Software Engineering for Health Education and Care Delivery Systems: The Smart Condo Project

Eleni Stroulia, David Chodos, Nicholas M. Boers, Jianzhao Huang,
Pawel Gburzynski, Ioannis Nikolaidis
Computing Science Department
University of Alberta
Edmonton, Alberta, T6G 2E8, Canada
{stroulia, chodos, boers, jianzhao, pawel, yannis}@cs.ualberta.ca

Abstract

Providing affordable, high-quality healthcare to the elderly while enabling them to live independently longer is of critical importance, as this is an increasing and expensive demographic to treat. Sensor-network technologies are essential to developing assisted living environments. In our Smart Condo project, we have deployed a sensor network with a variety of sensor types in an 850 square-foot condominium. The sensor network records a variety of events and environmental parameters and feeds the related data into our web-based system. This system is responsible for inferring higher-order information about the activities of the condo's occupant and supporting the visualization of the collected information in a 2D Geographic Information System (GIS) and a 3D virtual world, namely Second Life (SL).

1. Introduction

Providing affordable, high-quality healthcare to the elderly—an expensive demographic to treat—while enabling them to live independently longer is critical. The overall problem of at-home health monitoring and care delivery is socially important and technically challenging. It comes with a variety of social requirements, distinct yet equally important as the technical requirements relevant to each of the types of technologies employed in its context.

1) First is the issue of privacy: patients, although they may appreciate the increased sense of safety that comes with the monitoring infrastructure, are leery to have their every move monitored. The question then becomes the identification of an acceptable trade-off between privacy intrusion and safety.
2) Second is the issue of variability: 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.

In the context of our service-systems activities, (http://ssrg.cs.ualberta.ca) we have recently started working with colleagues in Rehabilitation Medicine, Art and Design, Pharmacy, and Education towards developing a Smart Condo that can support seniors and patients living at home or in rehabilitation facilities. Although these individuals are, by and large, able to live independently, they are still susceptible to harmful incidents related to physical infirmities or memory loss. Thus, we are developing a model Smart Condo, designed according to Universal Design [22] principles, 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.

In this manner, healthcare professionals have a live stream of the person's activity and can be alerted to intervene at the occurrence of a harmful event, or they could even go in the virtual world to communicate with the patient there. One of the objectives of the Smart Condo is to model and instrument health care "transition" facilities, where individuals that have been subjected to a major medical intervention are expected to develop autonomy before they are officially released from care. To encourage the development of such autonomy, it is important to limit intervention by others, but still be able to monitor their progress over a period of time. Eventually, the same technology employed by Smart Condo can be subsequently used in the individual's residence.

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 in an accelerated mode, 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.

In this paper, we first review the substantial literature on the use of sensors for caring for patients and the elderly in hospitals and at home (Section 2). We then report on our experience to date developing the Smart Condo infrastructure (Section 3) and we identify a list of research challenges for software engineering in this domain (Section 4). We summarize with a few lessons from our work to date (Section 5).

2. Related Work

Our work on the Smart Condo touches upon several research areas and it is impossible to review all related work here. Instead, we have chosen to discuss a few relatively mature projects exemplifying the state-of-the-art on the use of sensors for home monitoring and control (Section 2.1). For a less eclectic survey of this domain, the interested reader should see [13]. Finally, we are starting to see several projects aiming towards using virtual-world platforms for reflecting and controlling real-world state through sensors and actuators (Section 2.2).

2.1 Smart Environments for Elderly and Patient Care

As can be seen in Table 1, there are already several efforts to develop a smart home. The most well-known project in this area is most likely Georgia Tech's *Aware Home Research Institute,* which is "devoted to the multidisciplinary exploration of emerging technologies and services based in the home" and seeks to "provide services to [the home's] residents that enhance their quality of life or help them to maintain independence as they age." A variety of distinct research activities have been carried out in the context of this project, most focusing on usability concerns around a smart space. For example, Fetch [11] assists visually impaired people to locate misplaced objects, and Cook's Collage [16] assists seniors in following recipes. Most likely, the activity closest to our the Smart Condo is the Power Line Positioning (PLP) project [14], which analyzes the frequencies of signals sent over power lines to infer the location of electronic devices within the home. In effect, special modules located at each end of the house serve as sensors for localizing domestic robots (such as the Roomba) and potentially finding missing items, e.g., keys and wallets.

