenges for designers and engineers, but these challenges are well worth tackling because the potential rewards of relieving suffering are very great.

If pervasive computing is going to be successfully applied to healthcare, it is vital that design and development teams fully understand the users and the environments in which their systems are to be deployed. Both of these are likely to be alien to design teams. Even if designers have been temporarily disabled or hospitalized at some stage in their lives, they are unlikely to have concentrated on the pervasive computing design challenges at the time! It is thus absolutely vital that they become aware of not only the potential of pervasive computing technology but also the sensory, motor, and cognitive characteristics of the users for whom they are designing and the environments in which users are likely to use the equipment. It is only after designers have absorbed this background information that they are in a position to investigate the real needs and wants of the healthcare sector.

The design and development process itself needs an understanding of human factor issues, but it is also important for the research team to contain healthcare professionals and, where possible, patients and clients. There are a number of ethical issues in the use of patients and clients, however, particularly if they are minors or cannot give informed consent. My group suggests the concept of "mutual inspiration," whereby both computing professionals and potential users work together to produce a solution, and we also address how to facilitate interaction with users by using a range of techniques including theater work.[2]

There can be substantial ethical issues in research in this field, and it will often be necessary for the research and development process to have the approval of an ethics committee. In addition there will be ethical issues of privacy and consent with the introduction of pervasive technology and these need to be thought through at an early stage of the design process.

The final hurdle for the healthcare sector is providing appropriate evidence that one's equipment is effective, but there are significant challenges for showing the effectiveness of pervasive computing. Because of the dominance of pharmaceutical interventions, the norm for clinical evaluations is to have large "n" randomized double-blind studies that include a control group. These are often impractical or impossible for systems involving pervasive computing. (How do you fool a user into not using a PDA or conceal this from an observer?) Developers of technology not only need to consider appropriate ways to evaluate their systems, but they also must have a robust defense of their methodology.

I have outlined the various aspects of changes presented to developers of pervasive computing for healthcare. A team that develops pervasive computing systems for healthcare needs a wide range of background knowledge. This book provides an excellent grounding in the various aspects of the process that need to be considered; each chapter is written by authors who have long and distinguished careers in this field. I recommend this book to all those venturing down this exciting and rewarding path.

—Alan F. Newell, Ph.D., MBE, FRSE

References

1. Newell, A.F. and Gregor, P. Human computer interfaces for people with disabilities. In Helander, M., Landauer, T.K., and Prabhu, P., editors, *Handbook of Human-Computer Interaction*. Amsterdam: Elsevier, 1997, pp. 813–824.
2. Newell, A.F. Older people as a focus for inclusive design. *Gerontechnology* 4:4 (March 2006), 190–199.

Acknowledgments

We would like to first and foremost acknowledge the tireless efforts of each of our contributors and authors, without whom this book would not exist. The chapters reflect the wide range of skill, expertise, and knowledge of each of our authors, and they were selected to be a part of this volume because they represent the leading edge in the fields of computer science, healthcare, and pervasive computing.

Furthermore, we would like to thank all of our reviewers who spent many hours providing us with thoughtful and insightful comments and feedback.

A special thank you goes to Jennifer Boger at the University of Toronto, who dedicated much time to assisting the editors in reviewing all of the chapters and compiling the final volume. We are indebted to her service.

Finally, we would like to thank those at CRC Press who gave us the opportunity to pursue this project. Without their confidence, patience, and support we would have not been able to achieve our goal.

—Jakob, Alex, and Dadong

Introduction

Why pervasive healthcare?

