From Computer Innovation to Human Integration: Current Trends and Challenges for Pervasive Health Technologies

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Abstract. This chapter starts with an overview of the technical innovations and societal transformation processes we have seen in the last decades and as well as the consequences those changes have for the design of pervasive healthcare systems. Based on this theoretical foundation, emerging design requirements and research challenges are outlined, which are crucial to be addressed when developing future health technologies.

Keywords: Pervasive Health, Ambient Assisted Living, E-Health, Trends, Research Challenges, Design Requirements.

1 Introduction

Identifying and understanding current trends and challenges for pervasive health technologies in the 21st century is a challenging endeavor (Necheles 1982; Webster 2002, Ziefle et al. 2011a). It requires the careful consideration of two major trends and their interplay. A first line of research addresses emerging technological innovations over time. Technology itself has made substantial progress and has undergone a fundamental change over the last decades in both the medical sector as well as the field of information and communication technology, which brings a variety of new possibilities to provide and deliver medical services (Leonhardt 2006; Kleinberger et al. 2007; Röcker et al. 2011). A second line of research addresses differences in the characteristics of target groups and user profiles (Arning and Ziefle, 2009; Wilkowska and Ziefle, 2011). Today, users of medical technology show completely different requirements than earlier users of these technologies did. The diversity of users who come into contact with medical and/or information and communication technologies is constantly increasing (Arning and Ziefle 2009; Mynatt and Rogers 2001). Hence, the adequate consideration of personal factors like gender or age as well as aspects of culture and ethnicity are key concepts for human-centered technology development (Alagöz et al. 2011; Gaul and Ziefle 2009; Meyer and Mollenkopf 2003).

At the same time, today's information and communication technologies touch a fragile cross-over point between surveillance and control on one side and support and personal benefit on the other (Lahlou 2008; Renn et al. 1992; Vlek and Stallen 1980). Especially in the context of medical technology, a sensible trade-off between benefits and empowerment of patients on the one hand and barriers and stigma on the other hand needs to be respected.

The potential of pervasive health technologies is connected to a multitude of possible benefits on different scales (Röcker 2011). They reach from societal benefits on a macro level, in terms of meeting existing shortcomings with regard to the care of elderly and providing universal access to medical technology, up to individual benefits on a micro level, in terms of independent living. However, there are also serious concerns regarding the violation of personal boundaries and comfort zones as well as issues of data security and privacy (Wilkowska and Ziefle 2012; Ziefle and Schaar 2011; Lahlou et al. 2005; Röcker and Feith 2009). As current medical technology is increasingly entering private spheres and literally crosses personal borders in case of invasive technologies, questions of 'control,' 'intimacy,' 'trust,' 'risk,' and 'reliability' are critical aspects to address (Renn and Swaton 1984; Alhakami and Slovic 1994). Also, societal attitudes towards frail and old people as well as constructive handling of the ageism problem are serious issues which need to be considered (Palmore 2001; Nelson 2004).

In addition to the negative and stigmatizing attitudes towards older persons in public perceptions of most societies (Iweins et al. 2013, Ziefle and Schaar 2014), older persons themselves regard a dependency on technology and the resulting perceived loss of autonomy and control as highly negative. This situation requires a profound change in the way the individual aspects are addressed and calls for more holistic concepts of balancing the various requirements that have to be met (John 2013; Sharma and Thomas 2013). Beyond the exclusive focus on the technological potential and feasibility of pervasive health services, the inclusion of human values, different usage contexts, and requirements of user diversity are key aspects for the successful development of pervasive health technologies (Allen 1987; Ziefle et al. 2009).

In the following, we first concentrate on the description of technical innovations and the way technology has changed over the years. In a second step, social and societal challenges are outlined. Bringing both lines together, the third part of this paper identifies future research challenges.