The MavHome project at the University of Texas at Arlington [6] takes a more active approach to helping the smart-home occupants. It uses 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 powerline control automates all lights and appliances, as well as HVAC, fans, and miniblinds. Perception of light, humidity, temperature, smoke, gas, motion, and switch settings is performed through a sensor network developed in-house.

The Gator Tech Smart House at the University of Florida [7] is yet another high-tech house, currently under construction, in which a variety of sensors will be embedded to assist with the behavioral monitoring (and alteration) of elderly occupants or patients suffering from diabetes and obesity.

Table 1: Comparative Overview of Smart Homes

	Architecture	Sensors	UI	Analysis / Functionality
GT Aware Home	Software infrastructure to assist with rapid development	Ultrasonic; floor sensors; video	?	Locates/identifies a person Locates lost objects Provides several distinct interactions with the home
MavHome	CORBA	Light; temperature; humidity; motion; door and seat status	Specialized interface agent	Detects behavioral patterns via sequential data mining (ED) Makes recommendations based on prediction (ALZ) Automates repetitive tasks
Gator Tech Smart House	Open Services Gateway initiative framework	Smoke detectors; security-system motion detectors	?	Senses the state of both home and resident Provides remote monitoring and intervention services
AAL	Service-oriented architecture	EIB-based home automation for switches, blinds, and power sockets; ambient sensors; RFID; ultrasonic and radio-frequency-based motion sensors; "intelligent" appliances (e.g., fridge, cups); "intelligent" walking aid; vital sensors (pulse, skin temp., skin humid.)	Dynamically-rendered UI – likely form based Audio and visual devices for multimodal interaction	Monitors daily behavior; builds histories and medical/activity patterns for the elderly Assists people in maintaining their well-known daily routine Recognizes emergency situations (from vital data) Provides remote care and information systems for relatives and care personal Incorporates an interactive TV-based video-telephony system Provides an autonomous transportation platform: a robotic unit for emergency recognition, multimedia interaction, and transportation assistance
SensorRAUM	Special-purpose, likely driven by Open Croquet	Coffee cup with temperature, orientation, and switch sensors; temperature and ambient light sensors	Open Croquet	Queries the current state (e.g., number of cups in the room) Uses non-explicit addressing/identification of communication partners Allows devices to detect their geometric location via a location system
WASP	Service-oriented architecture	Ambient sensors including microphones, pressure sensors, RFID tags, electricity and water usage sensors, "blob" sensor; wearable sensors including arm band, waist, shoe, and ear-worn sensors	?	Incorporates intelligent data analysis to infer data from multiple sensors, detect patterns across datasets, and identify risks Uses multi-sensor fusion to obtain better classification rates and decrease ambiguity between activities
Sensorized Elderly Care Home	?	Ultrasonic sensor (Ultra Badge)	?	Localizes head (when in/around bed) and wheel-chairs Provides remote monitoring of elderly people Detects accidents and notifies caregiver

The Sensorized Elderly Care Home [9] 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. In particular, the paper proposes a sensor-based system for localizing patients in a nursing home, monitoring their status, and raising alarms as necessary so that 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 is meant to monitor the patient's head position on and around the bed. This latter functionality is not completely evaluated and in place.

The SensorRAUM System [10] seeks to investigate, define, develop, and demonstrate user-friendly and intuitive user interfaces for wireless sensor networks. The SensorRAUM visualization is based on the Open Croquet [19] virtual world. To project the state of real-world objects into the virtual world, they propose to integrate sensors into objects, such as doors, clothes, and furniture. Thus, these objects are turned into soft media devices, which can communicate with other such devices throughout the environment.

