

Evaluation Metrics for Living Environments Defined by Mutual Symbiotic Human-Machine Relationships

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Abstract

Sensor networks and information appliances can be deployed to create intelligent environments that enable symbiotic relationships characterized by varying degrees of co-operation, support, and dependence between humans and machines. Intelligent environments are likely to be most effective given conditions of mixed human-computer initiative with adjustable autonomy to facilitate an effective “collaboratorium” for living. The present study reviews various industry and academic research efforts directed towards intelligent assistive designs for living. Analysis focuses on the “state-of-the-art” in deploying intelligent environments to support independent lifestyles for individuals who require assistance with daily living activities due to intrinsic, age-related, or injury-related cognitive and/or physical impairments. Evaluation methods are suggested for defining usability, effectiveness, and safety measures for the assistive functionalities present in complex ubiquitous living environments.

1. Introduction

Home appliances and vehicles that are considered “intelligent” or “smart” in some way pervade our lives. However, self-adjusting heating and cooling systems, washing machines that stop when the load is unbalanced, networked home computer and entertainment systems, and automobiles equipped with electronic stability control, GPS, and automatic crash notification are sensor-based affordances that function separately from one another and under pre-defined sets of circumstances. There is a fast-growing need for more comprehensive assistance with everyday living activities due to the aging of large segments of the population. While individuals having cognitive or physical impairments have always

needed various types of assistance with everyday activities, it has only recently become apparent that we are nearing the critical mass necessary to encourage development and deployment of more inclusive computer-aided supports for everyday living activities. Changing demographics are driving a growing need for in-home assistance with the tasks of everyday life and have motivated several research efforts directed towards sociotechnical solutions.

For purposes of the following discussion, an environment is considered “intelligent” if it is characterized by interactive agent-based synthesis of (a) continuous indicative information collected in real time from networks of sensors distributed throughout a living environment and (b) indiscriminate idiosyncratic information generated during human interaction with mobile appliances. This type of environment is a complex system managed by intelligent software agents. It is an environment that facilitates symbiotic relationships between humans and machines that are distinguished by varying degrees of co-operation, support, and dependence. Deployment of an intelligent environment that provides ambient support for mixed human-computer initiative with adjustable autonomy effectively creates a “collaboratorium” for living. We describe several recent “smart home” endeavors, comparing their effectiveness in view of their design intent. Our focus is on use of these technologies to support independent living for individuals who require various kinds and degrees of assistance with daily living activities due to cognitive or physical impairments. We suggest evaluation methods that begin to define usability, effectiveness, and safety measures for the assistive functionalities present in complex ubiquitous living environments.

The motivation for this paper is to investigate where developing technologies and human cognitive and physical needs converge in order to define the

extent to which human-machine cooperation is feasible. We can accomplish this goal by comparing a number of experimental assistive living environments designed to provide independent living support for individuals who require assistance with daily living activities due to cognitive or physical impairments. Evaluation of experimental systems through comparison of features, deployment, and outcomes suggests basic measures of usability, effectiveness, user satisfaction, and safety of sensor-based communication, health monitoring, decision-support and other functionalities characteristic of human-, sensor- and intelligent agent-driven ubiquitous environments.

The following discussion is organized to first review the meaning of “symbiosis” and how mutually beneficial symbiotic relationships can be seen to exist between humans and machines. After discussion of the concept of living environments having “intelligence” based on use of embedded sensors and interactive information appliances, potential uses of assistive environments is considered in terms of the elderly user and the disabled user. Then, an example of a comprehensive experimental environment is contrasted with a very simple potential solution for memory loss. Mention of these efforts is complemented by an example of an unusual large multi-media database solution. A list of some of the academic and industry research efforts that have been done and are still underway is given. Finally, we suggest metrics that might be used to evaluate the effectiveness of sensor-based activity monitoring, information exchange, decision-support, and situation awareness characteristics of human-, sensor- and agent-driven intelligent living environments.

2. Symbiosis

In biological or ecological terms, “symbiosis” describes the relationships among organisms and the environments they inhabit. Related terms that define the nature of a symbiotic relationship more narrowly include “mutualism” (both species benefit), “commensalism” (one species benefits and the other is unaffected), “amensalism” (one species is unaffected while the other is harmed), “parasitism” (one benefits while the other is harmed), “competition” (neither benefits), and “neutralism” (neither is affected) [2]. These descriptions of relationships between dissimilar organisms living together in natural systems can also be used to describe potential outcomes in the case of humans living and working in “intelligent,” “smart,” or “ubiquitous” environments.

The nature of the symbiosis may be commensal, or one-sided, where the human derives benefits from the use of a computer system. An elderly person living alone may relay sensor information containing vital health signs to a computer system for diagnosis to see whether or not he or she should consider scheduling a visit to the doctor. If the individual is homebound, interaction with the computer can take on the characteristics of a more co-operative and supportive relationship if the patient has access to a patient-centric portal that allows real-time or asynchronous interaction with caregivers. Alternatively, these health signs may be sent directly to the individual’s healthcare provider to be read, diagnosed, and returned to the individual with a prescription for medication or for a change in activity levels. This interaction enables better healthcare for the individual and lessen scheduling and staffing problems for the provider. While the sensor-machine system here is providing communicative and operational support for the “patient” as well as for the caregiver, the relationship between the human and the machine is balanced in favor of the human.

