E-Health, Assistive Technologies and Applications for Assisted Living:

Challenges and Solutions

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Chapter 13
The Smart Condo Project:
Services for Independent Living

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ABSTRACT

Most would agree that older adults want affordable, high-quality healthcare that enables them to live independently longer and in their own homes. To this end, ambient assisted living environments have been developed that are able to non-intrusively monitor the health of people at-home and to provide them with improved care. The authors have designed an environment, the Smart Condo, to support seniors and rehabilitating patients. They have embedded a wireless sensor network into a model living space, which incorporates universal design principles. Information from the sensor network is archived in a server, which supports a range of views via APIs. One such view is a virtual world, which is realistic and intuitive, while remaining non-intrusive. This chapter examines computing technologies for smart healthcare-related environments and the needs of elderly patients. It discusses the Smart Condo architecture, reviews key research challenges, and presents the lessons learned through the project.

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INTRODUCTION AND MOTIVATION

As baby boomers grow older and life expectancies increase, we need advances in health service-delivery models that address an increasing number of chronic conditions in ways that are appropriate for an increasingly informed older population. The healthcare and social implications of aging populations, and the need to enable them to live independently at home longer, is a priority for governments, industry, and researchers to address. Motivated by this need, an increasing number of industrial products and research prototypes today envision *ambient assisted living environments* that are able to non-intrusively monitor the health of people at-home and to guide and support more specialized, timely, and cost-effective care to them. The substantial and increasing wave of new research in this area is a testament to the social importance of the problem and the technical challenges involved. The technical challenges span a range of disciplines.

1. What types of monitoring technologies can be deployed for assisted living purposes? Today, we have a wide variety of technologies at our disposal, ranging from passive and active RFIDs[1], to sensors that can be embedded in the environment or to the patients' clothing and bodies, to wireless devices that are (or can be) integrated with home devices to communicate data on their status and readings.
2. How can data from the various technologies above be fused to infer clinically relevant information about patients? How can the inferred information be communicated to patients and their caregivers (health professionals and family members) in order to be effectively acted upon? And what healthcare disciplines might benefit from information thus obtained?
3. What types of physical, psychological, and cognitive assistance can be possible through digital technologies? Individual patients may suffer from a variety of ailments, such as limited mobility, diabetes with its variety of implications to stability and food concerns, and forgetfulness.
4. How should care-delivery activities be effectively orchestrated between the patients themselves and their caregivers? Depending on their condition, abilities, and their social environment, patients may be more or less able to manage their own conditions. How can the monitoring infrastructure flexibly support them, while also recognizing exceptional situations and triggering alarms to responsible health professionals?

Hand-in-hand with the above technical challenges (and the functional requirements they imply for an assisted-living infrastructure) come a variety of social requirements. These are distinct yet equally important as the technical requirements, and their fulfillment is a prerequisite for the eventual adoption of any such infrastructure.

1. First is the issue of ethical concerns around privacy, ownership of the collected data, patient access to it, and fair use. Patients, although they may appreciate the increased sense of safety that comes with the monitoring infrastructure, are leery of having their every move monitored. The question then becomes the identification of an acceptable trade-off between data collection and safety.
2. Second is the issue of adaptability. Patients come with different needs, and as their conditions progress, their needs change. This evolution of patient needs implies the need for an extendible assistive infrastructure that can evolve as necessary.
3. Third is the issue of training healthcare professionals. New technologies are only as effective as the people who are using them are knowledgeable; thus, an education program is needed for training health-sciences

professionals to effectively use the at-home health monitoring and care technologies to access rich information about the patient's health status, so that they can better serve these patients.

Our team has been involved in the Smart Condo project[2] for approximately a year and a half. Our objective is to design an environment, including the physical and the computing infrastructures, to support seniors and patients living at home in the community or in congregate housing. Although these individuals are, by and large, able to live independently, they are still susceptible to harmful incidents related to complex physical and cognitive impairments. Thus, we are developing a model Smart Condo, designed according to universal design principles (Center for Universal Design, 1997), within which we have embedded a wireless sensor network. Information from the sensor network is archived in a server, which supports a range of REST APIs through which the information is visualized as a range of views. Among the most useful views is a virtual world (currently, Second Life), in which a model of the Smart Condo has been built. This view into the patient's activity is realistic and intuitive, while at the same time non-intrusive, since personal-appearance details are not actually monitored or recorded. A reengineered SL client accesses information regarding the patient's activities, as inferred by the sensor data stream through the server's REST APIs, and uses it to control an avatar mirroring the patient's activity in the real world.

Our intent is to make the live stream of the person's activity available to their caregivers and potentially healthcare professionals, who can recognize potentially subtle harmful events and communicate with the condo occupant through this low-bandwidth videoconferencing tool. Event detection is, of course, not delegated simply to caregivers "watching" the virtual-world feed: we are developing stream-mining methods for recognizing pre-specified patterns of sensor readings indicative of potential problems in order to alert caregivers and cause them to intervene. Finally, analytics methods inspect the archive of recorded sensor readings in order to extract patterns and to recognize trends associated with clinically significant symptoms. In addition to enabling better care for independent individuals, this infrastructure can advance the state of healthcare knowledge and delivery practices through the systematic collection and analysis of evidence. A recording of the virtual-world activity, "annotated" with the readings of the various sensors, can also serve as an aspect of the patient's health record, providing detailed and contextual information on the patient's history. It can be replayed at an accelerated rate, to allow quick viewing of large spans of time for diagnostic purposes. Recordings of "pedagogically interesting" activity segments can also be used for simulation training of health-sciences students. We believe that this integration of sensor networks with virtual worlds represents a "sweet spot" in the spectrum of at-home health monitoring and care delivery.

The rest of this chapter is organized as follows. We first review the broad background of this work. We examine the computing technologies that have been developed in the service of smart environments, with a special focus on environments designed for healthcare related purposes. We also review, at a rather high level of abstraction, the needs of elderly people living independently at home or in long-term care facilities. Next, we discuss the overall architecture of our Smart Condo. We then review what we perceive as key research challenges in this area. Finally, we conclude with a summary of the lessons we have learned in the context of this project.

UBIQUITOUS COMPUTING TO SUPPORT OLDER ADULTS

In this paper, our use of the term *Smart Home* means a home that has both a set of sensors to observe the environment and a set of devices/actuators to improve the inhabitant's experience at home. Our use of the term home may refer to one in the community or one in an assisted living or congregate living situation. A Smart Home can provide a variety of services from simple task automations, such as room temperature control, to more complex analyses, such as inference of the occupants' activities. Smart-home technologies are being deployed in a variety of application domains, including real-estate security monitoring, home energy consumption reduction, cognitive and memory aiding to people with special needs, and remote patient monitoring by healthcare professionals. Our Smart Condo work is motivated by the last type of applications, and thus, in the remainder of this section, we review (a) the potential applications of these technologies for supporting elderly people to live independently in their homes and (b) the technological advances in implementing smart homes.

Smart Homes in Service of an Aging Population

In healthcare, the concepts of *continuing care*, *assisted living*, and *aging in place* are recent when compared to the substantial amount of work that has been carried out under the heading of *long-term care* (LTC) in specialized facilities. To some extent, it is this large body of research in LTC that has motivated the idea of using technology to support people to continue living independently, in their own homes, as they age. For example, healthcare researchers found that the quality of life for LTC residents was enhanced if their physical and social environment were more homelike, with minimal institutional features (Morgan and Stewart, 1997; Morgan and Stewart, 1998; Zingmark, Sandman, and Norberg, 2002). More specifically, non-institutional environments were found to enhance mealtime experience. Gruber-Baldini et al. (2005) examined food and fluid intake of 407 residents in 45 assisted living facilities and discovered that, in addition to appropriate lighting and reduced noise levels (McDaniel, Hunt, Hackes, and Pope, 2001), staff monitoring of residents, dining in a public area, and non-institutional environmental features were associated with higher food and fluid intake. Furthermore, engagement in meaningful activities has been associated with less depression and better cognitive and physical function (Dobbs et al., 2005). Programming engaging activities in LTC facilities is challenging since it has to be balanced with personal choice and opportunities for appropriate levels of involvement. On the other hand, one can imagine that living in one's own home environment would enhance the degree of one's engagement in typical activities.

Having established as a desirable objective supporting people to stay and age in their homes as long as possible, there is a need to identify simple technological supports that could be used to address problematic behaviors observed in LTC facilities such as sundowning[3] (Nowak and Davis, 2007) and wandering[4] (Beattie, Song, and LaGore, 2005), to monitor activity engagement, to help ensure safety, and to provide therapeutic interventions. More specifically, these technologies could potentially (a) minimize the visible barriers that typical community homes place to independent living, while still ensuring an appropriate level of safety; (b) augment the normal care available to the elderly in their physical/social environments; and (c) expand the range of ways for family members and healthcare professionals to appropriately and respectfully monitor the movements of the individual for the purpose of providing help at the right moment. The first dimension of improvement is the subject of *universal design* research. The term universal design recognizes the importance of how things look and encompasses a set of principles that can lead to designs that delight and are accessible to users with a variety of abilities and disabilities. The latter two dimensions of improvement can be accomplished with sensor technologies. Sensors can be used to unobtrusively monitor people, recognize when they may need assistance from family members and care providers, and involve the necessary helpers in a timely manner. Alternatively, sensors and actuators can be used to control the environment and effectively assist people in their regular activities. For example, automatic lighting can simplify night-time activities and minimize fall risk. Technology can also help notify staff, who can offer care and support or provide automatic reminders for routine or *event-triggered* activities (e.g., electronic notification of individual medication needs and recording of documentation).