The Ambient Assisted Living (AAL) Laboratory [12, 17] developed by the Fraunhofer Institute for Experimental Software Engineering in Germany is an apartment-like environment for developing, integrating, and analyzing ambient intelligence technologies. Currently, the AAL Lab supports the following specific scenarios: (i) monitored drinking via a computerized cup, (ii) monitored food quality via an RFID system built into the refrigerator, (iii) item location tracking through motion sensors and RFID tags, and (iv) fall detection.[1]

Although, not conceived in the context of a smart home, the WASP architecture [4] focuses on the software infrastructure necessary 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.

2.2 Virtual Worlds

Virtual-world platforms are a relatively new phenomenon; they have appeared in large numbers and they are being adopted as experimental platforms for delivering a variety of services, including healthcare with a number of projects focusing on health education of the public and students in the health sciences. More relevant to the work discussed here, we highlight three projects that focus on reflecting the real world in a virtual world based on sensor information.

The Razorback hospital of the University of Arkansas [15] uses Second Life to model healthcare logistics. The goal is "a management system (that) can monitor inventory and distribution in real time without any human manipulation." A considerable amount of work has gone into creating virtual analogs of many of the real-world artifacts encountered in a healthcare setting. This ranges from equipment (IV poles and X-ray machines), to clothes (hospital gowns), and even internal organs. The SL replica of the hospital includes virtual artifacts and tools that are slightly ahead of current technology, as the environment is also meant to be used as a platform for usability evaluation of new devices. Examples include smart pill bottles and shelves that know when they need to be restocked. The project also looks at supply-chain management, augmented by RFID-tagged inventory, forklifts, shelves, and so on.

Another interesting project is the recently launched SHASPA, which is a collaboration between EOLUS® One and The Serious Games Institute. The objective of the project is "to bring together Virtual Worlds (OpenSim, Second Life®), Web 2.0 Applications and the world of mobile applications…." EOLUS® One initially started as an innovation project with the focus to revolutionize "the Real Estate industry with new approaches to facilities/property performance optimization and energy management" (see http://www.ugotrade.com/2008/10/16/mashing-up-virtual-worlds-with-web-20-and-online-gaming/ for more information).

Project Wonderland [18], developed by Sun, is also designed to support tight integration between the real and the virtual world. Using SunSPOTS, special-purpose wireless devices with embedded accelerometers, users can control their avatars. One can imagine that the infrastructure enabling this interaction could easily be exploited to feed sensor information to virtual objects in the world.

[1] It appears that the European Union has launched a new joint research and development (R&D) funding activity under the same name, implemented by actual 20 European Member States and 3 Associated States – see http://www.aal-europe.eu/.

3. The Smart Condo project

The Smart Condo project is a fairly recent interdisciplinary activity at the University of Alberta. Our team includes researchers from Rehabilitation Medicine (RM), Pharmacy (P), Art and Design (AD), Education (E), and Computing Science (CS). All of these individuals had already been working and collaborating in the context of smaller groups, in related areas, for quite some time before the initiation of the Smart Condo project. Our RM, P, and AD researchers had been working on the application of Universal Design principles in the architecture and interior design of homes of patients with special needs. Our E and CS researchers had been investigating issues of training inter-professional teams of health scientists, including through simulations in virtual worlds. Finally, the CS researchers had been working on the design of wireless sensor networks for the monitoring of environmental parameters in indoor and outdoor spaces.

The opportunity for the Smart Condo project became possible when a physical space became available to us, namely an 850 square-foot condominium. Since September 2008, we have been working together to deploy a sensor network for monitoring the activities of the condo tenants and a software architecture for analyzing the recorded sensor stream to extract information of interest to patients, their family members, and their healthcare providers.

