Smart rehabilitation for the 21st century: The Tampa Smart Home for veterans with traumatic brain injury

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INTRODUCTION

In this editorial, we report on the development of a smart-home–based cognitive prosthetic that will deliver 24/7 rehabilitation at the James A. Haley Veterans' Hospital Polytrauma Transitional Rehabilitation Program (PTRP) facility in Tampa, Florida. The Tampa Smart Home was designed to address two weaknesses identified by PTRP clinicians in the rehabilitation process for patients with traumatic brain injury (TBI): (1) patient safety and (2) inadequate timing and repetition of prompts used to overcome TBI-related cognitive and memory deficits.

Smart homes monitor residents' behaviors and provide assistance for various physical and neurological disabilities [1]. The Tampa Smart Home creates a pervasive supportive environment to assist cognitive rehabilitation in patients with TBI [2–3] by continuously identifying the movements and locations of all patient residents and clinical staff. The location information permits the intelligent software to deliver customized prompts and information to the patient via numerous interactive multimedia displays located on walls throughout the PTRP. The residential setting lends itself well to the enriched interactive rehabilitative environment, in which patients with TBI are "immersed" in their rehabilitation, and leverages the "digital generation" of veterans' active technology engagement to facilitate their own recovery [4].

A powerful feature of the Tampa Smart Home is the precision of the customized therapeutic information that can be provided to the recovering veteran. Individual-level data for every interaction with clinical and medical staff and with the interactive displays are recorded continuously and analyzed using state-of-the-art data mining, which, when fully implemented, will allow staff to visualize subtle but therapeutically significant behavioral changes to better inform treatment plans and potentially prevent untoward medication effects on veterans' memory, as well as gait and balance. This approach is expected to yield important insights into the cognitive recovery process by assisting therapists in targeting problem behaviors for remediation and then linking the behaviors to automata that ensure consistently provided therapy. Consistently delivered automated interventions will shorten recovery time while complementing or reducing therapist monitoring of patient locations and activities within the facility.

BACKGROUND AND RELATED WORK

Department of Veterans Affairs Polytrauma Centers

The signature injuries of soldiers returning from Afghanistan and Iraq are polytrauma and TBI [5–6]. In the majority of Department of Veterans Affairs (VA) clinical cases, polytrauma and TBI are caused by blast injuries from improvised explosive devices, although TBI also results from noncombat events such as motor vehicle accidents. Polytrauma is defined as injuries to two or more body systems from one event. An extreme example would be injuries that simultaneously result in limb amputation, TBI, burns, deafness, and blindness, with long-term physical and cognitive impairments and functional disabilities.

TBI, while part of the constellation of injuries encompassing polytrauma, is the most serious and common injury [5]. The variable emotional, cognitive, and behavioral consequences of TBI determine the specific course of rehabilitation [3]. Mild injuries, managed properly, have excellent recovery prospects; moderate to severe injuries require specialized care and intensive early rehabilitation and often require lifelong assistance to manage routine daily activities.

The VA has four polytrauma centers that serve as regional centers for medical and rehabilitation care and hubs for research and education located in Minneapolis, Minnesota; Palo Alto, California; Richmond, Virginia; and Tampa, Florida. The comprehensive medical and rehabilitation services provided include acute medical care, outpatient programs, and PTRPs.

The Tampa PTRP provides residential facilities and supplemental therapy for 10 veterans with TBI and aids their reintegration into the community. The goal is to raise the veterans' awareness of barriers that interfere with their community reintegration and develop strategies that allow them to independently plan, organize, and complete important everyday activities; length of stay varies from a few months to more than a year.

Smart Home Rehabilitation Strategy

The most common deficits requiring rehabilitation at the Tampa Smart Home relate to executive functioning. Executive functioning refers to a set of higher cognitive processes, which include procedural sequential memory, attention and response inhibition, and motivation [7–11]. Specific manifestations of executive function deficits involve problems planning activities and managing time [12–13]. Expressing inappropriate social behavior is a major issue for many persons with TBI. Repeating environmental cues that trigger specific behaviors and cues to facilitate attention are crucial for therapeutic progress [6]. Growing neurophysiological evidence supports the contention that task-specific therapy involving repetition facilitates cortical reorganization or neuroplasticity [14–22]. Little disagreement exists that the therapies are effective and facilitate change in neuronal connections, but emphasis has shifted to the factors and patient characteristics that maximize clinical outcomes [23]. In animal studies, exposure to long-term enriched environments has a positive effect on restoring spatial memory functions. The functional recovery in rats with brain injury involves highly complex processes generating new cells and cellular alteration [24].