Another service of potentially high value to the increasing population of seniors – they account for almost 14% of the Canadian population (Statistics Canada, 2006) – is effective medication management. There is increasing medication use with age, with those aged 80 years and older receiving the greatest number of prescriptions. In Canada, 76.3% of senior households used any medications in the preceding 2 days, and there was an association between multiple medication use and ill health (Ramage-Morin, 2009). Seniors also account for half of visits to physician specialists (US Department of Health, 2009). Older adults also have an increased disease burden. Many seniors have at least three chronic medication conditions, and these seniors consume a disproportionate amount of healthcare resources (Boyd et al., 2005). Disease states often present atypically in older adults, and geriatric syndromes are common (Tinetti and Fried, 2004).

Cassel (2009) has identified six characteristics of optimal quality of care for older adults with frailty, including reducing the risk of medications in older adults, communications, and managing healthcare across the healthcare system. Due to the significant use of medications by seniors and the associated risks, monitoring is an extremely important issue. In fact, pharmacists are usually the first healthcare professional to have regular contact with people as they are approaching their "elderly" years, even before they have health concerns serious enough to require regular contact with other specialists. In addition to being accessible, pharmacist care has been shown to enhance medication management and the health of patients (Beney, Bero, and Bond, 2000; Roughead, Semple, and Vitry, 2005). The role of the pharmacists in North America has been expanding. The profession has moved its mandate from a provider of medication to a care provider who accepts responsibility for medication-related outcomes. Their role in providing patient care can be considered in the context of the medication management process (Bajcar, Kennie, and Einarson, 2005), which includes identifying the need for therapy, prescribing, dispensing, packaging, administration, and monitoring. There is a strong societal need for pharmacists to provide increased medication monitoring to reduce the patient burden of inappropriate medication use and identify unmet needs for therapy. Financial and healthcare system structures are emerging to support pharmacist's provision of care beyond dispensing. Smart technologies will allow them to monitor patients' use of medications and health outcomes.

Information and communication technology has been identified and accepted nationally as one of five key areas required to help pharmacists reach their vision of optimal drug therapy outcomes for Canadians through patient-centered care (Task Force on a Blueprint for Pharmacy, 2008). The challenge is to connect pharmacists and patients in an ongoing and systematic way. One means to connect them is via electronic medication monitoring systems that have been integrated into caps on vials, e.g., the Medication Event Monitoring Systems (MEMS), or into calendar packaging, e.g., a blister package (Santschi, Wuerzner, Schneider, Bugnon, and Burnier, 2007). These devices collect data regarding the day and time that the medication is accessed and communicate it to an external site. This technology has been used frequently in trials related to medication adherence. Unfortunately, they do not measure the medication administration or consumption, are quite large in contrast to contemporary medication packaging, remain expensive, and are not designed to be childproof. Due to these deficiencies, electronic medication monitoring has been predominantly used for research purposes and has failed to be integrated into clinical practice.

Establishing acceptance of technology-based health monitoring systems through pharmacy care is, we believe, an important step in introducing and widely disseminating this technology. We are interested in drug dispensation and usage monitoring as a clinically relevant application in the assisted-living area. At this time, we have not yet incorporated such technology into our project. However, since we have recognized its importance early, we have been aiming to explore the relevant technologies and incorporate them to some extent in the Smart Condo. We are now piloting a new project that will attempt to identify the types of patients who can benefit the most from technological support for medication reminders and intake monitoring.

There is evidence that monitoring, information, and feedback does increase adherence to medication regimens (Haynes, Ackloo, Sahota, McDonald, and Yao, 2008). While there is support for monitoring, it is important to ensure that such technology is integrated with software and systems used in clinical practice. Community pharmacies, for example, use one of many different software programs for dispensing and patient information. A monitoring system must be integrated seamlessly into the client's living environment and must also interface productively with the healthcare professionals who are providing care.

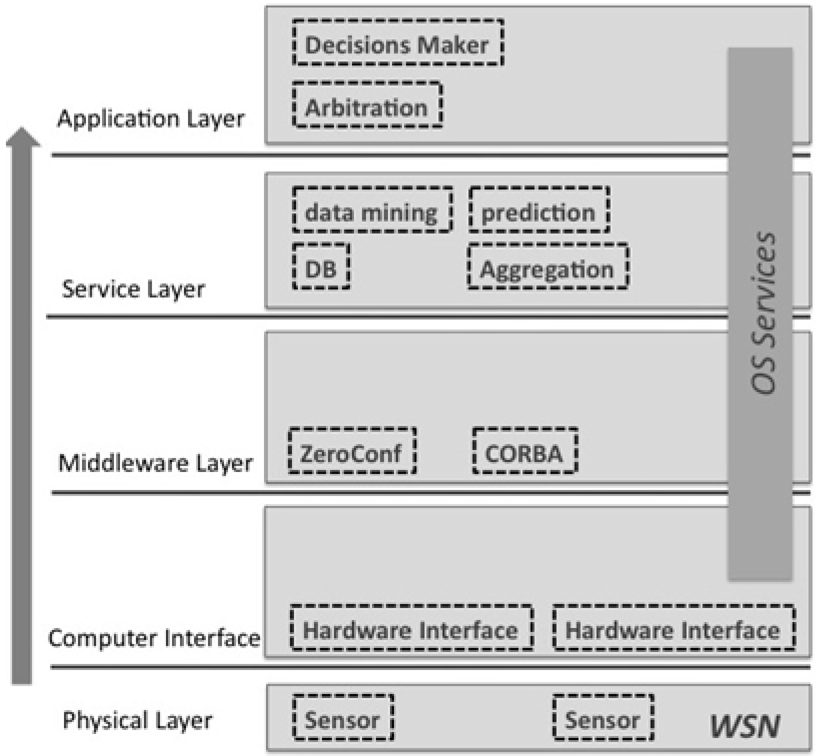
Smart-Home Technologies

There has been substantial research and development of smart-home technologies. Among the earliest projects in this area is most likely Georgia Tech's *Aware Home,* which is "devoted to the multidisciplinary exploration of emerging technologies and services based in the home" (Kientz, Patel, Jones, et al., 2008, p. 3675) and seeks to provide services to aging residents that enhance their quality of life and support aging-in-place. Rather than developing a general smart-home software platform, the project has been an umbrella under which a variety of distinct research activities have been carried out, most focusing on developing effective human-computer interfaces through which to support people with cognitive and memory impairments. For example, Fetch assists visually impaired people to locate misplaced objects (Kientz, Patel, Tyebkhan, et al., 2006) and Cook's Collage assists seniors in following recipes (Tran, Calcaterra, and Mynatt, 2005).

The Ambient Assisted Living Environment (AAL Environment) (Kleinberger, Becker, Ras, Holzinger, and Müller, 2007; Ras, Becker, and Koch, 2007), developed by the Fraunhofer Institute for Experimental Software Engineering in Germany, is an apartment-like environment for developing, integrating, and analyzing ambient intelligence technologies. A number of health-related research projects use this space as a realistic testing environment for new technology. Another project, the WASP architecture (Atallah, Lo, Yang, and Siegemund, 2008), is not motivated by specific healthcare concerns but focuses on the design of a software infrastructure for effectively integrating a population of wireless sensors to recognize events in a living environment and provide aural feedback. The system requires that the occupant wear an active radio-frequency identification (RFID) tag to help localization tasks and uses acceleration sensors to detect doors opening and closing.

The Sensorized Elderly Care Home (Hori, Nishida, Aizawa, Murakami, and Mizoguchi, 2004) is a system installed in a nursing home in Tokyo. This work is motivated by the desire to alleviate the routine workload of nursing personnel through automation. More specifically, a sensor-based system is used for localizing patients in a nursing home (LTC scenario), monitoring their status, and raising alarms as necessary so that

Figure 1. The software architecture used in the MavHome project

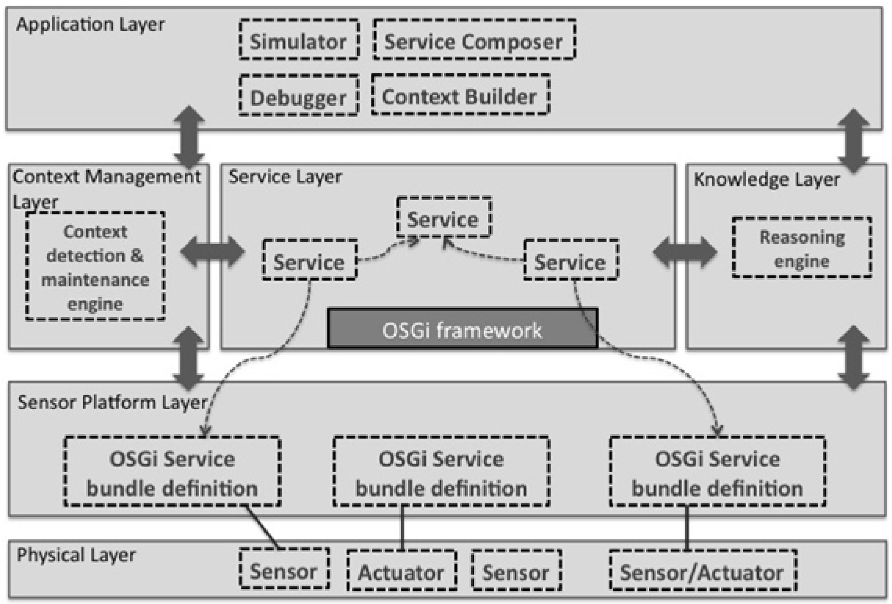


nurses do not have to do routine rounds. The system assumes a relatively limited level of activity on the part of the patients. It relies on "Ultra Badge" transmitters, placed on wheelchairs, and receivers, placed in several locations in the nursing home, to monitor wheelchair movement. Furthermore, a specially designed placement of transmitters and receivers on the ceiling monitors the patient's head position while on the bed to predict when the patient may leave the bed (Hori, Nishida, and Murakami, 2006).