The system is based on a service-oriented architecture, diagrammatically depicted in Figure 1. The main information resource is a sensor database, ***SensorDB***, which contains two types of data: "raw" sensor readings collected through the wireless sensor network (WSN) and higher-order information extracted through processing the sensor readings.

The nodes of the Smart Condo ***WSN*** run the PicOS operating system [1] and consist of several components built around a common transceiver module, the DM2200 (containing an MSP430F148 microcontroller, a TR8100 radio transceiver, and associated circuitry), and powered by batteries. The microcontroller operates at a low clock speed (~4.5 MHz) and has limited memory (48 KB Flash and 2 KB RAM). The radio transceiver communicates at a low transmission rate (9600 bps). Each DM2200 is connected to one or more physical sensors, such as acceleration sensors, pressure sensors, passive infrared motion sensors, and switches. One DM2200, attached to a more capable host (the sink) acts as the gateway between the WSN and the IP backbone network.

The sink transmits the packets it receives from the WSN to the PC, encapsulated in the TinyOS [2] serial message format. On the PC, the TinyOS program ***sf*** forwards between the serial port and a network socket, essentially giving one or more clients access to the serial port. Thus, only special-purpose clients process the data and not the sinks, since they too are limited in their processing capacity.

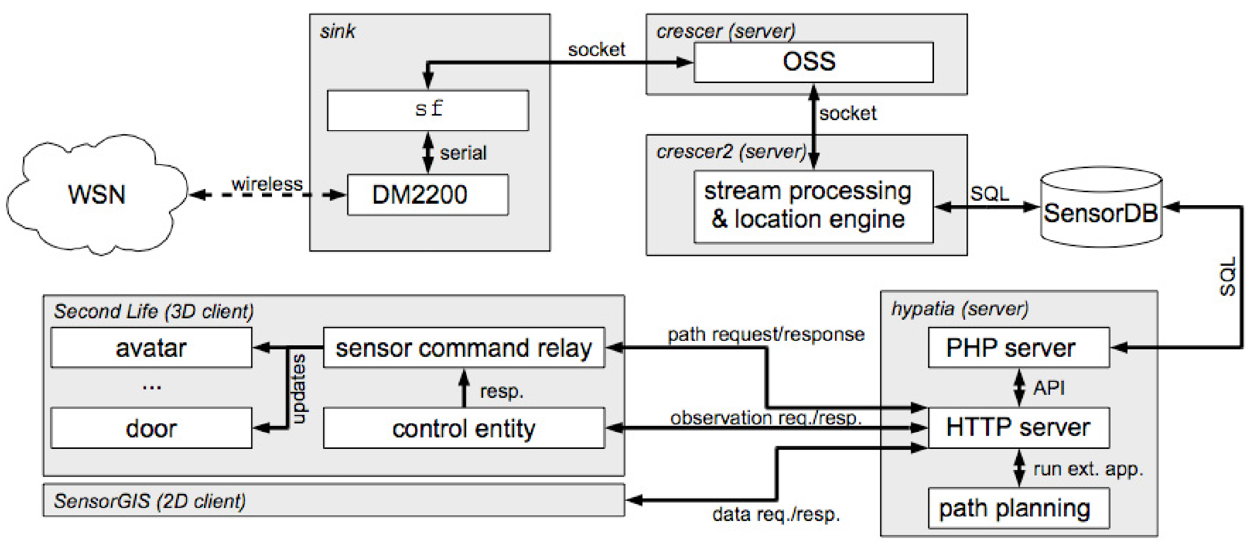

Figure 1: The Smart Condo Software Architecture

Another component, the ***Operations Support System*** (OSS) serves as a link between the raw sensor data elements, which include (i) time-stamp, (ii) network ID, (iii) node ID, (iv) sensor ID, (v) sensor type, and (vi) event type, and any application logic that needs to process sensor data in a particular fashion. In our application the OSS is connected to the stream processing and location engine, which is responsible for inferring the location of the condo tenant based on the sensor-data stream.