2 Technical Innovations

2.1 Intelligent Objects and Smart Environments

Over the past 50 years, we went through different phases of computing (see Shiode 2004). The years between 1960 and 1980 were characterized by mainframe computers that were primarily used by big companies, universities, and governmental organizations. With the emergences of smaller and more affordable computers in the 1980s, computing ushered into a new phase. Personal computers found their way into

many offices and were used as general-purpose tools for a variety of office activities (Röcker 2009b). The third wave of computing started with the wide-spread availability of mobile devices and increased networking capabilities around the turn of the century. This so-called ubiquitous computing era enabled computing anytime and anywhere (Röcker 2010a).

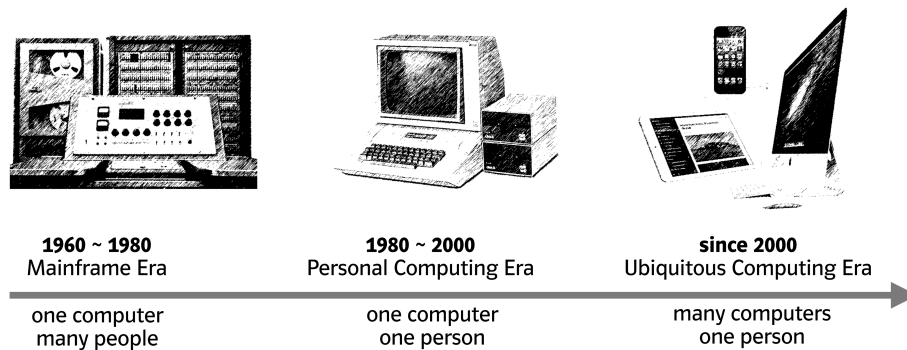|		
1960 ~ 1980 Mainframe Era	**1980 ~ 2000** Personal Computing Era	**since 2000** Ubiquitous Computing Era
one computer many people	one computer one person	many computers one person

Fig. 1 Phases of Computing.

During this time, we did not only see a tremendous increase in computing power, we also experienced a shift in the relationship between computers and users (Röcker 2010b). While early computing systems required an entire team of engineers and computer scientists to be operated and were jointly used by many people, this situation changed with the introduction of personal computing systems. This one-to-one relation between users and computers changed again with the emergence of mobile and embedded computers. Today, users interact with a multitude of computational devices throughout the day.

While this situation represents normality for many people, we are currently on our way towards a new era of intelligent, interconnected objects and smart environments in which more and more computers are embedded in our physical environment and unobtrusively support us in different areas of everyday life (see, for example, Streitz et al. 2005; Kasugai et al. 2010; Heidrich et al. 2011; Röcker and Etter 2007). In recent years, the term "Internet of Things" (IoT) is increasingly used to describe this vision. Especially in business literature, the original concept of ubiquitous or pervasive computing is often referred to as the Internet of Things. Projections about the growth of the IoT vary considerably. Estimates range from 15 billion (Intel 2009) to 25 billion (Evans 2011) interconnected devices in 2015, and from 50 billion (Evans 2011; Ericsson 2011) to 100 billion (IEEE 2013) in 2020. Nevertheless, there is little doubt that a world of networked devices will be the next big step. Some authors even argue that the "IoT represents the future of computing and communication" (Guo et al. 2011, p. 297).

2.2 Computing Moves to the Cloud

The Internet is often cited as one of the most influential developments of the last decades. Originally started as a project of the US defense department to enable the efficient usage of scarce computational resources in the late 1960s, the nature of the Internet changed significantly over the following decades (Röcker 2009a). While in the beginning access was restricted to a few research institutions, the wide-spread public usage of the Internet started in 1989 with the development of the World Wide Web (WWW), a global network of webpages. For the first time, the WWW enabled users to produce and consume content at the same time. However, its usage still required substantial computer knowledge. In 1993, this was fundamentally changed with the presentation of *Mosaic*, the first graphical web browser, which enabled easy access to web-based information. In the coming years, more and more companies and consumers discovered the Internet, which contributed to an immense increase in the number of users. While around 45 million people were using the Internet in 1997, the number of users increased to more than 1.8 billion in 2009. Today, over 2.7 billion people are using the Internet worldwide, and in the developed world even 78% of the households are connected to the Internet (ITU 2013).

