Guest Editorial
Introduction to the Special Section on Pervasive Healthcare

Pervasive healthcare may be defined from two perspectives: first, as the application of pervasive computing—or ubiquitous computing, proactive computing, ambient intelligence—technologies for healthcare, health, and wellness management; second, as making healthcare available everywhere, anytime—pervasively. Essentially, pervasive healthcare addresses those technologies and concepts that integrate healthcare more seamlessly to our everyday life, wherever we are.

Weiser, the father of the ubiquitous computing, stated “the most profound technologies are those that disappear” [1]. 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 means of its three most important enabling technologies: ubiquitous computing, ubiquitous communication, and intelligent user-friendly interfaces.

Ubiquitous computing refers to the concepts like disappearing computer, “when they are everywhere,” and pervasive computing, and means integration of computing power (microprocessors) and sensing (sensors) into anything, including not only traditional computers, personal digital assistants (PDAs), printers, etc., but also everyday objects like white goods, toys, houses, furniture, or even paint (“smart dust”). Ubiquitous communication, in turn, means enabling anytime, anywhere communication of anything with anything else, not only people but also artifacts such as those listed above. Central technologies in ubiquitous communication are ad-hoc networking and wireless communication technologies—including low-power low-range communications. Intelligent user-friendly interfaces enable natural interaction and control of the environment by the human “users,” or inhabitants of the ambient environment. The interfaces support natural communication (speech, gestures), take into account user preferences, personality, and usage context, and enable multisensory interaction. The envisioned pervasive computing infrastructure, hence, provides a seamless environment of computing, networking, and user interfaces. The infrastructure is aware: It has senses and it has the required intelligence to interpret the sensory information—it is context-aware.

The advances in these technologies during the last decade have already changed our daily life in many ways. Today, we are ubiquitously connected to our friends, colleagues, and information sources with our cellular phones. Our digital cameras may print their pictures directly on a nearby printer. Our children’s toys include microprocessors and sensors, etc. In many ways, pervasive computing technology already plays a major role in people’s everyday life.

One of the most important application areas for pervasive technologies is healthcare, including support for independent living and wellness and disease management. For example, developments in sensor, and more generally, measurement technology, make it possible to obtain health-related information from wearable or embedded sensors also in out-patient conditions, in our daily life. Ubiquitous communication based on mobile telephone networks, (wireless) local area networks, and/or some other wireless technologies makes possible anywhere, anytime transfer and access of all kinds of information—including health-related information such as measurement data or medical knowledge. Mobile communication devices provide ubiquitous user interfaces for the users (from healthcare professionals to citizens). The possibilities this technology offers for healthcare delivery are vast and the realization process of the potential has only just begun.

Besides this kind of monitoring and transfer of biological data, pervasive healthcare also contains a notion of using pervasive computing—or ambient technology—for social computing, for example, creating technologies for relatives and peers of chronically ill persons to stay in touch with a patient. And pervasive healthcare also contains a notion of helping the patient or citizen to better manage his or her own disease, as well as pervasive computer technologies for communication and collaboration among healthcare professionals.

The application of pervasive computing technology for healthcare is, however, not without its own inherent challenges. “Pervasive computing technology” is in itself not a well-defined technology but more like a multidisciplinary research agenda involving technologically oriented research on things like hardware, communication technology, embedded hardware and software, software infrastructures, sensor technology, distributed computing, computer-supported cooperative work, human–computer interfaces, sociological studies of the use of technology, etc. Hence, pervasive technology is not some specific technology you simply buy and use in a healthcare setting, but rather a new kind of a holistic concept of integrated and embedded application of modern technology in everyday settings.

Shaping pervasive computing technology for the healthcare challenges has a momentum created by various converging demands and trends. The most important of these demands is the well-known healthcare cost crisis in developed countries created by an aging population, which is demanding ever more
health services, which, in turn, are getting not only more powerful but also more expensive. As stated by Dishman [2], one possibility to meet these demands is to move beyond mainframe healthcare, from managing illness to maintaining wellness. In this transformation, pervasive technologies will play a major role, as we need “to personalize and ‘consumerize’ health and wellness technologies—pushing them into the home, where real-time prevention, diagnosis, and treatment can occur” [2]. This paradigm change means technical application of consumer-operated interoperable generic technologies—pervasive computing technologies such as PDAs, mobile phones, home networks, etc.—for health and wellness, and in parallel with other applications like personal communications, entertainment, banking, home automation, etc. Organizationally, it requires a change from physician- (or caregiver) centric systems to individual-centric operational models, in which the individual becomes an active partner in the care process [3].