At the core of the Smart Condo system lies a server that implements a range of ***application-specific services*** of three different types: (a) services necessary for deploying and managing the WSN, (b) services for producing information representations appropriate for “traditional” visualizations, and (c) services for supporting the simulation of the condo tenant activities in a virtual world.

The first category includes simple REST services for informing the system about the existence and the sensor configuration of a newly deployed node, any edits to the node’s configuration, and its potential removal. In addition, a special service enables a user to explore the coverage of alternative placements of motion sensors; once the user is satisfied that all the condo area is well covered, the coverage polygons and their associated sensors are recorded in the SensorDB. At run time, the OSS uses this information to infer the tenant’s location based on the motion-sensor data stream.

The second category includes another set of REST services for visualizing the sensor network on a Geographic Information System (GIS) based on Open Layers [20] and a variety of statistics on the readings of individual sensors and sensor groups through graphs, and tabular reports.

The third set of services supports the simulation of the tenant’s activities in Second Life (SL). First, a conversion utility turns a 2D blueprint into a 3D home; second, an automated character module moves the tenant’s avatar through the Smart Condo area, following the locations inferred by the OSS; third, a path-planning algorithm ensures that as the occupant’s avatar moves through these locations, it does not collide with any obstacles in the space; finally, a control service coordinates all these services.

Based on the first and second types of APIs, we have also developed a wiki-based environment to enable members of the involved community to record observations of interest, comment on them, and relate them with other data of interest on the web at large.

4. Research challenges

The Smart Condo project is in its infancy. Setting up the first version of the system was relatively easy, since our computing-science team had already developed the basic technologies (networks of a few basic types of sensors, service-oriented architecture for spatial information visualization, and basic virtual-world scripts). In our short experience setting up the condo with our colleagues in Rehabilitation Medicine, Pharmacy, and Art and 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.

4.1 WSNs for smart indoor environments

The development of sensor-network applications is not yet quite systematic. New sensor types require new drivers, and the core services of each application, i.e., data packetization, duty-cycle (sleep vs. processing) of each individual node, communication protocol, and message routing, have 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. Developing methods and tools for systematizing this process – like for example having a model checker prove that the delay between the sensor events on the basis of which person location is recognized is less than a threshold – is essential for enabling the flexible deployment of the system in different environments and the integration of different types of sensors as they become available.

The long-term objectives of our wireless sensor networks research are to develop a service-oriented model for sensor applications and corresponding IDE support for model-driven engineering [3] of sensor-network applications. Currently, WSN application development reuses very little code even though most applications share much functionality. As a result, their development necessarily requires a Computing Science skill set. We envision that this IDE will support the following functionalities.

a) Design, development, testing, and simulation of sensor-network applications: as long as the types of sensors used in the network are known, domain experts (e.g., residential property managers) should be able to use a high-level IDE to develop and deploy their applications (e.g., temperature sensing and HVAC controlling) and know in advance, though model checking and simulation, its properties (e.g., the temperature will not be above 20˚C for more than 3 minutes).
b) Application refactoring for optimizing the data accuracy vs. energy consumption trade off: communicating information through several traffic bursts consumes more energy than a single long message. Depending on the user's requirements for delay and energy consumption, the IDE should be able to automatically restructure the application, introducing data caching and packetization, modifying the communication and routing protocols, and adjusting the sleep-processing cycles as necessary.
c) Application evolution: the integration of new sensors should be systematically supported so that information archiving, analytics, and visualization services are able to take advantage of the new information. For example, if a new biosensor is introduced, the developer should be guided through the steps of defining alarm-generating patterns based on the information provided by the new sensor.

In addition to the IDE for WSN application development, we believe that an 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 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.

An important decision for developing sensor-network applications for smart indoor environments is the choice of the underlying operating system. In our work, we have adopted PicOS, an alternative to the perceived de facto standard, TinyOS. PicOS is designed to support the development of applications based on a state-transition based behavioral model. We believe that it renders itself to model-driven engineering, in a way analogous to engineering of real-time and embedded systems, which has been the subject of some model-driven development research (see [8] for example).