The MavHome and Gator Tech House projects focused on the development of a general extendible software architecture for smart homes that monitor and actively help their occupants, essentially sharing the same goal as our Smart Condo project. The MavHome project (Cook, 2006) uses a variety of sensors (light, temperature, humidity, motion, and door/seat status sensors) to monitor the state of the environment and analyzes the collected data to (a) identify lifestyle trends through sequential pattern mining, (b) provide reminders to the home occupants through prediction of future activities, and (c) detect anomalies in the current data when the actual sensed events are considered unlikely according to the system's predictions. MavHome's power-line control automates all lights and appliances, as well as HVAC, fans, and mini-blinds.

MavHome uses a layered software architecture, as shown in Figure 1. Perception of light, humidity, temperature, smoke, gas, motion, and switch settings is performed through a sensor network developed in-house. Sensors monitor the environment in the physical layer, and this information is available through the interface layer for components in higher layers, such as the database, the data-mining component, the prediction module, and the decision-making units. Each device in the physical layer registers itself using ZeroConf[5] (Zero Configuration) and

Figure 2. The software architecture used by the Gator Tech House project



CORBA[6] handles the communication in higher layers. Environment perception is a bottom-up flow; actions follow a top-down trajectory, where each action is invoked by the application layer, is subsequently recorded by the service layer, and finally is enacted by devices in the physical layer. For example, MavHome can perceive the room temperature and respond to that by sending an action to related actuators for automated temperature control.

The Gator Tech Smart House at the University of Florida (Helal et al., 2005) is yet another high-tech house that embeds a variety of sensors to assist with the behavioral monitoring (and alteration) of elderly occupants or patients suffering from diabetes and obesity. Its envisioned software architecture is shown in Figure 2. The space incorporates technology into many aspects of the home. For example, their Smart Front Door allows keyless entry using radio frequency identification (RFID) and incorporates a microphone, camera, text LCD display, and speaker in order for the occupant to communicate with visitors. Their Smart (Micro)Wave also uses RFID to detect the type of food to cook, and a screen displays a video instructing how to open the item. The sensor-platform layer adopts the OSGi (Open Services Gateway Initiative) framework to maintain the service definitions of the underlying devices and make them available to application developers. A sensor is registered when it is powered on by sending its "service bundle definition" to OSGi. The application developers can write new services or use available services in this layer for their applications. The knowledge layer is envisioned to contain an ontology of the available services and a reasoning engine that identifies valid composite service requests (i.e., composite services that can be performed). The context-management layer enables application developers to build new context for new services in their application. Finally, the application layer includes a graphical development environment for creating contexts or activating services, a simulator, and a debugger.

Yet another system is the one deployed in Tiger Place (Skubic, Alexander, Popescu, Rantz, and Keller, 2009), which is among the longer and more mature projects in the area, having been deployed in 17 apartments for between 2 and 3 years. The system sensors (motion, bed pressure, and stove on-off) communicate with the X10 protocol with a PC that collects the information from a home and pushes it in regular intervals to a central database that makes it available through a web application to care providers. The system architecture's design appears to be primarily motivated by the technologies adopted, but the project is especially interesting because it involves a substantial team of researchers across disciplines who have conducted very interesting case studies with their installation. The Tiger Place team interviewed elderly volunteers about their acceptance of being monitored by video cameras and found that, although they disliked in principle the idea of cameras, they liked the less fuzzified silhouettes when they reviewed their own videos. This finding sheds an interesting light on the acceptability of video monitoring, which appears to be a primary objective of this project. Another interesting contribution of this project is the fact that it has empirically demonstrated the social value of such monitoring installations, as both the elderly participating in the program and their family members agreed that they had an increased peace of mind with the system than without. The researchers also raised the very important question of the clinical value of such installations being conditional upon the ability to correlate the sensor data stream with clinical observations by the healthcare providers.

Of the above projects, MavHome and Tiger Place focused more on the data analyses and the information extraction that it could support, where the more recent Gator Tech Smart House – similar to our Smart Condo – attempts to consider the software-architecture issues in a more systematic manner. Indeed, as the available sensor types increase and development kits, such as the Arduino (2010) and the Sun SPOTs (Oracle, 2010) for example, make programming with sensors more accessible, the question of a flexible architecture that can integrate new sensor types communicating through different protocols with a common data repository becomes increasingly important. There is increasing attention being given to this question, with much of the work appearing under the heading of "Ambient Intelligence". The term refers to environments that integrate a variety of sensors through which to perceive the presence and activities of people so that they can transparently respond to them in a way that supports these activities by controlling the environment – i.e., lighting, sound, temperature – and the appliances included in it. Mukherjee, Aarts, and Doyle (2009) recently reviewed the research objectives of the field as context awareness, ubiquitous access, and natural interaction. There has been substantial work in this area, much more than what we can review in this paper. An interesting recent example of this field is Amelie (Metaxas, Markopoulos, and Aarts, 2009) a service-oriented framework designed to support the implementation of awareness systems based on a recombinant-computing paradigm. In this paradigm, devices implement a limited set of *recombinant interfaces* that enable them to interact with one another dynamically. In Amelie, these interfaces enable the dynamic specification of the information each entity exposes to others (nimbus) and the information each entity acquires from other (focus) entities in a given situation. Another approach focusing more on a standardized implementation – as opposed to a theoretical specification framework – is the Shaspa framework (2009) that aims at simplifying the development of smart environments by enabling users to visualize, monitor, and manage their environments. At the same time, interactive interfaces provide immediate feedback to users. Shaspa "provides a smart interface to the most widely used industry-standard protocols for assembling real-world data from different input streams to manage physical spaces", thus fundamentally simplifying the interfacing of the physical layer with the higher analysis and decision-making modules.

THE SMART CONDO AT THE UNIVERSITY OF ALBERTA

The Health Sciences Education and Research Commons (HSERC) at the University of Alberta promotes and facilitates inter-professional education and research. It supports the *Smart Condo* project that brings together researchers from occupational therapy, industrial design, pharmacy, and computing science to integrate universal-design concepts with sensor technologies to address the needs of older adults living in their community[7]. While we await the completion of the actual Smart Condo, we designed a mock Smart Condo located in a single large room (of approximately 850 square feet) in a building on the University of Alberta campus for the purpose of student learning and research. The project was originally inspired by the independent-living suite at the Glenrose Rehabilitation Hospital in Edmonton, where patients can stay for up to three days to help ensure that they are ready for discharge home. During this stay, they are supposed to live independently, i.e., take care of themselves as if they were at home. Healthcare personnel are supposed to unobtrusively monitor them and only become involved when needed. Thus, the primary research objective in the development of our Smart Condo has been to establish that, through sensors only, we can record a precise picture of the condo's occupant, which can be unobtrusive and equally useful as if the healthcare personnel were actually monitoring the occupant through video cameras.