However, these same interactions constitute a mutual and collaborative symbiotic relationship if sensor data based on this same patient’s daily activity, communication, and performance patterns is digested by intelligent agent components of the computer system designed to learn normal behavior patterns as a basis for ongoing determination of whether or not the individual’s activity fall within a given range determined to be “normal.” For example, the system’s receiving sensors might gather information from multiple transmitting sensors placed about the individual’s residence to monitor the individual’s activities. The system may issue a call for help to an outside agency should there be indication that the individual is more or less active at a given time of day. The human-system interaction then becomes one of co-operation and mutual dependence. The machine benefits by learning the individual’s patterns so that it can perform its function more effectively. The individual benefits by receiving the assurance that, should he or she fall and be unable to get up, the system will automatically issue a call for help.

The potential benefits of ostensibly “symbiotic” relationships between humans and machines have been the subject of serious thought for more than half a century [3]. It has been conceded that “Man-computer symbiosis is probably not the ultimate paradigm for complex technological systems” [4] and that the development of fluid interdependence between humans and computers lies in the future. However, we are in agreement with the view of technologies as assistive supports for humans that

complement human capabilities [5]. We consider the ideal relationship between human and computer as being a form of mutualism where benefits emerge from the relationship that accrue to both human and machine. Such a living environment is characterized by mixed human-computer initiative with adjustable autonomy.

3. Assistive living environments

Sensor technology has been used in industry to gauge the effectiveness of manufacturing processes, in the transportation industry to monitor performance of various means of conveyance, in medicine and in management of ecological systems to capture data on the spread of contaminants. These are only a few of many possible examples. While a defective fuel tank sensor recently delayed the launch of the space shuttle, Discovery [1], sensors provide valuable physical state and process information that cannot easily be gathered as effectively or as economically in any other way. Increasingly, discrete sensors and embedded networks of sensors have enabled the design and development of intelligent environments for living and working.

Specific uses of sensors, often in combination with small mobile appliances, enable a symbiotic relationship between man and machine. When combined with PDAs, smart telephones, sensor-laden clothing (as well as furniture, flooring, cupboard doors, etc.), wearable data collection devices such as active RFID tags, and a multitude of devices that can monitor and transmit vital signs wirelessly either constantly or on demand, the sensed environment becomes a kind of “collaboratorium” where the human is taken care of by the environment. Motivated to a large extent by the aging of a large part of our population, several research efforts have been directed at developing and testing such environments. These efforts have met with a fair amount of success. However, the creation of personalized living environments needs to account for a multitude of individual differences and a multitude of human conditions ranging from various forms of dementia that require intervention and help in conduct of daily functions (as well as cognitive therapy) to the presence of a variety of physical challenges and the occurrence of accidents. The goal is to make independent living not only feasible, but also comfortable and productive.

The fusion of data gathered from networks of sensors distributed throughout living and working environments and from personal information appliances will change the nature of interaction

between humans and computers. Ideally, “intelligent” environments will be designed to exhibit persistent “awareness” of human presence, needs, and activity. At the same time, the presence of the “machine,” due to its ambient form, will be less apparent to the human. As the machine becomes less visible [6], it will also become less dependent upon active human intervention. Human cognitive load may be reduced. Human cognition may be augmented. Depending on the purpose of the environment and the needs of the occupant of the intelligent space, assistance may occur more or less obtrusively and given varying degrees of human initiative and control. At the same time, many everyday needs that require physical activity can be assisted through human-invoked and autonomous robotic processes. Human-machine symbiotic activity greatly increases the tangible benefits that humans derive from computers. Extending the length of time individuals can live in their own homes with minimal assistance from formal healthcare systems greatly reduces the societal costs of aging and disability. Improved quality of life is achieved for those in need of assistance. The value of the services available from a reduced pool of skilled caregivers is maximized.

3.1. Aging populations

As a population ages, the need for devoting additional resources to monitoring health and activity levels increases. Individual differences aside, there are many commonalities among the everyday needs of older people. This means that much of the design of an intelligent environment can be replicated. Common among many elders are the needs to remember to: take medications at specific times, eat properly, exercise, make and keep appointments, and maintain contact with relatives and caregivers who need to be informed of their daily status and well-being. In many cases, elders who live on their own are unable to drive due to vision problems, cognitive deficits manifested as inability to maintain focused attention or short-term memory loss. These conditions may be exacerbated by arthritic or other physical conditions. As a result, they may need help with procuring and preparing food or getting to and from doctor appointments.

Falls are very common among the elderly. The ability to remotely sense a fall-prone context and alert the individual to prevent the fall and to detect that a person has fallen and needs assistance is critical for those who live alone. Sensors that can help detect such incidents are described further in the following section.

3.2. Disabled populations

Disabled populations also need to have additional resources devoted to monitoring their health and activity levels. In many cases these needs are permanent. In other cases, rehabilitation will ultimately be successful despite a lengthy period of intensive care and frequent monitoring of progress. While numerous reasons for cognitive and physical disability exist, the examples discussed here will focus on the array of challenges faced by many post-deployment military personnel. This is a representative population that covers a large number of possible everyday living needs.