4.2 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 are examining both the REST and WS* SOA styles for these purposes, since we believe that different styles will most likely be appropriate for different tasks. We envision WS* integration among existing applications, developed in procedural and object-oriented style; for example, home-care devices could feed their data into the core resource through well-defined operations. The REST style is more appropriate for integrating data-centered applications; for example, if health professionals were to access data from the patient's electronic health record and his history as captured by the Smart Condo. Finally, REST APIs are 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" of Table 1, 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 or pressure sensors embedded in the floor. 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 footware and sleep-pattern analysis based on bed sensors. In addition to these services, research is required to address the following issues.

a) Accessing and visualizing user-specific 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 physical therapist may be interested in knowing "the longest segment of continuous physical activity by the patient" and he should be able to specify this query, have the system translate it into an efficient SQL, and visualize the results in an appropriate view.
b) Enabling 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.

4.3 Virtual Worlds for simulation and training

One of the most innovative aspects of the Smart Condo infrastructure, we believe, is the use of SL, a virtual-world platform, 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. Although we do not actually expect health professionals to watch the Smart Condo residents' in the virtual world, we expect them to visit patients there and interact with them in a context that should be more engaging, and with a higher-degree of social presence. Furthermore, recordings of "interesting" resident behaviors might 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.

a) There are still technical problems involved in reflecting the physical environment in the virtual world in a way that is precise. Collada [21] is an emerging standard, supported by several virtual worlds although not Second Life, for digital-asset exchange within the interactive 3D industry.
b) 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.
c) 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, would that be of benefit in the context of patient support and healthcare team communication, or might it lead to even more isolation for patients who are not as motivated to visit their healthcare team as often?

5. Concluding remarks

Today we see an increasing interest in developing technical solutions, by academics and industry alike, to problems associated with healthcare delivery. The problem is technically challenging and socially important. A fundamental challenge for work in this area is the scale of the undertaking: in order to develop realistic solutions an interdisciplinary team is required. Furthermore, in the case of developing integrated home-care solutions (as our Smart Condo project aims to be), substantial physical resources are required. This requirement for substantial up-front investment makes the need for systematic software-engineering methods, tailored to the area, even more pressing.

Acknowledgments

This research was funded by the IBM Centers for Advanced Studies, NSERC, iCORE, and Alberta Advanced Education and Technology.

References

[1] E. Akhmetshina, P. Gburzynski, and F. Vizeacoumar, "PicOS: A Tiny Operating System for Extremely Small Embedded Platforms, " in *Proc. of ESA'03*, Las Vegas, Jun. 2003, pp. 116–122.

[2] P. Levis, S. Madden, J. Polastre, R. Szewczyk, K. Whitehouse, A. Woo, D. Gay, J. Hill, M. Welsh, E. Brewer, and D. Culler, Ambient Intelligence. Springer Berlin Heidelberg, 2005, ch. "TinyOS: An Operating System for Sensor Networks," pp. 115–148.

[3] D. C. Schmidt, "Guest Editor's Introduction: Model-Driven Engineering," *Computer*, vol.39, no. 2, pp. 25-31, Feb. 2006.

[4] L. Atallah, B. Lo, Y. Guang-Zhong, and F. Siegemund, "Wirelessly Accessible Sensor Populations (WASP) for Elderly Care Monitoring," Second International Conference on Pervasive Computing Technologies for Healthcare, 2008. pp. 2 – 7.

[5] C. D. Kidd, R. J. Orr, G. D. Abowd, C. G. Atkeson, I. A. Essa, B. MacIntyre, E. Mynatt, T. E. Starner and W. Newstetter. "TheAwareHome: A LivingLaborator for Ubiquitous Computing Research," in *the Proceedings of the Second International Workshop on Cooperative Buildings* - CoBuild'99. Position paper, October 1999.