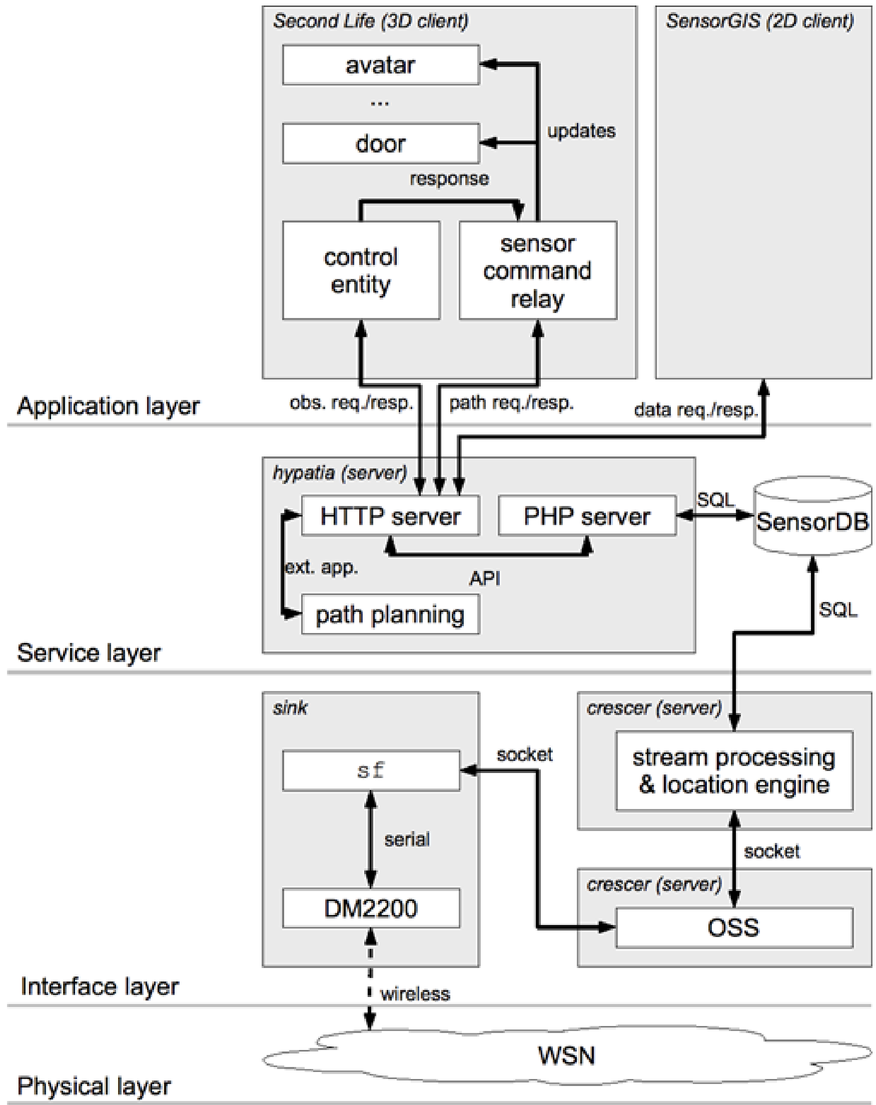
Teams of Industrial Design and Occupational Therapy (OT) students converted this area into a six-room condominium. Inside each room, they created prototypes for appliances, furniture, and other fixtures. Inside this space, we have deployed our wireless sensor network (WSN), which currently consists of nineteen nodes. These nodes contain four types of sensors, including (a) two types of motion sensors, (b) tactile pressure sensors, (c) reed switches, and (d) accelerometers. In terms of motion sensors, we have deployed six passive-infrared motion sensors for spot detection (Panasonic AMN43121) and seven passive-infrared motion sensors for wide-area detection (Panasonic AMN44121). Spaced throughout the condominium, the thirteen motion sensors cover the unit adequately to correctly locate the condo's occupant. Pressure sensors (FlexiForce A201, 1 pound) have been embedded in several chairs. They enable us to detect when someone sits on these chairs. We attached reed switches to the front door and the door of the microwave to determine whether they are open. Finally, we attached an accelerometer to the front door to detect knocking. Figure 3 diagrammatically depicts the software architecture of our Smart Condo infrastructure. The collection of the nodes we discussed above constitutes the WSN component, shown as a small "cloud" at the bottom of the figure.

The WSN communicates wirelessly with one (or more) sink(s). Through a wireless module peripheral, the sink receives packets generated in the WSN and passes them to the Operations Support System (OSS) on a server for parsing and acknowledgement generation. Acknowledgements then flow back to the sink where the attached wireless module transmits them to the WSN. The OSS component also generates a raw data stream of parsed sensor observations. It feeds these into a simple stream-processing component, which examines the data stream within a predefined time window and identifies sequences that conform to any of a set of predefined rules of interest. Finally, it archives the raw data stream, as well the instances of rules that have been matched by it to the Smart Condo repository, the SensorDB.

To support a variety of client applications a set of REST (representational state transfer) APIs (application programming interfaces) have been implemented to provide data of interest in a standardized XML schema to potential consumer applications.

Currently, two clients use these APIs: Second Life for 3D visualizations and SensorGIS for 2D

Figure 3. The Smart Condo's software architecture



visualizations. Second Life (SL) uses the information to change the state of the virtual world (e.g., location of the avatar and state of other objects) to reflect the sensed reality. SensorGIS uses the same APIs to reflect the information as points on a map and to generate a variety of tables and graphs, illustrating the history of the WSN readings over a time window and their statistics.

In the next four subsections, we discuss in more detail each of the four layers of the Smart Condo architecture.

Wireless Sensor Network (WSN)

As we have already mentioned, our first objective in the Smart Condo has been to unobtrusively, yet in a precise and timely fashion, recognize the occupant's location and activities. To this end, we have deployed several passive-infrared motion sensors throughout the environment. To augment these observations, we have deployed tactile pressure sensors on chairs to detect sitting and a bed occupancy sensor to detect presence on the bed. Moreover, by observing changes in the state of furniture and appliances we can further recognize the occupant's activities in the environment, e.g., whether he or she is opening or closing appliance doors, for example. Thus, we have deployed magnetic reed switches on both the entrance and microwave doors.

The sensors are connected to wireless nodes, currently the DM2200 module from RF Monolithics[8]. Each WSN node consists of (a) a microcontroller, (b) a radio transceiver, and (c) an energy source. The microcontroller enables the node to interface with sensors and executes a simple "observe sensor value, sleep, and wake up" application. The radio transceiver enables the node to communicate the observed data wirelessly with other nodes. Typically, wireless modules use simple microcontrollers and transceivers. They tend to have very limited processing and storage ability (e.g., the MSP430F148 microcontroller: 8 MHz, 48 KB flash memory, and 2 KB RAM). They also tend to communicate data at slow data rates (e.g., the TR8100 transceiver: 9600 bps). These characteristics stem from both the application requirements and a desire to keep both costs and energy consumption low. Each of our nodes runs the PicOS operating system (Akhmetshina, Gburzynski, and Vizeacoumar, 2003). The development tools associated with PicOS are reviewed in the section titled The Development Toolkit.

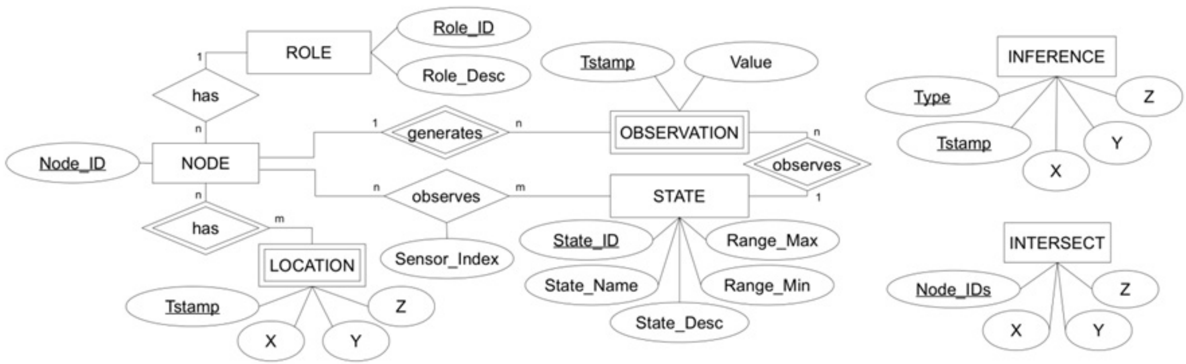
In a wireless network, there are two primary techniques for moving data from a sender to a receiver: single-hop and multi-hop communication. In the former case, the two nodes must be within each other's radio-transceiver range, in which case the sender transmits the data directly to the receiver. When the receiver is outside of the sender's transmission range, the sender relies on intermediate nodes to forward its data toward the receiver through multiple hops. The Smart Condo space is small enough that all nodes can communicate directly, in a single hop, with the sink node.

The Network-Service Interface Layer

The sink node is a node of the same type as described above with the exception that it is connected to an interface board, which is connected as a peripheral to a more capable host through a USB interface. It is actually this combination of wireless module, interface board, and host that we call a sink. These sink nodes bridge the WSN with a typically wired (Ethernet) backbone network. When observations arrive wirelessly from the sensor network to the sink, the wireless node encapsulates them in the TinyOS serial message format (Levis et al., 2005) and transmits them to the attached host through a socket. The Operations Support System (OSS), implemented in Perl, connects to this socket and sees all packets received at the sink. It parses the packets, generates acknowledgments for the WSN nodes in the WSN, and makes the data stream available to any other application that might need to process it, thus allowing the same WSN to be shared among multiple applications.

We see several benefits to this sink-to-OSS forwarding approach. First, it offloads all data processing on more capable servers. The sink node, even though more powerful than a WSN node, is still assumed to have limited resources of its own. Second, through its particular acknowledgement strategy, it enforces end-to-end reliability between each individual sensor node and the OSS. This is important for handling failures at any intermediate step and for removing stored sensed data at the sensor nodes only after it is absolutely certain that the data have been delivered to the application. Third, the approach simplifies maintenance. As we add new types of sensors, we only need to update the software on a central server rather than each individual sink node.

Figure 4. The SensorDB ER diagram



The OSS generated data stream is in the form of tuples, consisting of (a) time-stamp, (b) network ID, (c) node ID, (d) sensor ID, (e) sensor type, and (f) event type. The *time-stamp* indicates when the event occurred. The *network ID* allows several independent WSN deployments to report to a single OSS, and the *node ID* identifies a single node within each network. The *sensor ID* and *sensor type* together distinguish a specific peripheral connected to a wireless module. Finally, *event type* describes the observation made by an attached sensor.

In our application, the OSS is connected to the stream-processing engine that is responsible for saving all received observations in the Smart Condo repository, SensorDB, and inferring higher-order information by recognizing simple patterns on the data stream within a short time window. The basic intuition here is that, in some cases, co-occurring readings of individual sensors are caused by a single complex phenomenon in the world. Therefore, the hypothesis is that one can define the patterns of sensor readings that correspond to such phenomena of interest and then recognize instances of these patterns in the data stream as evidence of the occurrence of this phenomenon. In the Smart Condo, we use the stream-mining component to infer the occupant's location. Specifically, passive-infrared motion sensors have a view that ranges from around 38º (for the spot variety) to 116º (for the wide-angle variety) to a distance of either five or ten meters, respectively. The sensor's binary output simply indicates whether it detected movement within this field of view. As viewable regions overlap, patterns of independent sensor readings correspond to the recognition of the occupant in a location within their area overlap. Therefore, the smaller the area, the more precise is the inferred location.