Significant numbers of warfighters returning from active engagement require extended healthcare in the years following their deployment, with major factors that include diseases of the musculoskeletal, digestive, and nervous systems; mental disorders; disabilities due to a variety of orthopedic conditions; spinal cord injuries; partial or total blindness; amputations; and posttraumatic stress disorder (PTSD) [20, 21]. The war in Iraq, for example, is producing “a group of young combat veterans who face a lifelong struggle to cope with physical wounds so severe, they might not have lived through previous conflicts” [22]. Improvements in helmet design and protective body armor, in conjunction with better battlefield medicine have saved the lives of combatants, who now face longterm rehabilitation. However, physical injury caused by near proximity to explosions from car bombs and booby-traps has taken the form of a proportionately higher percentage of loss of multiple limbs and significant brain trauma injuries due to exposure to loud sounds and percussive damage than in earlier combat situations [27]. Beyond immediate disabilities and potentially lingering infections such as leishmaniasis recidivans [23], veterans leaving active duty face potential accumulation of additional diseases and problems resulting from stress, lack of mobility, and from disruption of their relationships with family and friends.

The healthcare industry has been moving toward outpatient care. This places a greater burden on the individual patient, requiring him to recognize important symptoms, contact the appropriate providers, make appointments, arrange transportation, etc. This affords more flexibility than hospital-bound recovery, but it also provides greater opportunities for serious health conditions to emerge undetected.

Sensors for individualized healthcare include those that monitor heartbeat and blood oxygenation [24], blood-pressure [25], and respiratory status [26]. Presently, these sensors may use different physical

devices as well as different control and communication protocols and can vary widely in accuracy and reliability. These problems need to be standardized before they can become part of remote health monitoring systems.

Sensor technology has been deployed in a number of commercially available prosthetic devices. The new synthetic limbs are wearable robotics that make a normal gait possible for individuals who have lost limbs. A sensor attached to the individual’s sound leg sends radio signals to a module inside the prosthesis, which interprets the amputee’s intention, and then the leg, powered by a small motor inside the knee, moves accordingly,” which affords the patient a “wider range of movement” and “also reduces fatigue, friction and back pain” [28, 29]. This “motorized prosthetic limb system for transfemoral amputees” is representative of a new generation of prostheses termed “anthropomorphic limbs” [30]. Another new affordance is the prosthetic ankle. This artificial foot, which will be available commercially in about two years, is currently customized to match the user’s walking style, but will ultimately use sensors to learn the patient’s gait and respond to changes in terrain. “The system uses several sensors again with the artificial intelligence system to be constantly thinking and analyzing the patient’s walking just like the person’s brain” [31].

Fall detection is another area where sensors can help. One research group has applied machine learning techniques to sensor data collected using two-axis accelerometers [33]. A wireless radio is used to send sensor information to a data collection center. Falls are detected using hidden Markov models to classify whether an event variance might indicate that a fall has occurred. This has met with mixed success in distinguishing a fall from similar actions. Other studies have had more success in recognizing activity type within a given context using a triaxial accelerometer sensor [34, 37]. A device potentially useful for preventing falls in the case of blind patients is a cane fitted with ultrasonic sensors that use sensed data to create a rudimentary map of the walking user’s immediate surroundings. Wheels on the cane-tip then “steer” the user around objects that are in the way [35].

3.3. Degrees of monitoring

A number of sensor-laden living environments are in actual or experimental use. Sensor networks installed in the home can be embedded in furniture and clothing, worn on the body, and serve as motion detectors to capture normal activity and detect unusual activity patterns [32]. “Smart Home” studies

are also under way. The home may be a laboratory environment where integrated data captured by infrared sensors, biosensors, computers, video cameras, and other devices are used to create a holistically safe and functional environment for disabled and elderly occupants [36]. Other “Smart Home” researchers, considering enabling comprehensive ubiquitous computing using sensor technology, are engaged in creating proactive systems that anticipate everyday human needs specifically with an eye to creating an improved quality of life for healthy elders as well as for caregivers and patients suffering from dementia of various kinds [38, 39].

A major challenge of any monitoring system is to provide sufficient monitoring to detect health-threatening events or trends while remaining unobtrusive and supportive of mobility and privacy. The system must allow end-users to choose the levels of sensitivity, oversight, and communication with which they are comfortable, and must provide the best possible performance within the bounds and policies chosen explicitly by the patient.

Any such system will require a great deal of flexibility to manage a variety of direct and indirect users at varied levels of health-care organizations and to achieve the goal of exploiting both local and wide-area connectivity resources to provide timely and accurate assessments and recommended courses of treatment. A distributed, decentralized approach is needed to support rapid, automatic (re)configuration, arms-length interaction with up-stream information systems, autonomous sensing and reasoning, and a cascade of automatic and human-in-the-loop services. The system must be able to provide fast, well-reasoned analyses, while permitting a cascade of the best available health care experts to provide oversight where the complexity of the case, timeframe, and level of connectivity support such an interaction.