The availability of broadband Internet lines and the introduction of flat-rate fees structures in the last decade contributed to a variety of new web-based services. Today, it is widely accepted that "cloud computing has emerged as a dominant paradigm" (IEEE 2013). Cloud computing does not only allow distributed computing over a multitude of connected computational devices, it also enables nearly unrestricted access to information for end users. Many cloud services are provided on a pay-per-use basis or are free of charge, reducing the costs for users and thereby lowering the entry barrier. Cloud computing also enables device independence as most services can be accessed via web frontends which means that only a web browser is necessary that can either run on a personal computer, tablet PC or mobile phone. In addition, applications and personal data are usually stored on a third-party server in the Internet which enables a location-independent use of services. Cloud-based services denoted a substantial increase in the number of users over the last years which was fueled by a steep drop in the costs for broadband connections. Worldwide, prices for fixed broadband decreased by 82% between 2008 and 2012 (ITU 2013). At the moment, an end of the cloud computing trend is not foreseeable. Instead, current estimates predict a further increase in cloud computing by 130% within the next two years (Smith 2013).

2.3 A World of Mobile Services

Besides cloud-based services, mobile computing is often regarded as the most important technological innovation of the last century (IEEE 2013). With currently 6.8 billion active mobile phone contracts, the number of subscriptions comes close to the world population of 7.1 billion people (ITU 2013). In its 2013 report, the International Telecommunication Union (ITU 2013, p. 6) announced that "mobile-broadband subscriptions have climbed from 268 million in 2007 to 2.1 billion in 2013" which "reflects an average annual growth rate of 40%, making mobile

broadband the most dynamic ICT market." And this trend is not restricted to mobile phones alone. Recent sales data show that mobile devices replace stationary computers in many areas. In the fourth quarter of 2012 – and less than three years after their introduction – global shipment of tablets PC surpassed the shipment of desktop computers and notebooks or the first time (Meeker and Wu 2013). With the widespread diffusion of mobile devices, it is highly likely that the usage of cloud services will further increase.

2.4 Collective Intelligence and User-Generated Content

The previous sections illustrated significant achievements in computer science which had a fundamental influence on our everyday life. However, not only technology was refined and advanced. The behavior of users and their attitude towards technology has undergone a significant process of change as well (Ziefle et al. 2011b). One of the most important changes of the last years is probably the increased willingness of users to generate web content. User-friendly webpages and new interaction concepts offer easy and intuitive ways of providing feedback and thereby contribute to a continuously increasing database. This independent collaboration in form of personal user feedback does not only increase the informational value of a specific webpage, it also contributes to the Internet as a whole: the more people contribute, the better the result. This effect is often referred to as collective or swarm intelligence. Group processes enable to accumulate knowledge in a way that goes far beyond what an individual would be able to achieve. A good example for such processes is open-source software. The collaboration of many independent programmers leads to sophisticated software, often on a par with commercial products. Open-source programs are written by dozens, sometimes even as many as thousands of individuals. None of these persons would have the ability to write the code on their own, neither from the technical programming skills required nor from the time that would be necessary to complete the code.
User-added value and collective intelligence are the founding principles of many Web 2.0 applications. This 'microwork' principle is the key to the success of most social media websites which would not be able to exist without the multitude of small contributions by a broad user base. Low technical entry barriers and high usability of most of today's websites are the basis for multi-party communication and the direct exchange of experiences and knowledge within communities.

2.5 Big Data and Knowledge Discovery

Biomedical sciences are becoming increasingly data intensive and require as well as advance new research strategies. Instead of following the classical research paradigm, i.e., to set the hypothesis first and then gain data from experiments designed to test this hypothesis, it is now the other way around. Consequently, data science is now established as the fourth paradigm in the investigation of nature (Hey et al. 2012), after theory, empiricism, and computation (Bell et al. 2009; Buxton et al. 2008). Data science is the study of the generalizable extraction of knowledge from data (Dhar

2013). The masses of unstructured information as well as dealing with large, complex, and often weakly structured data are often cited as mega challenges in biomedicine today (Holzinger et al. 2013). The increasingly large amount of data requires new, efficient, and user-friendly solutions for handling biomedical data. With growing expectations of end-users, traditional approaches to data interpretation often cannot handle the demands. Consequently, new computational and user-centered approaches are vital for coping with this rising flood of data (Holzinger 2013).