Note that, at this point, we assume only a single occupant with the condo. Given multiple occupants, radio-frequency identification (RFID) could help distinguish between them (Kanai, Nakada, Hanbat, and Kunifuji, 2008).

The Service Layer: SensorDB and the REST APIs

The SensorDB serves as the long-term repository of (a) the collected sensor data, (b) the information derived from it through the stream-mining component, and (c) the data extracted by a standard data-mining component. It contains five primary tables (see Figure 4).

1. NODE, with attribute Node_ID, records the sensor node IDs deployed in the network.
2. LOCATION, with attributes for the longitude, latitude, altitude, and a time-stamp, identifies the physical location of each node.

We include a time-stamp field to support mobile nodes.

3. STATE lists all the possible states/phenomena that a node may observe.
4. OBSERVATION contains the actual state measurements. Each observation must come from a node and measure one of the observed states.
5. ROLE lists the possible functions a node may assume in the network (e.g., sensor or sink). At any given moment, each node is associated with one of these roles.

Two additional tables, INTERSECT and INFERENCES, support the stream processing. We use an intersection analysis tool to convert possibly overlapping passive-infrared sensor polygons to non-overlapping regions; INTERSECT stores the results from this analysis. The localization procedure uses data from this table to compute the occupant's location and stores the results in the table INFERENCES.

The data hosted in SensorDB is made available to client applications in a service-oriented manner through a set of REST APIs (Fielding and Taylor, 2002). Service orientation is a new, increasingly adopted software-engineering paradigm, which advocates the design and development of complex software systems through the composition of (independently designed and developed) *services*. These services, although implemented in a variety of platforms and programming languages, are interoperable through open XML-based specifications of their interfaces. Today, under the term *service interface*, two distinct types of specifications are understood: (a) operation-based APIs specified in WSDL and accessed at run-time through SOAP and (b) data-centric APIs specified in terms of the XML schemas of the data communicated and accessed at run-time through HTTP. The latter type is simpler to implement, typically requires less parsing at run time, and, more importantly, makes no commitment to a standardized set of operations to be performed on the repository data, which is the case with WSDL APIs. These are the primary reasons why we chose this style for the Smart Condo architecture.

The decision to use REST was also validated by the fact that it accommodates the restrictions imposed by the Second Life programming environment, which we subsequently adopted as a 3D world in which to reflect the condo's state and the occupant's activities.

This environment limits communication with external web-based applications to a URL-based request and the receipt of the response as a string of text, which can then be parsed by the limited text-processing functions. Fortunately, these limited capabilities are sufficient for a REST-based system, and thus the SL client is able to communicate effectively with the intermediary program.

Second Life: The 3D Mirror of the Smart Condo

As we mentioned in the beginning of this section, SensorGIS (Huang, Boers, Stroulia, Gburzynski, and Nikolaidis, 2010) is one of the applications accessing the Smart Condo APIs to visualize the sensor data on a map and through graphs. We will not discuss this application in detail here. In this chapter, we will focus on the Second Life-based application (Boers et al., 2009) that reflects the state of the condo and the occupant's activities.

The Second Life-based application is composed of (a) a conversion utility that can turn a 2D blueprint of a home into a 3D model, (b) an automated character module that is responsible for moving the occupant's avatar through the locations at which the occupant has been detected by the stream miner, (c) a path-planning algorithm to extrapolate the occupant's avatar path around obstacles between these locations, and (d) a control system to coordinate these components.

We discuss the first component in the next section titled The Development Toolkit. Once the virtual space has been created, the occupant's avatar can be placed in an initial position within that space and given instructions on where it should move. The actual movement of the occupant's avatar is controlled by a Second Life script. This module essentially serves as the controller of the SL avatar of the occupant, instead of an actual user of the SL client, by interpreting a sequence of geographic (latitude/longitude) co-ordinates and associated time-stamps, accessed through the service-layer APIs, into instructions for movement and actions (sitting on a chair, opening/closing doors, lying on a bed). These data are then converted in both space and time: the spatial co-ordinates are translated to the virtual-world co-ordinates, and their associated time-stamps are translated to match the replay speed chosen by the user. Thus, the control system creates a list of local destination co-ordinates along with the appropriate delay between each destination. Before these co-ordinates are used to move the occupant's avatar, however, they are converted to a set of intermediate points using the path-planning algorithm. This component, a C implementation of a potential-fields algorithm (Greytak, 2005), ensures that the character does not walk through any obstacles on its way to a destination.

Our use of Second Life as a means of visualizing the activities of the Smart Condo occupant is motivated by several reasons. First it enables an intuitive comparison of the correctness of the system inferences against the video recording of the space. Video recording provides a very precise record of the occupant's life but it raises many challenges, both technical with respect to storage requirements and information extraction, as well as social, around privacy. The Second Life visualization is generated through the sensor data-stream analysis and need not be stored as it can be regenerated upon demand. At the same time, it provides an intuitive interface for health professionals and family members alike, who can be aware of the occupant's activities as opposed to simply being alerted to exceptional problematic events. Even if health professionals and family members want to only be alerted upon such events, the Second-Life visualization – regenerated upon demand – can potentially provide more context about the person's activities before the event of interest. Finally, we envision Second Life will be useful, not simply as a visualization environment, but also as a bidirectional communication platform between the Smart-Condo occupant and his/her health providers and family members. We would like to encourage the occupant's friends to visit with him/her in the Second Life Smart Condo as well as enable the occupant to visit other places and potentially develop a parasocial life in the virtual world. By no means, would we want to encourage further alienation of he elderly by "locking" them in the virtual world, as opposed to encouraging them to participate in real-world activities. However, in some cases (mobility issues, lack of family members in the vicinity, long winters), this environment can provide a rich alternative and augmentation medium of the occupant's social life.

The Development Toolkit

In this section, we discuss the utilities that we have developed to support the deployment of the Smart Condo. The first tools relate to the wireless sensor network and the later tools relate to the virtual world and visualization.

To develop our software, we relied extensively on the emulation environment named SIDE (Gburzynski, 1995; Dobosiewicz and Gburzynski, 1997; Gburzynski and Nikolaidis, 2006) and its API for PicOS named VUE[2] (Boers, Gburzynski, Nikolaidis, and Olesinski, 2010). These tools allowed us to build our application for either the actual hardware or the emulated environment simply by running the appropriate compiler. With only a little extra effort, we then built our Operations Support System (OSS) to work seamlessly with both the real and emulated system. This integrated combination allowed us to test the WSN node software, the OSS, and the stream processing components before actually

Figure 5. The Smart Condo rendered in SL

deploying any hardware. It allowed us to debug our code with ease.

In terms of the virtual world, the first tool supports the development of the 3D model of the particular space in which the infrastructure is deployed. The user can trace the location of the walls and indicate the location of furniture using a web-based blueprint creation tool. The tool stores these locations in a database. Once this input process is complete, a program written within SL reads the information from the database and creates walls and furniture in the specified locations. Finally, color and textures can be added, through built-in SL tools, to improve the appearance of the virtual condo. At the same time, the wall and furniture locations are used to create a grid-based obstacle map, which guides the path-planning algorithm. Figure 5 shows a top-down view of the Smart Condo, created in Second Life. Figure 6 shows a close-up of both an occupant's avatar and an observer.

Another development tool is designed to help with the deployment of the various sensors in the space. As we already mentioned, the occupant's location is inferred by recognizing patterns of related sensor readings in the data stream. Though each sensor detects environmental changes independently and has its own detection zone, different zones might overlap. A single movement of the patient may trigger multiple readings from different sensors, which, when detected, indicate that the patient is somewhere within the intersection of the detection zones. It is therefore essential to place sensors in such a way that we maximize the coverage of the space while taking advantage of any overlap. To determine sensor placement, an analysis tool was developed. The analysis tool imports the floor plan of the Smart Condo and, through a user interface, receives possible locations for the available sensors. Based on the sensor specifications, it then visualizes their coverage and overlap on the floor plan. The user can adjust the sensor layout easily and re-compute the visual coverage when that layout changes. After the user comes up with a satisfactory layout, he or she can save it for further adjustment and/or use the tool to export the respective table entries into the database for localization lookup. This way, the analysis tool can save the network developer much effort in identifying the intersections.

Figure 6. The occupant's avatar, wearing a white shirt, in the SL condo with an observer

Experience with the Smart Condo

After placing sensors within the unit, we worked with our colleagues in occupational therapy (OT) to evaluate our work. A test subject followed a number of scripts within the unit while the OTs evaluated the virtual representation. The Smart Condo contains a number of video cameras (which were installed in the room for a different project), which we used to verify inferences about the location of the occupant. Our OT colleagues matched the script with their observations of both the video feed and the virtual representation. The scripts included such actions as moving from room to room, sitting on chairs, and opening and closing doors. The initial reaction of our colleagues was positive: they were very satisfied with the fidelity of the virtual representation with respect to the real world and felt that this would be a useful tool for monitoring patients undergoing rehabilitation.

RESEARCH CHALLENGES

In our short experience setting up the condo with our colleagues in Occupational Therapy, Pharmacy, and Industrial Design, one challenge we had to meet was our differences in "language" and methodological assumptions. As Computing-Science researchers, we were primarily concerned with the technical capabilities of the infrastructure, its potential for extendibility and scalability, and its technical constraints. Our colleagues were very much guided by the needs of the personas for whom they were designing the space and had to ensure that all functions developed made sense to (and were usable by) these personas. As a team, we are continuously adjusting to each other and the experience has been interesting and rewarding. Having acknowledged this social/methodological challenge, in this section, we discuss the technical research challenges we see for the next stages of the project, as we move to develop an extendible, easily deployable system.