Most countries will face the same set of healthcare challenges in upcoming years: skyrocketing costs needed for caring for an increased number of elders; a rapid increase in lifestyle-related and chronic diseases; a demand for new medical treatments and technologies; and a shortage in the number of available clinicians, nurses, and other caregivers. The statistics and numbers are overwhelming. To name but one example, medical care for people with chronic diseases such as arthritis, asthma, cancer, diabetes, and heart disease accounts for more than 75 percent of healthcare expenditures in the United States.[1] These challenges are evident in most industrialized countries, whether a country has a publicly funded welfare and healthcare system as in Canada and Europe or whether it is based on insurance as in the United States. Furthermore, these challenges will affect all parties involved in the healthcare system, including patients and their families, employers, governments, clinicians, caregivers, and administrators. The current healthcare model can no longer meet these challenges simply because it is poorly suited to serving an increasing number of chronically ill and elderly people. The current Western healthcare model, which is concentrated around highly specialized and centralized experts located in large hospitals focusing on acute care, can be compared to a centralized data processing model evident in a mainframe computer.[2] This mainframe healthcare model needs to be transformed into a more distributed and highly responsive "healthcare" processing model, where locally available and distributed systems can help empower patients to manage their own health in the form of wellness management, preventive care, and proactive intervention. A distributed healthcare model that pervades the everyday lives of citizens is much more suited to managing the kind of lifestyle and chronic disease challenges underlying the current healthcare system.

The goal of *pervasive healthcare* is to *enable* this distributed and pervasive care model for health and wellness management through the use of information and communication technology. In this respect and for the purpose of this book, we define pervasive healthcare in two ways. First, it is the application of pervasive computing (or ubiquitous computing, proactive computing, ambient intelligence) technologies for healthcare, health, and wellness management. Second, it is about making healthcare available everywhere, anytime, and to anyone. In essence, pervasive healthcare addresses a set of related technologies and concepts that help integrate healthcare more seamlessly to our everyday lives, regardless of space and time.[3] Mark Weiser, the father of ubiquitous computing, stated that "the most profound technologies are those that disappear."[4] In that sense, pervasive computing may be considered as the opposite to virtual reality. While in virtual reality the user enters the world created by computers, in pervasive computing it is the computing that enters the physical world and bridges the gap between the virtual and physical worlds. This bridging is perhaps best described by three important enabling technologies: ubiquitous computing, ubiquitous communication, and intelligent user-friendly interfaces.

Ubiquitous computing refers to the integration of computing power (microprocessors) and sensing (sensors) into anything, including not only traditional computers, personal digital assistants, and printers, but also everyday objects and environments. Ubiquitous communication means enabling anytime and anywhere the communication of anything with anything else, not only between people but also between the objects of which the computing is part. Important ubiquitous communication technologies include ad hoc networking and wireless communication, such as low-power, short-range networks. Intelligent user-friendly interfaces enable natural interaction and control of the environment by the users, or inhabitants of the ambient environment. The interfaces support natural communication (e.g., speech, gestures) and multimodal interactions, which take into account user preferences, personalities, and usage context. The envisioned pervasive computing infrastructure provides a seamless environment of computing, networking, and user interfaces. It is context aware in that it has senses and the required intelligence to interpret sensory information and make reasonable decisions when taking actions.

One of the most important applications for pervasive computing technologies is healthcare, including wellness and disease management, and support for independent and assisted living. For example, developments in sensors, and more generally measurement technology, make it possible to obtain physiological data from wearable or embedded sensors. Ubiquitous communication based on mobile phone networks, WiFi, and other wireless technologies makes it possible to deliver and access data including measurements, person-to-person communications, and health information anywhere and anytime. Mobile devices provide ubiquitous user interfaces for users ranging from healthcare professionals to average citizens. We have just begun to unleash the vast potential that this technology has to offer for healthcare delivery. In addition to health monitoring, pervasive healthcare also has great potential in social computing. For example, these technologies can be used by relatives, family members, and peers of chronically ill persons to remain in contact no matter where people are physically located. Furthermore, pervasive healthcare also helps patients to manage their own diseases better and helps healthcare professionals to communicate and collaborate.