4. Experiments in assistance

4.1. Ubiquitous environments

Environments enhanced with sensors for detection of movement, touch, and sound, monitored by video systems, and inhabited by researchers outfitted with various forms of wearable computing devices and handheld “information appliances” [8, 6] have been established over the last ten years as laboratories for experiments in assisted living. Much of this work was inspired by the research on what was termed “ubiquitous” or “pervasive” computing at Xerox PARC in the late 1980s. The environmentally embedded invisible computer was seen as the 21st

Century’s replacement for the confined, task-specific desktop computer that had proliferated throughout work spaces and began to enter living environments at the very end of the last century [7]. Some of the described environments are supported by industry and others by academic institutions.

The “Aware Home” is an academically-based, industry-supported research project that began as a “Residential Laboratory” managed by the Broadband Institute at the Georgia Institute of Technology [10]. Among the goals for this project is the extension of human-computer symbiosis to support time awareness and pacing of daily activities [11]. The work on pacing has been extended to managing the relationship between user-centered and system-centered design elements of environmental support for cognitively-impaired individuals, specifically focused on those who experience memory impairment and attention deficits due to traumatic brain injury [12]. As discussed in Section 3.2, significant brain trauma injuries are among the most frequent injuries found in today’s post-deployment warfighters. While there are a number of other research initiatives under way, time and space do not permit complete review at this time. However, it should be noted that intelligent living environments and robotic supports are also being tested at a number of universities (e.g., Carnegie-Mellon University, MIT, Linköping University in Sweden, the University of Massachusetts, the University of Hawaii, the University of Texas at Arlington) as well as by corporations such as Microsoft, Intel, and Honeywell.

4.2. Less comprehensive efforts

Other research has focused on specific facets of a comprehensive living environment (e.g., coordination of resources [19]) or on complementary intelligent artifacts that may or may not fit into what might constitute a “typical” assisted living environment. An intelligent thermostat might infer user intent from patterns based on a variety of factors such as time of day, current room temperature versus user-preferred temperature, and whether or not the room is currently occupied [9]. A video augmentation of a standard medical apparatus for analysis of a digestive disorder provided supplementary information that made the need for surgery unnecessary [14]. Work is continuing on development of an information appliance to assist Alzheimer’s patients and their caregivers with reduction of repetitive questioning behavior [15].

Providing assistance for memory deficits due to cognitive aging has been approached from a minimalist perspective by Matthew Sharps [40]. In

one series of experiments, rather than using technology to support memory, Sharps used an everyday dinner plate as an inexpensive mechanism for enhancing older adults memory for performing everyday tasks. The plate had to be significantly unusual, or “ugly”, so that it stood out from all the other objects in the person’s environment. Items that might be misplaced or forgotten (keys, medications, etc.) were left on the plate, which was placed in an often-frequented area such as on the kitchen table. Post-it® Notes were stuck to the plate at odd angles as reminders of appointments. Through his “plate-and-note” experiments, he found that about 65% of participants experienced enhanced memory performance for the very low cost of the plate and some training [41]. It would be helpful to know if participants regressed once the “ugly plate” became an accustomed part of their surroundings.

MyLifeBits is a novel project being carried out by Gordon Bell and Microsoft Corporation. Central to an extensive “memory augmentation” effort at Microsoft (and as part of the information retrieval aspect of Microsoft Windows Vista/Longhorn), Bell’s project involves his wearing a small still camera complemented by sensors (to pick up light level, tilt, temperature, acceleration, infrared). The camera (called the SenseCam) hangs around his neck and takes pictures every minute that are stored along with the time of day and the associated GPS coordinates. All captured information is downloaded to MyLifeBits, which also captures keystrokes and mouse clicks, e-mail, Web sites browsed and documents created when he is at his computer. A database of information capture in this way is a fairly complete history of a day’s activities. One experimental use of this kind of information has been to relieve anxiety due to loss of memory for a woman with a neural disorder. At the end of the day, her husband played back the events of her day and discussed them with her. Knowing that there would be a “review” at the end of the day appeared to relieve the woman’s daylong anxiety caused by her fear of forgetting [42].

5. Discussion

While there is great potential for providing the elderly, the injured, and those permanently cognitively or physically impaired with varying degrees of independent-living assistance, it is imperative that what we refer to as “aware technologies” are also pervasive and so the user’s needs requirements must be balanced by attention to

the user’s attitudes [13] as well as ethical issues related security and privacy [16, 17].

5.1. Evaluating ubiquitous environments

While rapidly changing technologies and sociotechnical needs make it difficult to determine how best to create meaningful empirical measurements for evaluation of ubiquitous environments, Scholtz et al. [43], examined six instances of efforts to evaluate various kinds of ubiquitous environments: Classroom 2000 [47], Tivoli [48], Sotto Voce [49], Exploratorium [50], Labscape [51], and Rasa [52]. Scholtz and Consolvo [44] have made a good start towards development of a framework for evaluations of such environments and have developed a set of assessment topics that they have termed “UbiComp Evaluation Areas” (UEAs).