WSNs for Smart Indoor Environments

The task of integrating new types of sensors to wireless nodes still requires specialized programming skills, not necessarily taught as part of most computing-science degree programs. To simplify this process, a development-support toolkit is required, including tools to support (a) the development of new sensor drivers and core applications and (b) the deployment of the heterogeneous sensors within an interior space to maximize the coverage of the space (thus improving the degree to which the occupant's activities are recognized) and to optimize the number and type of necessary sensors.

The integration of new sensor types in a WSN requires the development of a standard set of core software services at the WSN node level, i.e., data packetization, duty-cycle (sleep vs. processing) of the sensor node, selection of a (variant of an existing) communication protocol, and message routing. This software has to be optimized for code-footprint, data-loss, and energy-consumption minimization. In the Smart Condo installation, for example, we had to fine-tune the node sleep-processing cycle in order to make sure that the delay between the activity in the real world and its reflection in the virtual world was less than 20 seconds. The long-term objective of our WSN research is to develop a service-oriented model for sensor applications, and a corresponding IDE[9] for model-driven engineering (Schmidt, 2006) of such applications.

Beyond the development of software for new sensors, this envisioned IDE should also support the design, development, testing, and simulation of the overall sensor-network application; as long as the types of sensors used in the network are known, domain experts (e.g., residential property managers) should be able to deploy their applications (e.g., temperature sensing and HVAC controlling) and know in advance, possibly though model checking and/or simulation, its properties (e.g., the temperature will not be above 20˚C for more than 3 minutes). An essential step in this process is the placement of the sensors themselves, which is currently an empirical, experience-based activity. The automation of the placement of heterogeneous sensors in order to meet the monitoring and control requirements of the application is an important challenge that has to be met if these systems are to be widely adopted.

Finally, in addition to the IDE for WSN application development, another essential activity for effective health management and care delivery is the reengineering of existing health-monitoring devices in order for them to serve as "sensors" in our sensor networks. Patients are increasingly using commercially available off-the-shelf devices to monitor and manage their health, e.g., blood glucose meters, blood pressure monitors, etc. Information arising from the use of these devices (possibly stored in a proprietary format) can be essential to having a complete picture of the patient's current status and history. This is of special interest to pharmacists who can use this information when interacting with patients to renew medications.

SOA Systems for Monitoring, Analysis, and Control

The core objective in developing the software architecture of the Smart Condo system has been to support the flexible integration of various data streams, whether from sensor networks or from home-care devices potentially, and to accommodate multiple types of data analyses and user views and the flexible integration of new analyses and views.

We have considered both the REST and WS* SOA styles for our system and we decided to adopt the REST style, since the implied data-centric application model is simpler to conceptualize and enables more flexible integration of future modules, as it does not assume any agreement on standard operations. REST APIs are also very appropriate for communication between the Rich Internet Clients, through which the archived information may be communicated to its different classes of users (i.e., patients, their families, healthcare professionals, educators, and students). To date, our work has focused mostly on a variety of views for effectively communicating the sensed information through standard graphs and plots, a 2D GIS view, a 3D virtual-world visualization, and a wiki through which patients and healthcare professionals can record their observations on the recorded information.

Clearly, as can be seen by reviewing the "smart homes" listed previously, the primary functionalities of interest are (a) mining the collected data to extract higher-order information and (b) using the inferred information to control the environment or somehow support the resident. Several types of data-mining services are potentially useful. In a short time scale (seconds), data streams can be examined to recognize patterns on the basis of which to raise alarms, such as for example, recognizing falls based on accelerometers either worn on the person or embedded in the floor (Rajendran, Corcoran, Kinosian, and Alwan, 2008; Alwan et al., 2006). In a longer time scale (days), data can be mined to recognize patterns in the residents' behavior. These patterns can be associated with specific control actions or interactions with the residents. For example, recognizing the completion of the resident's nightly routine, the system may switch off all lights and remind the resident of his nightly medicine. Recognizing near misses from well-established routines, such as for example sleeping unusually late, may also trigger alarms to family members and health professionals. Finally, special purpose mining algorithms are necessary for analyzing patterns of physiological variables recorded by wearable and embedded sensors, such as for example, gait analysis based on sensors embedded in footwear and sleep-pattern analysis based on bed sensors. In addition to these services, research is required to address the following issues.

Further support is necessary for users interested in accessing and visualizing information. Instead of having a pre-designed set of views to the information, high-level domain-specific languages are necessary to enable domain experts to query the collected data for information of interest. For example, a health professional may be interested in knowing the longest segment of continuous standing or walking activity by the patient and he should be able to specify this query, have the system translate it into an efficient SQL query, and visualize the results in an appropriate view.

Finally, in order to better support the interpretation of the collected data, it is essential to enable the appropriate stakeholders to annotate information of interest with their observations. We envision that the information sensed by the Smart Condo, aggregated and abstracted through data mining and further redacted by the resident patient and his healthcare providers, will be part of his electronic health record. To enable this vision, the system users, both patient and healthcare professionals, should be able to review the collected information and annotate it with their (self) observations and interpretations. We are experimenting with an access-controlled wiki for that purpose.

Virtual Worlds for Simulation and Training

One of the most innovative aspects of the Smart Condo infrastructure, we believe, is the use of a virtual-world platform (Second Life, more specifically) for visualizing the activities of the condo tenant through an avatar. We believe that this type of view into the patient's everyday life can fundamentally enhance the interaction between patients and their healthcare providers and family members. This view is more intuitive than information visualization and enables realistic communication between the patients and their pharmacists, nurses, doctors, and family who can "visit" the patients in their own (virtual) home. This increased realism can potentially improve the social life of patients who may have difficulties getting out of their homes, without compromising their privacy to the degree video-based monitoring systems do. As the technologies mature, we expect health professionals to visit patients in a virtual world and interact with them in a context that should be more engaging, and with a higher-degree of social presence. Furthermore, recordings of clinically relevant resident behaviors are available to be reviewed by healthcare teams for education purposes.

Clearly, there are a variety of concerns to be addressed by further research on the potential benefits that these platforms may bring and the potential issues they may bring forward. There are still technical problems involved in reflecting the physical environment in the virtual world in a way that is precise. Collada (https://collada.org) is an emerging standard, supported by several virtual worlds, although not Second Life, for digital-asset exchange within the interactive 3D industry. In parallel with the development of these aware environments, there is a need to also develop corresponding virtual-world-based instructional programs for health science students, so that they can effectively use the system to improve patient care and potentially decrease its costs. Finally, the psychological and social effect of enabling virtual socialization needs to be studied. Although, it has been shown that virtual worlds enable a sense of communication among people, it is not clear how this can benefit patient support and healthcare team communication and not lead to even more isolation for patients who are not as motivated to visit their healthcare team as often.

CONCLUSION

In this chapter, we discussed our work in the Smart Condo project. Our interdisciplinary team includes researchers from Occupational Therapy, Industrial Design, Pharmacy, and Computing Science. Together, we have developed a model condo, designed according to universal design principles, within which we have embedded a wireless network with a variety of sensors. The raw observations recorded by the sensor network, as well as the information inferred based on this raw data, are archived in a server, which supports a range of REST APIs. Using these APIs, the information is visualized in a 2D GIS and a 3D virtual world.

Our Smart Condo is one of a new breed of smart-home applications, all of which envision the (semi)automated monitoring and control of buildings, in order to improve interior climate control, reduce energy consumption, and support residents with physical and cognitive disabilities to live independently longer. There are three specific innovations in our work that distinguish it from the other research in the area. First, we are experimenting with a variety of sensor types, and we are looking into integrating commodity home-care device sensors in our networks. Second, we have developed an integrated software architecture with a component for collecting and archiving sensor-network data which is unaffected by changes in the sensor network topology, a stream-data mining component for synthesizing raw sensor network data into higher-order information, and a set of APIs through which the information can be provided to different clients for different types of visualization. Finally, we are using a virtual world, i.e., SL, as a highly realistic visualization of the condo and the activities of its occupant. This visualization is intuitive and easy to use for all healthcare professionals, who do not need to interpret graphs to infer information about the patient. Moreover it can also serve as a communication channel between the patient and the caregivers. At the same time, the system is minimally intrusive, since the patient is not required to wear any special-purpose devices and their appearance is not monitored or recorded – people, in general, do not like to be monitored by cameras and are generally resistant to wearing a “tag” with an RFID.

This work is in its initial stages, but based on our preliminary evaluation, our virtual-world visualization shows promising results. We have established that our approach is effective and capable of driving such visualizations.

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REFERENCES

Akhmetshina, E., Gburzynski, P., & Vizeacoumar, F. (2003). PicOS: A tiny operating system for extremely small embedded platforms. In *ESA '03: Proceedings of the International Conference on Embedded Systems and Applications* (pp. 116-122). Las Vegas, NV:CSREA Press.

Alwan, M., Rajendran, P. J., Kell, S., Mack, D., Dalal, S., Wolfe, M., & Felder, R. (2006). A smart and passive floor-vibration based fall detector for elderly. In *ICTTA '06: Proceedings of the International Conference on Information and Communication Technologies* (pp. 1003-1007).