A historical perspective

Technology has always played a central role in medical diagnosis, treatment, follow-up, monitoring, and prevention. *Medical engineering* has been central to medical progress, and most medical diagnoses and treatments are only possible through the use of quite advanced technology. These technologies range from the simple stethoscope to advanced scanning techniques, such as x-rays and magnetic resonance imaging (MRI). In parallel, *medical informatics* covers the discipline of using computers for medical purposes. Medical informatics is, however, primarily concerned with *informatics*, which is the use of information technology for storing, managing, and accessing medical data and information. This research is traditionally built on more general information systems (IS) research that studies the use of computers for information processing in large organizations. Telemedicine, which can be viewed as a subdiscipline of medical informatics, uses communication technology for establishing medical consultations and conferences over distances. Common to medical informatics and telemedicine is that these research approaches have focused on the use of computers by medical professionals for electronic record keeping and for conducting *indirect* medical treatment over distances. As such, there has been little focus on the use of computer technology for direct patient treatment, where patients play active roles in their healthcare management.

Pervasive healthcare takes a slightly different approach by focusing much more explicitly on the use of new pervasive computing technology for patient self-treatment and self-care (i.e., empowering the patient to take a more active role in managing and treating disease). In particular, pervasive healthcare pays special attention to the tools and services that put the patient at the center of the healthcare process. This includes support for patient self-management, self-care, preventive efforts, cooperation between the patient and the healthcare institutions, cooperation between home and hospital, self-monitoring, remote monitoring, remote consultation, and assistive technologies.

More recently, there has been growing interest in the research and development of healthcare-related technologies from the more traditional application-oriented disciplines of computer science such as human–computer interaction (HCI), computer-supported cooperative work (CSCW), and the emerging research community in pervasive and ubiquitous computing, including wireless sensor networks for healthcare (e.g., body sensor networks). A particularly interesting observation is that large computing technology companies such as Intel, IBM, Microsoft, Nokia, Cisco, Samsung, and Sony are currently investing a huge amount of resources to researching and developing technologies and applications for healthcare. While these companies traditionally supply basic computer and communication hardware and software, they now see healthcare, especially patient-centered healthcare, as one of the biggest application areas for computer technology. We believe that pervasive computing holds great potential for transforming the business of healthcare by helping improve the quality of care while reducing overall healthcare costs. This new model of care bears significant economic consequences and will become especially relevant to the chronically ill and the elderly, who are the heaviest users of healthcare services.

Pervasive healthcare—A multidisciplinary research agenda

Given this historically diverse background for pervasive healthcare, and the multidisciplinary nature of the research, it is not surprising that the field draws on research from a wide range of different professions. On the surface, "pervasive healthcare" is defined as the application of pervasive computing in healthcare. However, "pervasive computing" is itself not a well-defined computer science area but a multidisciplinary research agenda involving technological-oriented research on topics such as hardware, communications, embedded hardware and software, software infrastructures, sensor technology, distributed computing, CSCW, HCI, and sociological studies of the use of technology. Hence, pervasive computing is not something one simply buys and installs in a healthcare setting. Rather, it is a new kind of technology that has not yet been defined and that must be shaped according to the changing needs and challenges of healthcare. The creation of pervasive healthcare technologies and services involves a wide range of professions, including doctors with various specialties, nurses, caregivers, therapists, engineers, computer scientists, human factor professionals, industrial designers, and patients and citizens. As pointed out by a number of authors in this book, innovation in pervasive healthcare requires a community of dedicated researchers and practitioners to cooperate closely in the design, development, and evaluation of the technology while focusing closely on the users. Furthermore, pervasive healthcare applications represent only some of the dramatic changes currently taking place in the healthcare industry. To be effective, these innovations must go hand in hand with other system-level changes, including government policies, business processes, and reimbursement models.