[6] D. J. Cook: "Health Monitoring and Assistance to Support Aging in Place, " J. UCS 12(1): 15-29 (2006).

[7] S. Helal, W. C. Mann, H. El-Zabadani, J. King, Y. Kaddoura, E. Jansen: "The Gator Tech Smart House: A Programmable Pervasive Space," *IEEE Computer* 38(3): 50-60 (2005).

[8] S. Henker, J. Greenyer, M. Hirsch, W. Schäfer, K. Alhawash, T. Eckardt, C. Heinzemann, R. Löffler, A. Seibel, and H. Giese, "Synthesis of Timed Behavior From Scenarios in the Fujaba Real-Time Tool Suite," in *Proc. of the 31th International Conference on Software Engineering (ICSE), Vancouver, Canada*, May 2009.

[9] T. Hori, Y. Nishida, H. Aizawa, S. Murakami, and H. Mizoguchi, "Sensor Network for Supporting Elderly Care Home Sensors," in *Proceedings of IEEE*, vol 2, pp. 575-578, 2004.

[10] F. Hupfeld, and M. Beigl, "Spatially Aware Local Communication in the RAUM System," in *Proceedings of the 7th international Workshop on interactive Distributed Multimedia Systems and Telecommunication Services* (October 17 - 20, 2000). H. Scholten and M. v. Sinderen, Eds. Lecture Notes In Computer Science, vol. 1905. Springer-Verlag, London, 285-296.

[11] J. A. Kientz, S. N. Patel, A. Z. Tyebkhan, B. Gane, J. Wiley, and G. D. Abowd. 2006. "Where's My Stuff?: Design and Evaluation of a Mobile System for Locating Lost Items for the Visually Impaired," In *Proceedings of the 8th international ACM SIGACCESS Conference on Computers and Accessibility* (Portland, Oregon, USA, October 23 - 25, 2006). Assets '06. ACM, New York, NY, 103-110.

[12] T. Kleinberger, M. Becker, E. Ras, A. Holzinger, and P. Müller. "Ambient Intelligence in Assisted Living: Enable Elderly People to Handle Future Interfaces," In Universal Access in Human-Computer Interaction. Ambient Interaction, volume 4555/2007 of Lecture Notes in Computer Science, pages 103–112. Springer Berlin / Heidelberg, 2007.

[13] S. Meyer, A. Rakotonirainy: "A Survey of Research on Context-Aware Homes," *ACSW Frontiers 2003*, pp. 159-168.

[14] S. N. Patel, K. N. Truong, and G. D. Abowd, "Powerline Positioning: A Practical Sub-room-level Indoor Location System for Domestic Use," in Proceedings of UbiComp 2006: Ubiquitous Computing, 2006, pp. 441–458.

[15] C. W. Thompson and F. Hagstrom, "Modeling Healthcare Logistics in a Virtual World," IEEE Internet Computing, vol. 12, no. 5, pp. 100–104, 2008.

[16] Q. Tran, G. Calcaterra, and E. Mynatt, "Cook's Collage: Deja vu Display for a Home Kitchen," in *Proceedings of HOIT: Home-Oriented Informatics and Telematics*, 2005, pp. 15–32.

[17] E. Ras, M. Becker, and J. Koch. "Engineering Tele-Health Solutions in the Ambient Assisted Living Lab," In *AINAW '07: 21st International Conference on Advanced Information Networking and Applications Workshops*, volume 2, pp. 804–809, May 2007.

[18] "lg3d-wonderland: Project Wonderland." [Online]. Available: https://lg3d-wonderland.dev.java.net

[19] "The Coquet consortium" [Online] Available: http://www.opencroquet.org

[20] "OpenLayers: Free Maps for the Web" [Online]. Available: http://www.openlayers.org

[21] "The COLLADA.org community" [Online]. Available: http://www.collada.org

[22] The Center for Universal Design. The Principles of Universal Design, Version 2.0, Raleigh, NC: North Carolina State University, 1997