3 Societal Transformation Processes

In contrast to technical systems and devices of past centuries, technology usage is no longer restricted to single technical systems within the working context but increasingly enters all areas of daily life. In addition, more diverse user groups have access to these new technologies. Yet the development of technology still seems to be limited to the requirements and characteristics of young, technology literate males of the middle and upper class in Western societies (Tedre et al. 2006; Rogers 2009; Maguire and Osmann 2003; Ziefle and Jakobs 2010). It is therefore highly imperative that the development of pervasive health technologies adequately addresses both the specificity and diversity of users. This is not only a matter of considering cognitive and sensory abilities and/or restrictions of target users, but also includes issues of technology acceptance and human values in the context of technology usage which are considerably affected by age and gender as well as culture and ethnicity. These three aspects will be briefly illustrated in the following sections.

3.1 Age, Technology Generation, and the Demographic Change

As a consequence to the demographic change (Holzinger et al. 2010), more and older adults are confronted with a broad range of technology that they have to understand and use in different situations of everyday life. Up to now, interfaces are often designed without considering the abilities and needs of this user group (Maguire and Osman 2003; Ziefle and Jakobs 2010; Rogers 2009). Another blind spot of today's system design is user differences in technology education and experience (Ziefle 2002). Although technologies are supposed to be accessible to everyone, a gap between computer literate and less computer experienced users (predominantly older users) emerges. In this context, it should be kept in mind that older users differ considerably with regard to their needs, abilities, and competencies (Zimmer and Chapell 1999; Mynatt and Rogers 2001; Durndell and Zsolt 2002). This aggravates the situation especially for older adults, as the understanding of how technology works is mainly gained through upbringing and socio-cultural factors. Older adults were educated in times when technical devices were far less ubiquitous and complex (Ziefle and Bay 2005). In order to address elderly users as a growing consumer group, age-sensitive interface designs are needed (Arning and Ziefle 2009).

3.2 The Impact of Gender

While there is a considerable number of studies addressing gender differences in the interaction with information and communication devices (Venkatesh and Morris 2000), comparably few studies addressed gender differences in the field of acceptance of medical technology (Ziefle and Schaar 2011). However, especially gender seems to have specific importance for the acceptance of pervasive medical technologies. Research has shown that women report lower levels of computer-related self-efficacy and higher computer anxiety (Adam 2000; Busch 1995; Gefen and Straub 1999) as well as a lower perceived technical confidence when using technical devices (Wilkowska et al. 2010). As a consequence, more negative attitudes of women towards technology reduce the probability of active interaction and lead to a generally lower computer-expertise (Rodger and Pendhakar 2004). The lower technology aptitude and/or affection in general could also negatively bias the acceptance of medical technologies. In addition, there are gender-specific body-related attitudes that should be considered. Women have different standards of morality and ethics in comparison to males (Kreie and Cronau 1998), especially in combination with expected physical harm (Feingold and Mazella 1998; Keogh and Mansoor 2001; Miller et al. 1988). This could also have an influence on women's evaluation of pervasive medical technologies and, in turn, modulate the acceptance attitudes. Furthermore, it was found that women have different health-related cognitions, connected to higher vulnerability perceptions towards feelings of physical threat (Schwarzer 1994; Billings and Moos 1981). Additionally, the degree of risk-taking behaviors turned out to be gendered. Men have a higher risk threshold and take higher risks than women (Vaughan 1993; Ziefle and Schaar 2011). Finally, the acceptance of invasive medical technology is of specific interest, given the gendered nature of the nursing profession which is associated with the traditional female role of caring for and nurturing others (Wilson 2002). As women have a higher life expectancy, an increasing number of female seniors will be a major target group of pervasive health technology. Consequently, gender should be taken serious as a key factor of technology acceptance in the medical sector.