As a result of its multidisciplinary nature, pervasive healthcare lies at the intersection of different research paradigms. There are fundamental differences between research methodologies employed in medicine, engineering, computer science, design, and ethnography. These disciplines have their roots in noncompatible philosophical traditions. Therefore, we cannot claim that pervasive healthcare subsumes to one particular scientific approach or methodology. This is most apparent in what we call the "fundamental methodological challenge" of pervasive healthcare.[3] Typical research in pervasive computing uses experimental computer science methods,[4] where researchers design, develop, program, and evaluate prototypes of a new technology. The original ubiquitous computing technologies created at Xerox PARC are an excellent example of this approach. The "proof of concept" is a term often used to denote a prototype, which illustrates and implements the important aspects of a computer system that one wants to demonstrate. Such an experimental approach becomes highly problematic when dealing with health-related research. Modern evidence-based medicine is rooted in statistical significance, in which one has to demonstrate with significant confidence that a treatment or cure works and that it has minimal side effects. This proof is generated through clinical trials, which often involve great numbers of human subjects with experimental and control groups. To set up such a clinical trial running over several months or years clearly takes much more than a proof-of-concept prototype. One must have the resources to design, develop, implement, and maintain a full-fledged computer system to be used by thousands of real-world users. Conducting such large trials presents a huge financial challenge, especially for researchers who are used to a more traditional computer science research. With this in mind, perhaps one methodological contribution of pervasive healthcare is developing alternative ways of bringing such healthcare technologies to market without the full rigor of traditional clinical trials. This is especially significant in light of the increasing acceptance of consumer-grade devices and the future importance of consumer-centric healthcare.

The book

This book provides an introduction and an overview of the new emerging field of pervasive computing in healthcare or, simply, pervasive healthcare. Drawing from the contributions of leading researchers in this field, we provide readers with in-depth discussions of relevant topics. This book offers the first known comprehensive resource on the application of pervasive computing to healthcare. It covers such broad topics as the current healthcare system and its challenges, core computer science approaches underlying pervasive healthcare, and leading research on specific software architectures and systems for pervasive healthcare, including how they can be applied within hospitals, homes, and public spaces. It also discusses a wide range of issues related to development and research methods in pervasive healthcare systems, including human factors, clinical trials, evidence-based medicine, and potential business models.

Chapter 1 provides an overview of healthcare, diseases, and disabilities. It begins with a discussion of shifting demographics and their impact on the healthcare system. Next, it describes in detail the current healthcare system in the United States. Specifically, it covers home- and community-based healthcare, outpatient care, hospitals, and assisted-care institutions. For each, the authors describe major challenges and how technologies have been and could be used to address these challenges. The chapter concludes with a call for large-scale, clinical trial-like studies of pervasive healthcare technologies to demonstrate their clinical efficacy and to accelerate their adoption by the healthcare system.

Chapter 2 introduces a number of key computer science principles underlying pervasive computing and its applications described in subsequent chapters. Pollack and Peintner provide a technical baseline to ensure that a wide range of readers can benefit from this book, including first-timers who have never been exposed to this area and those who are from computer science backgrounds. The chapter focuses on three core computer science topics within pervasive healthcare: (1) pervasive computing technologies, protocols, and devices; (2) essentials for creating intelligent applications, including machine learning and artificial intelligence techniques; and (3) privacy and security approaches and technologies for keeping sensitive patient health data private and secure. The chapter provides sufficient background to enable a reader to understand the remaining chapters in this book. Special emphasis is given to key computational trade-offs that typically arise in the design of pervasive healthcare systems. For example, these trade-offs include those between making a system easy to use and ensuring a high level of security; between collecting maximal sensor information and minimizing power use so that battery replacement is infrequent; and between having frequent updates of a highly detailed, fine-grained model of patient activity and having efficient, real-time computation.

Chapter 3 describes some key challenges in using computers in large, modern hospitals and how current software and hardware technology is evolving to meet these challenges. The chapter starts by discussing the core challenges in deploying contemporary computer technology designed for office use to a hospital setting. It then describes the current state of computer technology in hospitals, including electronic patient records (EPRs); picture, archiving, and communication systems (PACS); and intensive care unit (ICU) monitoring systems. Next, the chapter looks at several examples of present research in deploying pervasive computing technology in hospitals, including mobile computing, location- and context-aware computing, wireless communication, software infrastructures, support for cooperation and social awareness, and multimodal interaction with computers during a surgical operation. The chapter ends by discussing a core set of considerations in the design, development, and deployment of pervasive computer technology in hospitals.