Arduino. (2010). *Arduino website*. Retrieved January 5, 2010, from http://www.arduino.cc/

Atallah, L., Lo, B., Yang, G. Z., & Siegemund, F. (2008). Wirelessly accessible sensor populations (WASP) for elderly care monitoring. In *PervasiveHealth '08: Proceedings of the Second International Conference on Pervasive Computing Technologies for Healthcare* (pp. 2-7).

Bajcar, J. M., Kennie, N., & Einarson, T. R. (2005). Collaborative medication management in a team-based primary care practice: An explanatory conceptual framework. *Research in Social & Administrative Pharmacy*, *1*(3), 408–429. doi:10.1016/j.sapharm.2005.06.003

Beattie, E. R. A., Song, J. A., & LaGore, S. (2005). A comparison of wandering behaviour in nursing homes and assisted living facilities. *Research and Theory for Nursing Practice*. *International Journal (Toronto, Ont.)*, *19*(2), 181–192.

Beney, J., Bero, L. A., & Bond, C. M. (2000). Expanding the roles of outpatient pharmacists: Effects on health services utilisation, costs, and patient outcomes. *Cochrane Database of Systematic Reviews*, *2*, CD000336. doi:. doi:10.1002/14651858.CD000336

Boers, N. M., Chodos, D., Huang, J., Gburzynski, P., Nikolaidis, I., & Stroulia, E. (2009). The Smart Condo: Visualizing independent living environments in a virtual world. In *PervasiveHealth '09: Proceedings of the Third International Conference on Pervasive Computing Technologies for Healthcare*, 1-8.

Boers, N. M., Gburzynski, P., Nikolaidis, I., & Olesinski, W. (2010). Developing wireless sensor network applications in a virtual environment. *Telecommunication Systems*, *45*, 165–176. doi:10.1007/s11235-009-9246-x

Boyd, C. M., Darer, J., Boult, C., Fried, L. P., Boult, L., & Wu, A. W. (2005). Clinical practice guidelines and quality of care for older patients with multiple comorbid diseases. *Journal of the American Medical Association*, *293*, 716–724. doi:10.1001/jama.294.6.716

Cassel, C. K. (2009). Policy for an aging society. Review of systems. *Journal of the American Medical Association*, *302*, 2701–2702. doi:10.1001/jama.2009.1901

Cook, D. J. (2006). Health monitoring and assistance to support aging in place. *Journal of Universal Computer Science*, *12*(1), 15–29.

Dobbs, D., Munn, J., Zimmerman, S., Boustani, M., Williams, C. S., & Sloane, P. D. (2005). Characteristics associated with lower activity involvement in long-term care residents with dementia. *The Gerontologist*, *12*(1), 81–86.

Dobosiewicz, W., & Gburzynski, P. (1997). Protocol design in SMURPH. In *State of the Art in Performance Modeling and Simulation* (pp. 255-274).

Fielding, R. T., & Taylor, R. N. (2002). Principled design of the modern Web architecture. *ACM Transactions on Internet Technology*, *2*(2), 115–150. doi:10.1145/514183.514185

Gburzynski, P. (1995). *Protocol design for local and metropolitan area networks*. Upper Saddle River, NJ: Prentice Hall PTR.

Gburzynski, P., & Nikolaidis, I. (2006). Wireless network simulation extensions in SIDE/SMURPH. In *Proceedings of the 38th Winter Simulation Conference* (pp. 2225-2233).

Greytak, M. (2005). *Numerical potential field path planning tutorial*. Retrieved January 4, 2010, from http://ocw.mit.edu/NR/rdonlyres/Aeronautics-and-Astronautics/16-410Fall-2005/E6469924-5AE3-41C0-AA36-145D20739B7E/0/greytak.pdf

Gruber-Baldini, A. L., Zimmerman, S., Boustani, M., Watson, L. C., Williams, C. S., & Reed, P. S. (2005). Characteristics associated with depression in long-term care residents with dementia. *The Gerontologist*, *45*(1), 50–55.

Haynes, R. B., Ackloo, E., Sahota, N., McDonald, H. P., & Yao, X. (2008). Interventions for enhancing medication adherence. *Cochrane Database of Systematic Reviews*, *2*, CD000011. doi:. doi:10.1002/14651858.CD000011.pub3

Helal, S., Mann, W. C., El-Zabadani, H., King, J., Kaddoura, Y., & Jansen, E. (2005). The Gator Tech Smart House: A programmable pervasive space. *IEEE Computer*, *38*(3), 50–60.

Hori, T. Nishida, Y. Aizawa, H. Murakami, S., & Mizoguchi, H. (2004). Sensor network for supporting elderly care home. In *Proceedings of IEEE Sensors: Vol. 2* (pp. 575-578).

Hori, T., Nishida, Y., & Murakami, S. (2006). Pervasive sensor system for evidence-based nursing care support. In *ICRA '06: Proceedings of the IEEE International Conference on Robotics and Automation* (pp. 1680-1685).

Huang, J., Boers, N. M., Stroulia, E., Gburzynski, P., & Nikolaidis, I. (2010). SensorGIS: An integrated architecture for information systems based on sensor networks. In *WEBIST '10: Proceedings of the 6th International Conference on Web Information Systems and Technologies*.

Kanai, H., Nakada, T., Hanbat, Y., & Kunifuji, S. (2008). A support system for context awareness in a group home using sound cues. In *PervasiveHealth '08: Second International Conference on Pervasive Computing Technologies for Healthcare* (pp. 264-267).

Kientz, J. A., Patel, S. N., Jones, B., Price, E., Mynatt, E. D., & Abowd, G. D. (2008). The Georgia Tech Aware Home. In *CHI '08: Extended Abstracts on Human Factors in Computing Systems* (pp. 3675-3680).

Kientz, J. A., Patel, S. N., Tyebkhan, A. Z., Gane, B., Wiley, J., & Abowd, G. D. (2006). Where's my stuff?: Design and evaluation of a mobile system for locating lost items for the visually impaired. In *ASSETS '06: Proceedings of the 8th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 103-110).

Kleinberger, T., Becker, M., Ras, E., Holzinger, A., & Müller, P. (2007). Ambient intelligence in assisted living: Enable elderly people to handle future interfaces. In *Lecture Notes in Computer Science: Vol. 4555/2007. Universal Access in Human-Computer Interaction. Ambient Interaction* (pp. 103-112). Germany: Springer Verlag.

Levis, P., Madden, S., Polastre, J., Szewczyk, R., Whitehouse, K., Woo, A., & Gay, D. Hill, J., Welsh, M., Brewer, E., & Culler D. (2005). TinyOS: An operating system for sensor networks. In *Ambient Intelligence* (pp. 115-148). The Netherlands: Springer Verlag.

McDaniel, J. H., Hunt, A., Hackes, B., & Pope, J. F. (2001). Impact of dining room environment on nutritional intake of Alzheimer's residents: A case study. *American Journal of Alzheimer's Disease and Other Dementias*, *16*(5), 297–302. doi:10.1177/153331750101600508

Metaxas, M. Markopoulos. P., Aarts, E. H. L. (2009). Amelie: A Recombinant Computing Framework for Ambient Awareness. In *Ambient Intelligence 2009* (pp. 88-100).

Morgan, D. G., & Stewart, N. M. (1997). The importance of the social environment in dementia care. *Western Journal of Nursing Research*, *19*(6), 740–761. doi:10.1177/019394599701900604

Morgan, D. G., & Stewart, N. M. (1998). Multiple occupancy versus private rooms on dementia care units. *Environment and Behavior*, *30*(4), 487–503. doi:10.1177/001391659803000404

Mukherjee, S., Aarts, E. H. L., & Doyle, T. (2009). Special issue on Ambient Intelligence. *Information Systems Frontiers*, *11*(1), 1–5. doi:10.1007/s10796-008-9146-8

Nowak, L. A., & Davis, J. E. (2007). A qualitative examination of the phenomenon of sundowning. *Journal of Nursing Scholarship*, *39*(3), 256–258. doi:10.1111/j.1547-5069.2007.00177.x

Oracle Corporation. (2010). *Sun SPOTS*. Retrieved on January 5, 2010 from http://planets.sun.com/SunSPOT/

Rajendran, P., Corcoran, A., Kinosian, B., & Alwan, M. (2008). Falls, fall prevention, and fall detection technologies. In R. J. Pignolo, M. A. Forciea, & J. C. Johnson (Series Eds.) & R. Felder & M. Alwan (Vol. Eds.), *Aging medicine: Eldercare technology for clinical practitioners* (pp. 187-202). Totowa, NJ: Humana Press.

Ramage-Morin, P. L. (2009). Medication use among senior Canadians. *Health Reports*, *20*(1), 1–8.

Ras, E., Becker, M., & Koch, J. (2007). Engineering tele-health solutions in the ambient assisted living lab. In *AINAW '07: 21st International Conference on Advanced Information Networking and Applications Workshops*: *Vol 2* (pp. 804-809).

Roughead, E. E., Semple, S. J., & Vitry, A. I. (2005). Pharmaceutical care services: A systematic review of published studies, 1990 to 2003, examining effectiveness in improving patient outcomes. *International Journal of Pharmacy Practice*, *13*, 53–70. doi:10.1211/0022357055551

Santschi, V., Wuerzner, G., Schneider, M., Bugnon, O., & Burnier, M. (2007). Clinical evaluation of IDAS II, a new electronic device enabling drug adherence monitoring. *European Journal of Clinical Pharmacology*, *63*(12), 1179–1184. doi:10.1007/s00228-007-0364-7

Schmidt, D. C. (2006). Guest editor's introduction: Model-driven engineering. *Computer*, *39*(2), 25–31. doi:10.1109/MC.2006.58

Shaspa Smart Home Kit. (2009). Retrieved from http://www.shaspa.com

Skubic, M., Alexander, G., Popescu, M., Rantz, M., & Keller, J. (2009). A Smart Home Application to Eldercare: Current Status and Lessons Learned. *Technology and Health Care*, *17*(3), 183–201.