I. STATE-OF-THE-ART TECHNOLOGY IN PERVERSIVE HEALTHCARE

As pervasive healthcare, according to the definition above, is a very broad topic, it is not possible or even sensible to try to cover all the involved technologies or applications in this editorial or special section. However, in the following, we try to highlight some of the essential developments to give the reader some concrete ideas about what this is all about.

A. Enabling Technologies

The momentum for pervasive healthcare is to a large extent created by the development of several contributing enabling information and communication technologies (ICT) as well as some specific technologies related to the measuring and modeling of the human physiology. Here, some of these technologies with great potential impact are introduced.

The basic trends in ICT include the increase in processing power and communications bandwidth and the parallel decrease in the cost for both processing and communications—both in terms of hardware and power consumption. This is gradually making it both technically and economically feasible to integrate processing power to more simple and inexpensive devices and objects than before, and to make these devices also communicable. The consequences of these developments were already discussed above. It is obvious that these trends will continue. The PDAs and mobile handsets are gradually becoming powerful but also more expensive. As stated by Dishman [2], one possibility to meet these demands is to move beyond mainframe healthcare, from managing illness to maintaining wellness. In this transformation, pervasive technologies will play a major role, as we need “to personalize and ‘consumerize’ health and wellness technologies—pushing them into the home, where real-time prevention, diagnosis, and treatment can occur” [2]. This paradigm change means technical application of consumer-operated interoperable generic technologies—pervasive computing technologies such as PDAs, mobile phones, home networks, etc.—for health and wellness, and in parallel with other applications like personal communications, entertainment, banking, home automation, etc. Organizationally, it requires a change from physician- (or caregiver) centric systems to individual-centric operational models, in which the individual becomes an active partner in the care process [3].
patients—themselves, potentially but not necessarily in collaboration with their caregiver.

A typical application connects the patient suffering from some chronic condition such as asthma or diabetes mellitus with his/her caregiver (typically physician) on a more continuous manner by using some mobile technology and ambulatory monitoring devices, such as a glucometer. These kinds of applications have reached the required level of maturity to be used with real patients in daily clinical practices—also outcome studies exist (e.g., [8]). Currently, these applications are largely based on special devices, lack interoperability with other systems or devices, and may poorly fit to the differing organizational needs in different countries and institutions. Hence, the next developments will most likely address these challenges as well as the usability and reliability issues, which are of utmost importance while making these applications applicable for a widespread clientele.

There is support for independent living, or aging-in-place, targets for extending the possibilities of the elderly to stay at their homes despite their declining functional abilities and health. Pervasive technologies have a great potential here. Different assistive technologies, such as wheel chairs, walking aids, home automation, and remote controls, etc., have been used to support independent living for years—now these technologies are improved by adding automatic features and intelligence to them and by making them increasingly interoperable. This is close to smart-home technologies (see Section I-C). In addition, the homes may be equipped with sensors and alarm systems, which aim to provide mechanisms to call for help in case the user happens to need it. The term “telecare” is commonly used here, and in several countries (e.g., in the U.K.), the home-care and elderly-care system is in the process of being revised to utilize the potential of this technology more efficiently. An example of a state-of-the-art technology for independent living is the IST Vivago Wristcare [9]. It is an intelligent social alarm device, which consists of a wireless wrist-worn device with several sensors, a base station communication over telephone lines, and an alarm-receiving software, and includes both panic alarms, automatic alarms related to health, device usage and access control, and unobtrusive monitoring of wellness. This device is a good example of integration of several existing technologies into a pervasive health product successfully. In the coming years, the development should focus on developing dependable yet advanced integrated solutions to support independent care in the widely varying conditions where elderly people live currently. Dependability and an easy fit to varying needs is essential—otherwise, the technology will not be applied in real life.