Chapter 4 describes new pervasive technologies that can be used in the home and community for people with cognitive disabilities. It describes two possible avenues for assistance. The first is using an outdoor activity recognition system based through a global positioning system (GPS) to help people who make occasional cognitive errors recover safely. The second is an indoor activity recognition system based on a wearable computing platform and radio frequency identification (RFID) tags designed to monitor common activities in a home. In the outdoor case, the chapter demonstrates that such a system could successfully be built now. It also shows that, with a simple, intuitive user interface, such a system could serve as a valuable aid to those cognitively impaired. In the indoor case, the authors demonstrate that a single technology can subsume many previous activity recognition techniques in a way that is robust, easily deployable, and accurate at a fine level of granularity.

Chapter 5 identifies the main usage models and applications for mobile and personal health and wellness management and monitoring systems, often called mHealth applications. Advancements in sensor technology, wireless communications, and information technology in general give rise to new ways of providing healthcare and wellness or disease management that supports extended independent living at home and improvement of quality of life for individuals. The chapter examines personal disease or wellness management enabled by pervasive personal digital devices and their ubiquitous communication capabilities. These devices allow ubiquitous access to health information, flexible and time- and place-independent access to communications with health professionals or personal trainers, and support tools for personal health or wellness monitoring. The chapter focuses on the out-of-hospital use of mobile devices such as PDAs and mobile phones for disease or health management.

Chapter 6 describes sensors and wearable technologies for pervasive healthcare. It begins with a discussion of key challenges in healthcare and thus establishes the need for pervasive healthcare. It then describes the principal modules of a patient-centric pervasive healthcare system that addresses the typical user's requirements. Next, it discusses the role of sensors and wearable sensor systems for biomedical monitoring of patients with chronic ailments such as hypertension, cardiac disease, and diabetes. The authors establish the need for integrated multiparameter sensing and use the Smart Shirt as an example to illustrate the development of a fabric-based sensor network for pervasive healthcare. The chapter concludes with descriptions of the challenges and opportunities for research and development in pervasive healthcare.

Chapter 7 presents current research in assistive technologies. People with disabilities have long been early adopters of pervasive computing technologies. Smart homes and mobile computing devices help people compensate for physical, sensory, or cognitive limitations. This compensation provides increased educational, vocational, and recreational opportunities and improved quality of life. The chapter describes technologies for assisting people with different disabilities, including physical, sensory, communication, and cognitive impairments. The applications of pervasive computing, including mobile computing and smart environments, are described. The chapter looks at current state-of-the-art, ongoing research and the application of emerging technologies. It also examines the implications of pervasive computing technologies to the design of new assistive technologies. The chapter concludes with a description of a number of specific technologies for augmentative and alternative communication (AAC), including wheelchairs and walkers, wayfinding, reminder systems for taking medicine, and smart environments.

Chapter 8 addresses the challenges associated with human factors and the usability of healthcare systems. The chapter focuses on how pervasive computing can be integrated into healthcare practices so that users can maximize the benefits of new computing capabilities. Topics discussed include requirements engineering for new applications, the use of workflow studies in designing unobtrusive and effective system–user interactions, design and testing of pervasive applications in geriatrics, the application of usability engineering methods, and issues of user testing. A range of applications are used to illustrate human-centered methodological approaches in the design and evaluation of pervasive healthcare systems. Examples include a computerized patient record system that is integrated with a range of new pervasive applications, and the relation of pervasive computing to telemedicine applications, location awareness, the need for integrating standards, and usability considerations in mobile and Internet-based medical applications. The chapter also discusses the importance of an improved understanding and consideration of human cognition and communication modalities, including speech, handwriting, head-mounted displays, and combined approaches.

Chapter 9 presents methods for technology innovation in pervasive healthcare. This chapter introduces the requirements, recommendations, and routes for commercializing medical devices and gives pervasive healthcare researchers a basic understanding of how medical applications are assessed and regulated. First, the author defines the concept of health technology assessment, which serves as the framework within which the effectiveness and the value of a device are evaluated. Second, the regulations pertaining to medical devices are explained in some detail, including definitions, classifications, and processes for obtaining ethical and clinical approval, with examples from Europe and North America. Some newly proposed concepts in clinical trials are introduced that may, if adopted, be particularly suited to medical devices. Also covered in this chapter are deployment and data issues. The latter arises from the link between the predominantly independent worlds of devices and computer networks that are now coming together in pervasive healthcare. Third, the product design process for medical devices is described, concentrating on quality systems, standards, and recommendations for good practice in validation and human factors. Some of these recommendations are already finding their way into updated regulations in this rapidly changing field. The conclusion section reiterates the multidisciplinary role of the pervasive healthcare engineer and points to sources of additional information and advice.