3.3 Ethnicity and Culture

A clear shortcoming of current research in the field of pervasive health is the discussion of interaction between technology, society, and culture. The claim for "universal access" and overcoming of the "digital divide" is related to political systems, socio-economic standards, and legal frameworks. Even today, there is a striking lack of knowledge of how society and culture affect technology acceptance and the underlying reasons for or against technology usage (Straub et al. 1997, 2002). Comparably few studies have been concerned with the investigation of technology acceptance across national boundaries (Alagöz et al. 2010; Teo et al. 2008; Arenas-Gaitána et al. 2011; Srite et al. 2006; Röcker et al. 2005). It is highly probable that the knowledge about technology acceptance and its underlying framing conditions referring to highly developed western countries do not hold for other cultures and

ethnical groups. Cultural beliefs, habits, and values form a cultural mental model (Hofstede 1980) and impact the willingness to adopt and use medical pervasive technologies in different ways (Leidner et al. 2006; Straub et al. 1997; Kedia et al. 1988; Choon 2005).

Technology is never used in isolation but within a social and cultural context. Social taboos, legal and political constraints as well as ethical, social, and religious traditions and habits differ across cultures. These contextual factors influence how humans interact with technology (Ziefle and Jakobs 2010) as well as how they evaluate the usefulness and the need of a technology (Alagöz et al. 2011; Campiniha-Bacote 2002; Pai and Huang 2011; Wilkowska et al. 2012; Röcker 2010c).

Thus, users around the world do differ in perceptions, cognitions, and the individual styles of thinking, cultural assumptions, and values (Ingelhart et al. 2000). This especially applies to the developing world and countries with underdeveloped societal and economic standards. But it also applies to those countries that experienced a very fast technological change over the last years, strive for economic welfare, and that are keen on closing the technological gap to highly developed countries (Anandarajan et al. 2000, 2002). Whether pervasive health technology is accepted in different cultures also depends largely on cultural mindsets of family care, as well as on cultural ageing concepts (Wilkowska and Ziefle 2011). Last but not least, the openness to adopt pervasive technology also relies on societal frames and healthcare structures (Campiniha-Bacote 2002), which might imply a different form of social and societal responsibility of others. In addition, the cultural handling of illness and the acceptance of end of life decisions are highly culturally sensitive (Klessig 1992; Searight et al. 2005; Berger 1998).

4 Resulting Research Challenges

The changes illustrated above lead to a variety of new research challenges of technical as well as non-technical nature. Some of the most important ones are addressed in the following sections.

One of the mayor technical research problems refers to the meaningful visualization of the vast amount of medical data that is collected and stored in pervasive health systems. In general, biomedical data models are characterized by significant complexity (Akil et al. 2011; Holzinger 2012a). This makes manual analysis by end users often impossible. At the same time, experts are able to solve complicated problems almost intuitively (Polanyi 1974), often enabling medical doctors to make diagnoses with high precision without being able to describe the exact rules or processes used during their diagnosis, analysis, and problem solving (Popper 1996). Consequently, it is a grand challenge to work towards enabling effective human control over powerful machine intelligence by integrating machine learning methods and visual analytics, and thereby supporting human insight and decision making (Holzinger 2011a). While *Human-Computer Interaction* (HCI) deals mainly with aspects of human perception, cognition, intelligence, sense-making, and most of all the interaction between human and machine, *Knowledge Discovery and Data Mining* (KDD) deals primarily with aspects of machine intelligence, in particular with the

development of algorithms for automatic data mining. Both disciplines have large areas of unexplored and complementary subfields. Consequently, possible solutions to many current problems in data intensive systems may be found at the intersection of HCI and KDD. One very promising approach is to combine HCI and KDD in order to enhance human intelligence with computational intelligence (Holzinger 2012b) and enable end users to find and recognize previously unknown yet potentially useful and usable information.