C. Pervasive Technologies for Healthcare Professionals in Institutional Settings

The use of ICT in hospitals can be divided into two broad categories. On the one hand, computers are to a large extent pervasively used in medical equipment for the monitoring and diagnosis of patients. A wide range of specialized monitoring equipment for ECG, blood pressure, O$_2$, ultrasound, etc., exists, and some of these are wireless, thereby allowing the patient to walk freely without being tied to the bed. This kind of technology, however, is highly specialized for their specific medical purposes and seldom works together or plugs into a more general infrastructure in a hospital—hence, it may be barely considered to support Weiser’s vision of ubiquitous computing as quoted in the beginning of this editorial. On the other hand, standard computer technology is used extensively for administrative purposes as well as for electronic patient records (EPRs). However, personal computers (PCs) and their operating systems were designed and built for personal office use, and basically they fit poorly into the nomadic, interruptive, and collaborative work of clinicians in a hospital. Running an EPR application on a PC, tied to the desktop, conflicts with a working environment where nurses and doctors move around constantly, collaborate extensively, and do not even have their own desks. Wireless local area networks (LANs), PDAs, and TabletPCs are emerging in hospitals and these technologies help clinicians to use the technology while moving around. However, these technologies are mostly designed for office work as well, and as such, still leave much to be desired for clinical users. For example, PDAs and TabletPCs are still very personal and not suited for collaboration; they are not designed for a rugged environment with a lot of dirt, water, and disinfection liquids; and most clinicians complain that the PDA is too small in terms of screen size and processing power, and the TabletPC is too heavy and bulky to carry around, and is hard to use while talking to patients.

All these observations point the need to develop technologies which are designed to “move away from the desktop”—or in other words, create pervasive computing technologies for hospitals. Some of the original ideas and prototypes developed at PARC [1] were potentially better suited for more efficient support of clinical work in hospitals. For example, using public computers (rather than PCs) of all sizes (tab, pad, wall) is well suited for work in a hospital. And the further development of these original ideas into “cooperative buildings” [10], interactive spaces [11], and adaptive environments with multimodal interaction also contains potential for hospital usage. The notion of “context-awareness” is highly relevant in a hospital; during the day, clinicians face many patients, are engaged in many parallel activities, and talk to many different colleagues. Clinicians, hence, change work context at a fast pace, and making computer technology sensitive to the changing context of the user carries with it huge potential for improving the efficiency of using a computer for clinical work and decisions—and hence, for appropriate patient treatment. As a simple example, if the computer could be sensitive to the work context of a nurse handing out medicine, it would be able to help her see the right patient and the right medicine on her handheld computer. Furthermore, the computer might come with simple suggestions and be aware if an error in medication is occurring.

A few hospitals have experimented with location awareness of clinicians and critical resources, like mobile X-ray machines. However, so far there seems to be no context-aware application taking advantage of this location information beside research prototypes [12]–[14].

Outside hospitals, ICT or pervasive computing technologies currently play a minor role in institutions like nursing homes or

supported living facilities for the elderly. However, the situation is rapidly changing. For example, access control and tracking equipment are appearing to prevent people with Alzheimer’s Disease to wander off the institution’s premises. In fact, it is suggested that these institutional care facilities for elderly people are among the first adopters of pervasive computing technology. This occurs by equipping these facilities with “smart-home” technology, which can, e.g., automatically adjust heating, ventilation, air-conditioning, open and close windows, lock and unlock the doors, turn off the stove and other electrical appliances, monitor the well-being of the inhabitants, etc. An example of a nursing home which has taken up the use of pervasive computer technology is the Elite Care’s Oatfield Estates Cluster (Milwaukee, OR). This nursing home is equipped with location sensors, embedded weight sensors in the beds, computers in the departments, and personalized databases. The facility’s networked sensors let the staff identify residents who might need immediate care. Databases that monitor trends over time also reduce stress on staff members who must track the details of vital signs and medication status in delivering quality care. The environment includes actuators that can respond to the activities and whereabouts of residents, lighting the way to the bathroom if someone gets out of bed late at night and recording the period of wakefulness for the staff to interpret later [15].