They present clear definitions [44, Sect. 4.3, p. 8]: “A measure is an observable value. A metric associates meaning to that value by applying human judgment.” They identify the users of the application in terms of direct and indirect stakeholders [45]: “*Direct stakeholders* interact with the application and/or its output in a direct way. *Indirect stakeholders* are affected by the application in a meaningful, but not direct way.” These definitions are very helpful in analyzing the beneficiaries of what is, basically, a “conversational relationship” between the direct and the indirect stakeholders who make up the elderly and/or cognitively impaired and/or physically impaired users in the ubiquitous environments under discussion here. Table 1 in the Appendix presents the direct and indirect beneficiaries of a ubiquitous support environment.

Table 2 in the Appendix is a condensation of the quite comprehensive foundation for the UbiComp Evaluation Areas framework suggested by Scholtz and Consolvo in [44]. The table delineates the evaluation area, the metric(s) associated with the area, and potential conceptual measures associated with the particular metric. It is well worth examining as a basis for design and development guidelines and for evaluation standards for ubiquitous environments.

As indicated in [44, Sect. 3, p. 4], current usability evaluation focuses on three metrics (efficiency, effectiveness, and user satisfaction per ISO 92411-11): “*Efficiency* measures the amount of time users take to perform a particular task. *Effectiveness* measures the percentage of that task the majority of users are able to complete with and without assistance. *Satisfaction* measures are obtained from users’ ratings of their interactions with the application.” However, usability of ubiquitous environments must go beyond this, chiefly because

“they move the site and style of interaction beyond the desktop and into the larger real world where we live and act ... the ever changing context of use” [46].

5.2. Collaboration and coordination

Activity in a ubiquitous environment is by nature collaborative whether the collaboration takes place between the user(s) of the space and the “intelligence” of the space or between the user(s) of the space and humans or machines external to the space. Collaboration is implicit in the symbiotic relationship. Thus, one of the evaluation areas defined by Scholtz and Consolvo [44] is “Trust” and this is gauged by the metric “Privacy” as measured by the amount of information the user needs to provide to get assistance from the application and the use to which the data captured about the user’s activities is put. The other metric used to gauge “Trust” is “Awareness”, which is conceptually measured by how easy it is to coordinate [activities and resources] with others in a multi-user application as well as how often users’ activities are in conflict with those of other users [44, Sect. 4.3, p. 11].

A ubiquitous environment (application) is interactive and, by nature, it is distributed. The user has a conceptual model of what the affordances available in the environment, what they are for, how they work, when to invoke them, and when they are being autonomously invoked by the application. Because of the distributed nature of the environment, it is difficult for users to construct “unified models of behaviors and interactions ... how does a user know when they are in a “smart room? ... When the user is in a smart room, will they know how to interact with the room?” [44, Sect. 4.3, p. 12]. It is clear that, regardless of cognitive or physical challenges, the user needs to have a working mental model of the environment and how it is distributed in order to successfully exist in it. By the same token, shared mental models must exist among multiple users of the ubiquitous environment. In the present case these are the user/patient, the designers and developers of the environment, and the external resources with which the user interacts.

Another area (UEA) where collaboration plays a vital role is “Interaction”. The metric, “Collaborative interaction”, is evaluated using conceptual measures specifying the number of conflicts that occur, the degree to which the application can successfully resolve these conflicts, how the user responds (in an affective sense) to conflict and the way in which it is resolved, and the way and extent to which the user recovers (or does not) from the occurrence of conflict [44, Sect. 4.3, p. 13].

6. Summary

In general, we can consider a number of factors that will determine the efficacy of an environment characterized by degrees of human-machine symbiosis. The most straightforward metric for which a baseline can be established is *Costs versus Benefits*. A second more subjective, but no less important, indicator is *Acceptance and Satisfaction* by both users and the medical establishment.

6.1. Costs

Each intelligent environment will have to be created as a unique, custom-built system depending upon the needs of each user. As such, these prototype systems will be costly. The nature and degree of monitoring and interaction required will determine the cost. As sensing devices become more reliable and more widely used, economies of scale should reduce the manufacturing cost of each device. However, the installation expenditures for labor will remain high as will the ongoing cost of modifications and maintenance of the living environment. Also adding to the initial price tag will be the review and decision making process to determine which affordances are required for each installation.

6.2. Benefits

Savings in medical manpower will offset some or all of these high front-loaded and ongoing outlays. Unlike the high costs of maintaining fixed infrastructures such as hospitals and assisted-living facilities, a smaller number of caregivers will be able to monitor and interact with a larger number of patients. In many cases, savings will mitigate cost in caregiver time. The expensive time and effort associated with home visits will, likewise, be reduced, as information on vital signs will be available on a continuous basis at remote sites.

6.3. Acceptance and Satisfaction

Measurements of user acceptance of and satisfaction with intelligent environments will have to be obtained by surveys. Where possible, the patient will be queried as to how they feel about having their privacy intruded upon by ubiquitous monitoring. Subsequent surveys will reveal if their opinions change over time as they experience the satisfaction of functioning in their familiar home environments, the convenience of not having to make repeated trips to clinics or hospitals for testing, and the sense that

they have more control over their lives. These factors might outweigh privacy issues.