Chapter 10 discusses user evaluations in pervasive healthcare with a special focus on real-world deployment and assessment of the technology. Central to the success of pervasive healthcare technologies is the end users' acceptance of the systems. Hence, methods for proper user evaluations and redesign during the development and design of a piece of technology are fundamental to pervasive healthcare. This applies both for concrete medico-technical equipment, like a new blood pressure monitor, as well as more overall systems and infrastructures, such as home monitoring. This chapter presents state-of-the-art methods and discusses some of the special requirements concerning medical technologies. The authors especially discuss methods for putting an evaluation in context in order to establish how the technology can work in a complex clinical or community-based environment.

Finally, Chapter 11 discusses the business aspects of pervasive healthcare. It describes potential business opportunities and implications of pervasive healthcare technologies, including remote patient monitoring, to key stakeholders involved. First, the authors provide an overview of the key enabling technologies, including consumer/sensing devices, wireless networks, analytic engines, decision support, and collaboration solutions. Second, the chapter presents the economic and business case for pervasive healthcare. Specifically, it describes how such technologies can be used to address the root causes of the current healthcare crisis by redefining care management to meet the critical needs of the chronically ill and the elderly population and by helping reduce emergency room visits and hospital stays. Third, the authors highlight a number of successful commercial pervasive healthcare applications in the marketplace and describe how these applications have demonstrated compelling business values to key healthcare stakeholders. The chapter concludes with a discussion about major challenges and barriers ahead in adopting pervasive healthcare technologies, including reimbursements, resistance among physicians and patients, standards, data security, and usability.

Pervasive healthcare is an exciting, emerging research area that is bound to play an important role in an increasingly aging society. By providing the first known book fully devoted to this field, we attempt to give our readers a holistic view by covering a variety of topics, including basics of healthcare and computing; examples of applications of pervasive and mobile healthcare in settings such as hospitals, communities, and homes; assistive technologies; human factors; evaluation methods; and business models. We also try hard to make this book appealing to readers with computer science or healthcare backgrounds. Given the broad scope of this field, the rapid rate of change in both technologies and healthcare, and the length constraint of this book, there are inevitably interesting and relevant topics that are missing here. Nevertheless, we believe that this book provides a solid foundation on which current and future researchers and practitioners can build and use to further their endeavors that will eventually make these technologies truly pervasive, especially to those who need them the most.

—Jakob E. Bardram, Alex Mihailidis, and Dadong Wan

References

1. Centers for Disease Control and Prevention. Chronic disease prevention. See www.cdc.gov/nccdphp/overview.htm.
2. Dishman, Eric. Inventing wellness systems for aging in place, *IEEE Computer* 37:5 (May 2004), 34–41.

3. Korhonen, Ilkka, and Bardram, Jakob E. Guest editorial introduction to the special section on pervasive healthcare, *IEEE Transactions on Information Technology in Biomedicine* 8:3 (September 2004), 229–234.
4. Weiser, Mark. The computer for the 21st century, *Scientific American* 265:3 (September 1991), 94–104.

Editors

Dr. Jakob E. Bardram is an associate professor in the Department of Computer Science of the University of Aarhus, Denmark, and is the manager of the Centre for Pervasive Healthcare in Denmark. Dr. Bardram's research interests include software architecture, pervasive computing, human–computer interaction, software engineering, and computer-supported cooperative work. He has focused specifically on the design and development of pervasive computing systems in healthcare, for both patients at home and staff working in hospitals. Dr. Bardram has more than fifty international publications and his work is done in close cooperation with industry and healthcare organizations.