Further technical challenges include solutions for unobtrusive and ethically acceptable patient monitoring (Waltisberg et al. 2014), new forms of patient-centered interaction devices (Lightbody et al. 2014) as well as approaches for efficiently integrating such devices into a shared environment (Turner 2014). However, current research challenges are not restricted to the technical domain alone, but they also include more general questions and conceptual design decisions like viable solutions for integrating hospital and home care (Seo et al. 2014; Grönvall and Lundberg 2014), new concepts for independent rehabilitation (Bongers et al. 2014) as well as ways of providing universal access to such solutions (Böcker and Schneider 2014).

However, when addressing these challenges, it is important to also adapt the resulting systems and applications to the dynamically changing needs of a diverse and culturally biased user population. Against the background of user diversity, there are a number of reasons that the acceptance of medical technology distinctly differs from acceptance patterns of other technologies. First, medical devices are used for critical health conditions and essential usage, instead of only for communication and entertainment purposes as is the case for most modern information and communication technologies (Arning et al. 2010). Second, beyond the importance of patient safety, medical technology refers to "taboo related" areas that are associated with disease and illness (Wikowksa et al. 2010; Ziefle and Schaar 2011; Malinowski et al. 1996). Third, medical technology touches serious personal and vital issues. As a consequence, medical monitoring is often perceived as intruding into private spheres and violating individual intimacy, thereby provoking feelings of being permanently controlled (Lahlou 2008; Ziefle and Röcker 2010). The acceptance of medical technology is a consequence of balancing the envisioned benefits against the perceived concerns in a dynamic process, influenced and shaped by a variety of individual and situational aspects (Arning et al. 2013). Consequently, design approaches have to undergo a radical change by taking current societal trends into account (Ziefle and Röcker, 2011). User diversity, in terms of age, gender, social, and cultural factors, has to be systematically integrated into the development process in order to provide human-centered pervasive health technologies that truly meet the diverse requirements of their users. Studies show that older users face difficulties in learning and using new computer applications and have higher demands for usable interface designs (Rodger and Pendakhar 2004; Ellis and Alliare 1999; Himmel et al. 2013). Whenever interfaces are designed with the abilities of older users in mind (meeting the age-related decrease in sensory, motor, and cognitive abilities over the life span), the interaction of older users with technology is considerably improved and even able to match the performance of younger adults. Age-sensitive interaction concepts allow users with different ability levels to successfully interact with new technical applications. Consequently, only the integration of technical, personal, and societal requirements (Jacobs et al. 2014) can lead to truly personalized (Stokes 2014;

Caporusso et al. 2014), age-sensitive (D'Angelo et al. 2014), and context-aware designs (Alnaniha et al. 2014; Jiménez García et al. 2014).

5 Conclusion

A systematic inclusion of human perspectives into technical development is a crucial challenge for the design of future healthcare applications. Even though the idea of user-centered design has been formulated a long time ago, the development focus of technical products and services is still predominately on technical, economic and legal aspects. Especially in the field of medical services in which technical innovations led to numerous novel applications in the last years, it is of high importance to consider the requirements and the needs of patients - and in particular elderly and frail persons - in early phases of the design process. In this context, user acceptance is a delicate good which can be supported by integrating the intended users into the technical design process.

Only if needs, values, and individual usage habits are included into technology development, humane and human technology designs may result. Higher acceptance can be achieved by a conceptual device design that includes usability aspects and human values from the very beginning. In this way, a medical device can turn into something that patients are proud to wear or to possess, even for persons who have to cope with illness.

Consequently, the huge potential of pervasive health technologies in terms of daily support and medical care of the increasing number of seniors can only be leveraged if current technology design follows the demands raised by the need of incorporating human needs and values into its design development. This includes aspects of user diversity like age, gender, upbringing, culture and technology generation, but it also contains usage requirements arising from different application contexts. As such, addressing the fragile trade-off between the potential benefits of pervasive healthcare applications (ubiquitous support, reachability and universal access) and possible pitfalls (disregard of human values, violation of privacy and security) is of utmost importance.

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