6.4. Healthcare Industry

Widespread use of intelligent environments will come about only if the stakeholders in the medical business accept them. These participants include hospitals, clinics, assisted living facilities, nursing homes, doctors, nurses, pharmaceutical companies, medical insurance entities (either private companies or government insurers – Federal Medicare and State Medicaid), prosthesis manufacturers, attorneys specializing in malpractice litigation (a defective sensor is a lawsuit waiting to be filed), rehabilitation centers, and many others. Intelligent environments present new dimensions that these entities will have to deal with. Many of these stakeholders have opposing interests, and those interests do not necessarily consider patients' welfare as top priority. Computer-aided supports for everyday living will have to address these issues to be accepted by all parties.

7. Future work

The work presented here is representative of the large amount of research that has been done to date. While we have attended to the large body of research focused on management of home entertainment appliances [18], we have focused on research related to supporting populations having cognitive and physical needs.

It is clear that effective implementation of ubiquitous living environments requires deployment of adaptive, intelligent, semi-autonomous multi-agent systems capable of synthesizing information from multiple sources and initiating apropos embedded assistive mechanisms with adequate human guidance. We are presently analyzing fusion of information gathered from networks of sensors and information appliances characterized by system adaptation via mixed human-agent initiative. Evaluation of our work will be guided by the work done so far to develop a formal UEA framework for evaluation and by the contributions we will make to maturing an evaluation framework and extending assessment techniques for complex ubiquitous environments.

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10. References

- [1] Tobin, K. and Walton, M., "Shuttle launch delayed", Cable News Network, July 18, 2005. <http://www.cnn.com/2005/TECH/space/07/15/space.shuttle/index.html>
- [2] <http://en.wikipedia.org/wiki/Symbiosis>
- [3] Bush, V., "As We May Think," *The Atlantic Monthly*, 176(1), July 1945, 101-108.
- [4] Licklider, J. C. R., "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Electronics*, HFE-1, March 1960, 4-11.
- [5] Roy, D., "10x: Human-machine symbiosis," *BT Technology Journal*, 22(4), October 2004, 1-5.
- [6] Norman, D. A., *The invisible computer*, The MIT Press, Cambridge, MA, 1998.
- [7] Weiser, M., "The Computer for the 21st Century", *Scientific American*, 265(3), September 1991, 94-104.
- [8] Raskin, J., "The Humane Interface: New Directions for Designing Interactive Systems", Addison-Wesley Professional, 2000.
- [9] Keyson, D. V., de Hoogh, M. P. A. J., Freudenthal, A., Vermeeren, A. P. O. S., "The Intelligent Thermostat: A Mixed-Initiative User Interface", *Proceedings of Human Factors in Computing Systems (CHI 2000)*, ACM, 59-60.
- [10] Mynatt, E. D., Essa, I., Rogers, W., "Increasing the Opportunities for Aging in Place", *Conference on Universal Usability (CUU '00)*, November 16-17, Arlington, VA, ACM, 2000, 65-71.
- [11] Mamykina, L., Mynatt, E., Terry, M. A., "Time Aura: Interfaces for Pacing", *Conference on Human Factors in Computing Systems (SIGCHI'01)*, March 31 - April 4, Seattle, WA, USA, ACM, 2001, 144-151.
- [12] Paradise, J., Mynatt, E. D., Williams, C., Goldthwaite, J., "Designing a Cognitive Aid for the Home: A Case-Study Approach", *The 6th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'04)*, October 18-20, Atlanta, GA, USA, ACM, 2004, 140-146.
- [13] Mynatt, E. D., Melenhorst, A.-S., Fisk, A. D., and Rogers, W. A., "Aware Technologies for Aging in Place: Understanding User Needs and Attitudes", *Pervasive Computing*, April-June 2004, IEEE, 36-41.