Statistics Canada. (2006). *2006 Census: Portrait of the Canadian Population in 2006, by Age and Sex: National portrait*.Retrieved on January 6, 2010, from http://www12.statcan.ca/census-recensement/2006/as-sa/97-551/p3-eng.cfm

Task Force on a Blueprint for Pharmacy. (2008). *Blueprint for pharmacy: the vision for pharmacy*. Ottawa, ON: Canadian Pharmacists Association.

The Center for Universal Design. (1997). *The principles of universal design, version 2.0*. Raleigh, NC: North Carolina State University.

Tinetti, M. E., & Fried, T. (2004). The end of the disease era. *The American Journal of Medicine*, *116*(3), 179–185. doi:10.1016/j.amjmed.2003.09.031

Tran, Q., Calcaterra, G., & Mynatt, E. (2005). Cook's collage: Deja vu display for a home kitchen. In *HOIT '05: Proceedings of Home-Oriented Informatics and Telematics* (pp. 15-32).

US Department of Health and Human Services. (2010). *Exhibit 2.11 estimated percentage of physician's time spent providing care to patients, by age of patient*. Retrieved on January 6, 2010, from http://bhpr.hrsa.gov/healthworkforce/reports/changedemo/images/2.11.htm

Zingmark, K., Sandman, P. O., & Norberg, A. (2002). Promoting a good life among people with Alzheimer's disease. *Journal of Advanced Nursing*, *38*(1), 50–58. doi:10.1046/j.1365-2648.2002.02145.x

ADDITIONAL READING

Abowd, G. D., Atkeson, C. G., Bobick, A. F., Essa, I. A., MacIntyre, B., Mynatt, E. D., & Starner, T. E. (2000). Living laboratories: the future computing environments group at the Georgia Institute of Technology. In *CHI '00 extended abstracts on Human factors in computing systems* (pp. 215-216).

Brumitt, B., Meyers, B., Krumm, J., Kern, A., & Shafer, S. A. (2000). EasyLiving: Technologies for Intelligent Environments. In *Proceedings of the 2nd international symposium on Handheld and Ubiquitous Computing* (pp.12-29).

Canadian Healthcare Association. (2009). *New directions for facility-based long-term care*. Ottawa: Canadian Healthcare Association.

Carswell, W., McCullagh, P. J., Augusto, J. C., Martin, S., Mulvenna, M. D., & Zheng, H. (2009). A review of the role of assistive technology for people with dementia in the hours of darkness. *Technology and Health Care*, *17*, 281–304.

Chan, M., Estève, D., Escriba, C., & Campo, E. (2008). A review of smart homes-Present state and future challenges. *Computer Methods and Programs in Biomedicine*, *91*(1), 55–81. doi:10.1016/j.cmpb.2008.02.001

Christensen, D. B., & Farris, K. B. (2006). Pharmaceutical care in community pharmacies: Practice and research in the US. *The Annals of Pharmacotherapy*, *40*(7), 1400–1406. doi:10.1345/aph.1G545

Das, S., Cook, D. J., Bhattacharya, A., Heierman, I. E. O., & Lin, T.-Y. (2003). *The role of prediction algorithms in the MavHome smart home architecture*. IEEE Wireless Communications.

Emiliani, P. L., & Stephanidis, C. (2005). Universal access to ambient intelligence environments: Opportunities and challenges for people with disabilities. *IBM Systems Journal*, *44*(3), 605–619. doi:10.1147/sj.443.0605

Fuchsberger, V. (2008). Ambient assisted living: elderly people's needs and how to face them. In *SAME '08: Proceeding of the 1st ACM international workshop on Semantic ambient media experiences* (pp. 21-24).

Hanák, D., Szijarto, G., & Takacs, B. (2007). A Mobile Approach to Ambient Assisted Living. In *IADIS Wireless Applications and Computing* (pp. 1-8).

Hayes, G. R., Shehan, E., Iachello, G., Patel, S. N., Grimes, A., Abowd, G. D., & Truong, K. N. Physical, Social, and Experiential Knowledge of Privacy and Security in a Pervasive Computing Environment. In *IEEE Pervasive Computing*, Oct. – Dec. 2007.

Henkler, S., Greenyer, J., Hirsch, M., Schäfer, W., Alhawash, K., Eckardt, T., et al. (2009). Synthesis of timed behavior from scenarios in the Fujaba real-time tool suite. In *ICSE '09: Proceedings of the 31st International Conference on Software Engineering* (pp. 615-618).

Jones, E. J., MacKinnon, N. J., & Tsuyuki, R. T. (2005). Pharmaceutical care in community pharmacies: Practice and research in Canada. *The Annals of Pharmacotherapy*, *39*(9), 1527–1533. doi:10.1345/aph.1E456

King, J., Bose, R., Zabadani, H., Yang, H., & Helal, A. (2006). Atlas: A Service-Oriented Sensor Platform. In *Proceedings of the 31st IEEE Conference on Local Computer Networks* (pp.630-638).

Kohler, M., Patel, S. N., Summet, J. W., Stuntebeck, E. P., & Abowd, G. D. (2007). TrackSense: Infrastructure Free Precise Indoor Positioning using Projected Patterns. In *Proceedings of the 5th International Conference on Pervasive Computing*, 334-350.

Lesser, V., Atighetchi, M., Benyo, B., Horling, B., Raja, A., Vincent, R., et al. (1999). The intelligent home testbed. In *Proceedings of the Autonomy Control Software Workshop.*

Lester, J., Choudhury, T., & Borriello, G. (2006). A Practical Approach to Recognizing Physical Activities. In *Proceedings of the 4th International Conference on Pervasive Computing* (pp. 1-16).

Mynatt, E. D., & Rogers, W. A. (2002). Developing technology to support the functional independence of older adults. *Ageing International*, *27*(1), 24–41. doi:10.1007/s12126-001-1014-5

Nehmer, J., Karshmer, A., Becker, M., & Lamm, R. (2006). Living Assistance Systems – An Ambient Intelligence Approach. In *Proceedings of the 28th International Conference on Software Engineering* (pp. 43-50).

Perry, M., Dowdall, A., Lines, L., & Hone, K. (2004). Multimodal and ubiquitous computing systems: Supporting independent-living older users. *IEEE Transactions on Information Technology in Biomedicine*, *8*(3), 258–270. doi:10.1109/TITB.2004.835533

Spanoudakis, N., Moraitis, P., & Dimopoulos, Y. (2009). Engineering an Agent-based Approach to Ambient Assisted Living. In *Ambient Inelligence '09: Workshop on Interactions Techniques and Metaphors in Assistive Smart Environments* (pp. 268-271).

Tapia, E. M., Intille, S. S., & Larson, K. (2004) Activity recognition in the home using simple and ubiquitous sensors. In *Proceedings of Pervasive Computing* (pp. 158-175).

Weippl, E., Holzinger, A., & Tjoa, A. M. (2006). Security aspects of ubiquitous computing in health care. *Elektrotechnik and Informationstechnik*, *123*(4), 156–162. doi:10.1007/s00502-006-0336

Welch, G., & Foxlinv, E. (2002). Motion Tracking: No Silver Bullet, But a Respectable Arsenal. *IEEE Computer Graphics and Applications*, *22*(6), 24–38. doi:10.1109/MCG.2002.1046626

Yang, H., King, J., Helal, A., & Jansen, E. (2007). A Context-Driven Programming Model for Pervasive Spaces. *Proceeding of the 5th International Conference on Smart Homes and Health Telematics (ICOST)* (pp. 31-43).

KEY TERMS AND DEFINITIONS

Smart Home: In this paper, our use of the term *Smart Home* means a home that has both a set of sensors to observe the environment and a set of devices/actuators to improve the inhabitant's experience at home.

Wireless Sensor Network: A network that consists of distributed sensors that monitor physical or environmental conditions and are integrated on network nodes that wirelessly communicate these measurements through radio-frequency communication.

Virtual World: A 3D computer-based virtual environment, in which users can socialize, form communities and interact with one another and objects in the world.

Ambient Intelligence: Technologies that integrate a variety of sensors through which to perceive the presence and activities of people so that they can transparently respond to them in a way that supports these activities by controlling the environment.

Assisted Living: Physical and technological support for daily-life activities, for elderly and people with disabilities.

ENDNOTES

1 Radio Frequency Identification devices

2 http://ssrg.cs.ualberta.ca/index.php/Smart_Condo

3 Sundowning is a syndrome of six behaviors: physical aggression, resistiveness, disconcerted verbalizing, night-time sleeplessness, wandering, and daytime sleepiness.

4 Wandering is associated with complex physical and mental co-morbidities in people, who tend to be socially isolated, have limited attention span, and have impaired verbal communication skills.

5 ZeroConf is a protocol that provides self-configuration, i.e., without any user involvement, of devices joining a network and enables them to be accessible using IP protocols.

6 Common Object Request Broker Architecture enables inter operation of programs in different languages regardless of their operating system.

7 http://www.healthscience.ualberta.ca/nav02.cfm?nav02=87350&nav01=15074

8 The choice of hardware was completely pragmatic; nothing in our architecture depends on this particular piece of hardware.

9 Integrated Development Environment