Dr. Alex Mihailidis is an assistant professor in the Department of Occupational Science and Occupational Therapy at the University of Toronto with cross appointments in Biomedical Engineering and Computer Science. He has conducted research in the field of pervasive computing and intelligent systems in healthcare for the past eight years, and he has published or submitted over thirty publications. He has focused specifically on intelligent systems for elder care and wellness. He holds several major research grants from internationally recognized funding agencies and industrial partners to support this work, including from the Canadian and American Alzheimer Associations, Intel Corporation, Natural Sciences and Engineering Research Council of Canada (NSERC), and Canadian Institutes of Health Research (CIHR).

Dr. Dadong Wan is a senior researcher with Accenture Technology Labs, the research and development organization for Accenture. For the past ten years, Dr. Wan has investigated how emerging technologies, specifically ubiquitous computing, can be used to create new kinds of consumer experiences and business opportunities. He is the inventor of the Magic Medicine Cabinet, the world's first smart medicine cabinet that integrates face recognition, RFID, and health-monitoring devices to provide consumers with compliance support, vital sign monitoring, and personalized health information. Currently, his research focuses on patient-centered, connected healthcare using sensors, wireless networks, and service-oriented architecture. Dr. Wan's work is widely covered in the media, including by the *Wall Street Journal*, *Financial Times*, *Wired*, BBC, CNN, ABC News, and TechTV.

Contributors

Tim Adlam
Bath Institute of Medical Engineering
Bath, United Kingdom

Heribert Baldus, Ph.D.
Philips Research Laboratories
Aachen, Germany

Jakob E. Bardram, Ph.D.
University of Aarhus
Aarhus, Denmark

Elizabeth Borycki, Ph.D.
University of Victoria
Victoria, British Columbia, Canada

Michael P. Craven, Ph.D.
University of Nottingham
Nottingham, United Kingdom

Teresa Dunn
Bath Institute of Medical Engineering
Bath, United Kingdom

Jesus Favela, Ph.D.
Centro de Investigación Científica y de Educación Superior de Ensenada
Ensenada, Mexico

Dieter Fox, Ph.D.
University of Washington
Seattle, Washington, United States

Sundaresan Jayaraman, Ph.D.
Georgia Institute of Technology
Atlanta, Georgia, United States

Henry A. Kautz, Ph.D.
University of Washington
Seattle, Washington, United States

Jeffrey Kaye, M.D.
Oregon Health & Science University and Portland Veterans Affairs Medical Center
Portland, Oregon, United States

Ilkka Korhonen, Ph.D.
Technical Research Center of Finland
Tampere, Finland

Andre Kushniruk, Ph.D.
University of Victoria
Victoria, British Columbia, Canada

Lin Liao
Google Inc.
Kirkland, Washington, United States

Edmund LoPresti, Ph.D.
AT Sciences, LLC
Pittsburgh, Pennsylvania, United States

Elina Mattila, M.Sc.
Technical Research Center of Finland
Tampere, Finland

Alex Mihailidis, Ph.D., P.Eng.
University of Toronto
Toronto, Canada

Alan Newell, Ph.D.
University of Dundee
Dundee, Scotland

Roger Orpwood
Bath Institute of Medical Engineering
Bath, United Kingdom

Sungmee Park, M.Sc., M.F.A.
Georgia Institute of Technology
Atlanta, Georgia, United States

Donald J. Patterson, Ph.D.
University of California
Irvine, California, United States

Bart Peintner, Ph.D.
Artificial Intelligence Center, SRI International
Menlo Park, California, United States

Martha E. Pollack, Ph.D.
University of Michigan
Ann Arbor, Michigan, United States

Niilo Saranummi, Ph.D.
Technical Research Center of Finland
Tampere, Finland

Luis E. Taveras, Ph.D.
Accenture
Florham Park, New Jersey, United States

Dadong Wan, Ph.D.
Accenture Technology Labs
Chicago, Illinois, United States

Tracy Zitzelberger, M.P.H
Oregon Health & Science University
Portland, Oregon, United States

Contents

Section III: Design and development of pervasive healthcare technologies