- [14] Starner, T. and Ashbrook, D., “Augmenting a pH Medical Study with Wearable Video for Treatment of GERD”, *Proceedings of the 8th International Symposium on Wearable Computers* (ISWC’04), October 31 - November 3, Arlington, VA, USA, IEEE Computer Society, 2004.
- [15] Hawkey, K., Inkpen, K. M., Rockwood, K., McAllister, M., Slonim, J., “Requirements Gathering with Alzheimer’s Patients and Caregivers”, *The 7th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS’05), October 9-12, Baltimore, MD, USA, ACM, 2005, 142-149.
- [16] Bowen, J., “The Ethics of Safety-Critical Systems”, *Communications of the ACM*, 43(4), April 2000, 91-97.
- [17] Stip, E., and Rialle, V., “Environmental Cognitive Remediation in Schizophrenia: Ethical Implications of ‘Smart Home’ Technology”, *Canadian Journal of Psychiatry*, 50(5), April 2005, 281-291.
- [18] Möller, S. Krebber, J., Raake, A., Smeele, P., Rajman, M., Melichar, M., Pallotta, V., Tsakou, G., Kladis, B., Vavos, A., Hoonhout, J. Schuchardt, D., Fakotakis, N., Ganchev, T., and Potamitis, I., “INSPIRE: Evaluation of a Smart-Home System for Infotainment Management and Device Control”, *Proceedings of the International Conference on Language Resources and Evaluation (LREC)*, Lisbon, Portugal, v5, 1603-1606, 2004.
- [19] Roy, A., Bhaumik, S. K. Das, Bhattacharya, A., Basu, K., Cook, D. J., and Das, S. K., “Location Aware Resource Management in Smart Homes”, *Proceedings of the 1st IEEE International Conference on Pervasive Computing and Communications (PerCom)*, 2003.
- [20] “Operation Enduring Freedom Analysis of VA Health Care Utilization -- Report 1”, VHA Office of Public Health and Environmental Hazards, February 24, 2004.
- [21] Jones B., Editor, “Atlas of Injuries in the U.S. Armed Forces”, *Supplement to Military Medicine*, 164(8), August 1999.
- [22] Welch, W. M., “Iraq injuries differ from past wars: More amputations, brain traumas”, *USA Today*, February 28, 2005. www.usatoday.com/news/world/iraq/2005-02-28-cover-side_x.htm
- [23] Lesho, E. P., Wortmann, G., Neafie, R. C., and Aronson, N. E., “Cutaneous leishmaniasis: Battling the Baghdad boil”, *Federal Practitioner*, October 2004, 59-67.
- [24] Jossi, F., “Nine tech trends: Section on telehealth”, *Healthcare Informatics Online*, 2005, 66-70. www.healthcare-informatics.com/issues/2005/07_05/hardware.htm
- [25] “Remote monitoring of health conditions”, IBM Research, 2005. http://domino.research.ibm.com/comm/pr.nsf/pages/news.20031112_mobilehealth.html
- [26] Lemanske R, et al., “Inhaled Corticosteroid Reduction and Elimination in Patients With Persistent Asthma Receiving Salmeterol”, *Journal of the American Medical Association*, 285 (20), 2001.
- [27] Stern, S., “Body armor could be a technological hero of war in Iraq”, *The Christian Science Monitor*, April 2, 2003. www.csmonitor.com/2003/0402/p04s01-usmi.html
- [28] Calleja, D., “Bionic leg a step in right direction”, *Toronto Star*, Toronto, Ontario, June 21, 2004. p. D.06.
- [29] Marriott, M., “CYBERBODIES; Robo-Legs”, *New York Times*. MEN & HEALTH. Late Edition – Final, Section F, Page 1, Column 6, 2005.
- [30] “Ossur, Victhom team up for new technology”, *The O&P Edge*, May 23, 2003. www.oandp.com/edge/issues/articles/NEWS_2003-0523_01.asp www.ossur.com/template110.asp?pageid=1780
- [31] Ivanhoe Newswire, “Prosthesis with a brain”, Updated: 6/22/2005. TWEAN Newschannel of Raleigh, L.L.C. dba News 14 Carolina (www.news14.com). rdu.news14.com/content/headlines/?ArID=71137&SecID=2
- [32] Pollack, M. W., “Assistive Technology for Aging Populations”, Presented to the United States Senate Special Committee on Aging, April 27, 2004. www.eecs.umich.edu/~pollackm/Pollackweb_files/distrib/senate-testimony.pdf
- [33] Shih, E., Bychkovsky, V., and Guttag, J., “Medical emergency event detection: Detecting falls”, MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). www.csail.mit.edu/research/abstracts/abstracts04/PDF/92.pdf 2004.
- [34] Ravi, N., Dandekar, N., Mysore, P., and Littman, M. L., “Activity Recognition from Accelerometer Data”, *Proceedings of the Seventeenth Innovative Applications of Artificial Intelligence Conference (IAAI05)*, Neil Jacobstein and Bruce Porter (Eds.), July 19–13, Pittsburgh, PA, USA, AAAI Press, Menlo Park, CA, 2005 1541-1546.
- [35] Ulrich, I. and Borenstein, J., “The GuideCane – Applying mobile robot technologies to assist the visually impaired”, *IEEE Transactions on Systems, Man, and Cybernetics, -- Part A: Systems and Humans*, 31(2), March 2001, 131-136. www.engin.umich.edu/research/mrl/00MoRob_22.html
- [36] SMART MEDICAL HOME RESEARCH LABORATORY, Center for Future Health, University of Rochester Medical Center, Rochester, New York. www.futurehealth.rochester.edu/smart_home/index.html

www.futurehealth.rochester.edu/smart_home/smart_home.html

[37] Mathie, M. J., Coster, A. C. F., Lovell, N. H., Celler, B. G., Lord, S. R., Tiedemann, A., "A pilot study of long-term monitoring of human movements in the home using accelerometry", *Journal of Telemedicine and Telecare*, 10(3), 2004, 144-151.

[38] Proactive Health Research Project. Aging-in-Place: Advanced Smart-Home Systems. Intel Corporation. 2005. www.intel.com/research/prohealth/cs-aging_in_place.htm

[39] Intel showcases innovative wireless sensor networks for in-home health care solutions. Technology demonstration hosted by the Center for Aging Services Technologies (CAST) in Washington, D.C., March 16, 2004. www.intel.com/pressroom/archive/releases/20040316corp.htm

[40] Sharps, M. J., *Aging, representation, and thought : Gestalt and feature-intensive processing*, New Brunswick, N. J.; London: Transaction Publishers, 2003.

[41] Russell, M. L., "The plate's the thing: Memory performance subject of professor's research", *CSU Fresno University Journal*, 2(4), September 21, 1998.