II. CHALLENGES AND NEAR FUTURE

The use of pervasive computing for delivery of healthcare to citizens, however, raises numerous challenges. When dealing with personal, sensitive health-related aspects of a person’s life, this puts forth strong demands for systems that are reliable, scalable, secure, privacy-enhancing, usable, and configurable, among other things. At the same time, one has to consider that the average user for such systems is not the typical early adopter of new (pervasive) technology—on the contrary. This puts special focus on creating technologies that are very usable, and can adapt to, and seamlessly melt into, heterogeneous computing environments, like the home of the future.

Pervasive healthcare contains a fundamental methodological challenge. Typical research into pervasive computing uses methods of “experimental computer science” (to quote Weiser, again), where researchers design, develop, program, and evaluate prototypes of new technology. The various prototypes coming out of PARC are an excellent example of this method. The “proof-of-concept” is a term often used to denote a prototype, which illustrates and implements the important aspect of a computer system that one wants to demonstrate. Such an “experimental” approach becomes highly problematic when dealing with health-related research—what if the experiment falls out wrong? Modern evidence-based medicine, in contrast, is based on statistical significance—one has to demonstrate with significance that a treatment or cure actually works, and with limited and known side effects. The methods are also required to show their cost-efficiency and some improvement in the outcome—that they do make a difference. Collecting this kind of a proof requires setting up longitudinal clinical trials with a sufficiently great number of real subjects (e.g., patients) involving various test groups, including a control group. To set up such a clinical trial running over several months or years clearly takes much more than a “proof-of-concept” prototype. One has to have the resources to design, develop, implement, and maintain a full-fledged technological system, integrated to daily care delivery, used by thousands of users, both patients and health professionals. Addressing this fundamental challenge for collecting the evidence may be the toughest of challenges for the pervasive health technologies, and success clearly calls for multidisciplinary large-scale collaboration with technology developers, companies, health professionals, policy makers, and patient organizations. This methodological conflict is also evident in this special section. In fact, despite a high level of technological innovation and implementation, and promising early results, none of the papers present a technology that has been evaluated outside the laboratory in a real environment.

III. THE SPECIAL SECTION

This goal of this special section is to provide an introduction to the concept of pervasive healthcare and provide some examples of state-of-the-art research in the topic. As the topic is wide and covers a diversity of issues, the special section is also a representative, yet not complete, collection of reports about research in the domain of pervasive healthcare technologies. Some of the papers originate from the UbiHealth 2003 workshop (www.healthcare.pervasive.dk/ubicomp2003/) held in connection with UbiComp 2003 in Seattle, WA, in October 2003.

The special section starts with a position paper by Intille who provides a research agenda for pervasive health research. Taking an offset in Fogg’s concept of “persuasive technology” [16], he suggests using this idea of persuasive technology to motivate healthy aging. The healthcare systems in developed countries are experiencing severe financial stress as age demographics shift, leading to larger percentages of elder adults needing care. Intille suggests using technology, not only to cure sickness, but also to promote wellness throughout all stages of life. He argues that ubiquitous computing and context-aware algorithms offer a new healthcare opportunity: to exploit emerging consumer electronic devices to motivate healthy behavior as people age by presenting “just-in-time” information at points of decision making.

The next papers by Mihailidis et al., Jimison et al., and Adlam et al. concentrate on elderly care and support for independent living and aging-in-place.

The paper by Mihailidis et al. discusses the use of computer vision in the design of a sensing agent for an intelligent environment that assists older adults with dementia during an activity of daily living (ADL). The paper provides an overview of the techniques, which can be applied for detecting ADL, including vision-based systems and RFID technology. The paper presents a vision-based solution for the specific ADL example of handwashing, and presents preliminary trials completed using a new sensing agent. Even though the results are based on a relatively simple example of a vision-based sensing agent applied on only one ADL, the paper raises the possibility of using computer vision to develop intelligent environments to support aging-in-place.
Jimison et al. use unobtrusive monitoring of computer interactions during computer gaming to assess cognitive abilities in elderly users. As use of computers becomes more and more common among the elderly, this idea has a great potential for monitoring changes in cognitive performance over time, and hence, to enable early intervention. The results acquired by studying a small population of real users are encouraging.