[42] Cherry, S., "Total Recall", *IEEE Spectrum*, November 2005. <http://spectrum.ieee.org/nov05/2153>

[43] Scholtz, J., Arnstein, L., Kim, M., Kindberg, T., and Consolvo, S., "User-Centered Evaluations of Ubicomp Applications", IRS-TR-02-006, © Intel Corporation, May 2002.

[44] Scholtz, J., and Consolvo, S., "Towards a Discipline for Evaluating Ubiquitous Computing Applications", IRS-TR-04-004, © Intel Corporation, January 2004.

[45] Friedman, B., Kahn, Jr., P. H., and Borning, A., "Value sensitive design: Theory and methods", University of Washington Technical Report 02-12-01, December 2001.

[46] Moran, T., Dourish, P., "Introduction to This Special Issue on Context-Aware Computing", *Human-Computer Interaction*, 16(2-4), 2001, 87-97.

[47] Abowd, G. D., "Classroom 2000: An experiment with the instrumentation of a living educational environment", *IBM Systems Journal*, 38(4), 1999.

[48] Moran, T., Palen, L., Harrison, S., Chiu, P., Kimber, D., Minneman, S., van Melle, W., and Zellweger, P., "I'll get that off the audio": A case study of salvaging multimedia meeting records", *Proceedings of CHI'97*, 1997, 202-209.

[49] Woodruff, A., Szymanski, M. H., and Hurst, A., "The conversational role of electronic guidebooks", *Proceedings of the International Conference on Ubiquitous Computing*, Atlanta, GA, September 2001, 187-208.

[50] Fleck, M., Frid, M., Kindberg, T., O'Brian-Strain, E., Rajani, R., and Spasojevic, M., "From informing to remembering: Ubiquitous systems in interactive museums", *IEEE Pervasive Computing*, 1(2), April-June 2002, 11-19.

[51] Arnstein, L. F., and Borriello, G., "Landscape: The design of a smart environment", Intel Research Seattle Technical Report IRS-TR-02-008, 2002.

[52] McGee, D. R., Cohen, P. R., Wesson, R. M., and Horman, S., "Comparing paper and tangible, multimodal tools", *Proceedings of CHI'02*, 2002, 407-414.

Appendix

Table 1. Direct and indirect beneficiaries (stakeholders)

Beneficiaries of a Ubiquitous Environment Designed to Support Elderly, Cognitively Impaired, or Physically Impaired Users	
Direct Stakeholders	Indirect Stakeholders
User (individual who needs assistance with everyday living routines)	User's Family
Caregiver (Doctor, Nurse, Physical Therapist, etc.)	Insurance Company
Institution (Hospital, Assisted Living Facility, Nursing Home)	Institution (Owners, Shareholders)
	Other users in need of more "hands-on" care
	Taxpayers

Table 2. Ubicomp Evaluation Areas (UEAs) Framework
(Scholtz and Consolvo, 2004 [44])

Note: Items marked with an asterisk indicate suggested additions.

Evaluation Area	Metric	Conceptual Measures
UEA1: Attention	Focus	No. of times user needs to change focus due to technology
		No. of different displays or actions user need to reference to perform an interaction or check on progress of an interaction
		No. of events not noticed by user in reasonable time
		Workload on user that can be attributed to focus
UEA2: Adoption	Rate	New users/unit of time
		Adoption rationale
		Technology usage statistics
	Value	Changes in productivity
		Perceived cost/benefit ratio
		Continuity for user
		Amount of customer sacrifice (difference between what user gets and what user wanted)
	Availability	No. of actual users from each target user group
		Technology supply source
		Categories of users in post-deployment

UEA3: Trust	Privacy	Amount of information user must reveal to receive value from the application
		Explanation available to user about the use of recorded data
	Awareness	Ability to easily coordinate with others in a multi-user application
		No. of conflicts with the activities of others
UEA4: Conceptual Models	Predictability of Application Behavior	Degree of match between user's model and actual behavior of the application
	Awareness of Application Capability	Degree of match between user's model and actual functionality of the application
	Vocabulary Awareness	Degree of match between user's model and the syntax of multimodal interactions with the application
UEA5: Interaction	Effectiveness	Percent of task completed
		*Accuracy of task work completed
	Efficiency	Time taken to complete a task
		*Acceptability of completed work
	User Satisfaction	User rating of performing the task
		*User rating of outcome of performing the task
	Distraction	Time taken away from the primary task
		Degradation of performance in primary task
		Level of user frustration
	Interaction Transparency	Effectiveness comparisons using different sets of I/O devices
	Collaborative Interaction	No. of conflicts
		Percentage of conflict application resolved
	User feelings about conflict and conflict resolution by the application	
	User ability to recover from conflict	
UEA6: Invisibility	Intelligibility	User's understanding of system explanations
	Control	Effectiveness of interactions provided by application for user control of system initiatives
	Accuracy	Match between the application's contextual model and the actual situation
	Appropriateness of Action	Match between the system's action and the action the user would have requested
	Customization	Time to explicitly enter personalization information or time for the system to learn and adapt to user preferences
UEA7: Impact	Behavior Changes	Type, frequency, duration
		Match between user's current job description and application role assigned
	Social Acceptance	Requirements beyond social norms placed on user by system
	Environment Change	Type, frequency, duration