Most of the papers in this special section are based on limited experiences with real users in real environments. When the next steps for evaluation of the technology in real life circumstances are taken the researchers will find the paper by Adlam et al. very useful. They present down-to-earth experiences and guidelines for running an evaluation study of pervasive technologies with demented users in their real homes. This paper nicely highlights some of the surprisingly simple but easily ignored challenges with field evaluation, especially with cognitively impaired evaluators.

A central feature with pervasive computing technologies is the application of natural or multimodal user interfaces, the design of which is challenging, especially for heterogeneous user groups such as the elderly. Perry et al. present in their paper a design process for designing multimodal user interfaces to support the independent living of older users. They present some design implications, which may appear useful for other researchers, too, while they design pervasive computing technologies for healthcare and special groups of users.

A good example of the diversity of pervasive health research is acquired while comparing the paper by Valdastri et al. to the papers above. This paper describes a microcontroller-based multichannel telemetry system, suitable for in vivo monitoring of physiological parameters. The device can digitize and transmit up to three analog signals coming from different sensors. The small overall size (less than 1 cm²), the power density compatible with current regulations for the design of implantable devices, and the dedicated packaging make the system suitable for in vivo monitoring in humans. The paper describes experiments that demonstrate the system’s capabilities to acquire a pressure signal from the gastric cavity of a pig and to transmit the signal to the external receiver. The telemetric module is intrinsically suitable to be connected to an implantable sensor network, thus producing a totally wireless pervasive in vivo monitoring system. Such in vivo sensors might be used in pervasive home care systems in the future.

The last two papers are related to application of pervasive technologies to support health professionals, or to better connect the patients with the health professionals. The paper by Favela et al. describes how the central pervasive computing concept of “context-awareness” can be integrated in traditional hospital information systems. The paper presents an agent-based software architecture for creating context-aware public displays in a hospital. These displays are aware of the presence of physicians and nurses in their vicinity and adapt to provide users with personalized relevant information. The software system and the design of the context-aware public displays are grounded in a workplace study of how clinicians use large public whiteboards in hospitals. The subsequent evaluation of the system, including the displays, provided preliminary evidence that the functionality offered would help address issues faced by hospital clinicians.

The paper by Wang et al., in turn, describes a web-based personal health information management system and especially its application for management of referrals. This system, evaluated with real users, describes how ICT (in this case web) may be used to better connect the patients with the health professionals and to give them more control of their care process. This is well in line with the above-suggested vision, in which healthcare becomes more consumer-operated and personalized.

We wish to thank all authors for their articles and work for this special section and the reviewers who, as usual, carry part of the burden without receiving any award. We hope this special section will contribute to the development of pervasive health technologies and give the readers some new ideas about the possibilities it offers, and about the challenges that need to be met.

ILKKA KORHONEN, Guest Editor VTT Information Technology Pervasive Health Technologies Tampere, Finland
JAKOB E. BARDRAM, Guest Editor University of Aarhus Centre for Pervasive Healthcare, Computer Science Department Århus, Denmark

REFERENCES


Ilkka Korhonen received the M.Sc. and Dr.Tech. degrees in digital signal processing from Tampere University of Technology, Tampere, Finland, in 1991 and 1998, respectively. He is currently working as a Research Professor for intuitive information technology and ubiquitous computing at the VTT Information Technology, Tampere, Finland. He is a Docent in Medical Informatics (with a specialty in biosignal processing) at the Ragnar Granit Institute, Tampere University of Technology. His main research interests include biosignal interpretation methods and pervasive healthcare technologies, and especially their application in critical care patient monitoring, wearable biomedical monitoring, and home health monitoring. He has published more than 50 original papers in international scientific journals and conference proceedings.

Jakob Bardram received the M.Sc. and Ph.D. degrees in computer science from the University of Aarhus, Denmark, in 1995 and 1998, respectively. He is currently a Research Associate Professor at the Department of Computer Science at the University of Aarhus. He is the Manager of the Danish Centre for Pervasive Healthcare (www.cfph.dk). His main research interests include software architectures for pervasive computing, distributed computing, object-oriented software development, and pervasive healthcare, especially within hospital settings. Before becoming an academic researcher, he worked as an IT architect for IBM Denmark.