Unfortunately, extensive literature also documents that some cognitive functions such as memory cannot be restored, irrespective of amount or intensity of repetition. In those cases, rehabilitation focusing on establishing compensatory strategies using a variety of low- to high-technology aids is advocated [25]. These aids range from notebooks and diaries to electronic aids such as personal digital assistants and pagers. Accordingly, implementing a smart home at the Tampa PTRP that employs both pervasive and persuasive technologies as a cognitive prosthetic for patients with TBI is consistent with its use as a compensatory strategy.

Persuasive Technologies

Persuasive technologies are human-machine interactive systems designed to alter users' abilities to produce sustained behavior change either in themselves or in others and are (ideally) sustainable when the technology is removed [26]. Examples of sustained behavior change include achieving and maintaining an ideal weight or an exercise program in which the machine communicates motivational messages and results. Our application employs sensor technology to monitor a patient's behavior sequences, applies decision rules to detect key elements of the patient's behavior pattern that have been omitted, then finally prompts the patient to resume the sequence at the point where it was stalled or diverted. Depending on the desired behavior, more specific prompts may be employed (e.g., "Please resume loading the washing machine" becomes "Pick up the next item of clothing and place it in the washing machine"). Inherent in prompting is tacit acknowledgement of the necessity of maintaining motivation throughout the behavior sequence by electronically delivering approval ("Great job!") at the correct instant. Yet delivering too many approval messages may become irritating and have unintended consequences; prompts systematically delivered only when the behavior is about to stall out may inadvertently contribute to progressively slower rates of behavior (also termed a "Differential Reinforcement for Low Rates of Behavior" schedule). The behavioral effect of systematic variations in the scheduled delivery of positive reinforcers is an area of research pioneered by behaviorist B. F. Skinner [27].

For persons with TBI, the damage may be either widespread or quite limited depending on the nature of the injury. Whereas the hallmark characterizing dementia is the decline in short-term memory, no single defining characteristic of TBI exists—each case is unique. The intent of the Tampa Smart Home is to harness the power of pervasive, persuasive computing to rehabilitate damaged brains by building behavioral profiles for each patient that will track his or her progress on specific tasks necessary for independent living. The stability of a patient's relearned behavioral sequences can be measured in a number of ways, including probability of successful completion, and improved stability should accompany improvement in other commonly used clinical indices of a patient's progress. Ideally, patients with TBI who have undergone "smart home rehabilitation" would be weaned off prompts used to reestablish the behavior as they transition to a minimally or noninstrumented independent living environment. Home service providers can provide feedback to clinicians as to how effectively the behaviors modified by the clinic's smart home rehabilitation protocol are maintained.

SMART HOME ARCHITECTURE

The architecture of the smart home is organized around a central Linux server running the standard Ubisense core platform services (Ubisense Ltd; Cambridge, England). As of this writing, the Tampa Smart Home is specifically running Suse Linux version 11.3 (open SUSE Project, Novel, Inc; Alpharetta, Georgia) and the Ubisense Platform version 2.17. The Ubisense core platform services feed a wide range of applications with location data; many of these applications are written as Ubisense services to take advantage of the runtime monitor and data schemas that provide a convenient means of distributing data to all of the client devices. **Figure 1** shows six major components running on the server: schedule monitor, prompt generator, real-time fractal dimension (Fractal D) path analysis, behavior tracking, database (MySQL, Oracle; Redwood Shores, California) logging and post hoc analysis of patient behaviors and interactions, and .NET Web service to wrap portions of the Ubisense application programming interface (API) to provide access for iOS (Apple, Inc; Cupertino, California) and Android (Google, Inc; Menlo Park, California) devices.

The environmental sensor units are comprised of a task-specific sensor, such as a pressure sensor or a light sensor, connected to an ARM microcontroller, which is in turn connected to a Ubisense Tag Module. The sensor unit uses the tag module to send data over the Ubisense 2.4 GHz wireless backchannel. This provides the system with the exact location of a sensor (and/or the device to which it is attached) and avoids the need to install another wired or wireless communication system only used by the sensors. The Ubisense ultra-wideband sensors are the standard 7000 series sensors; however, the large number of sensors within the Tampa Smart Home

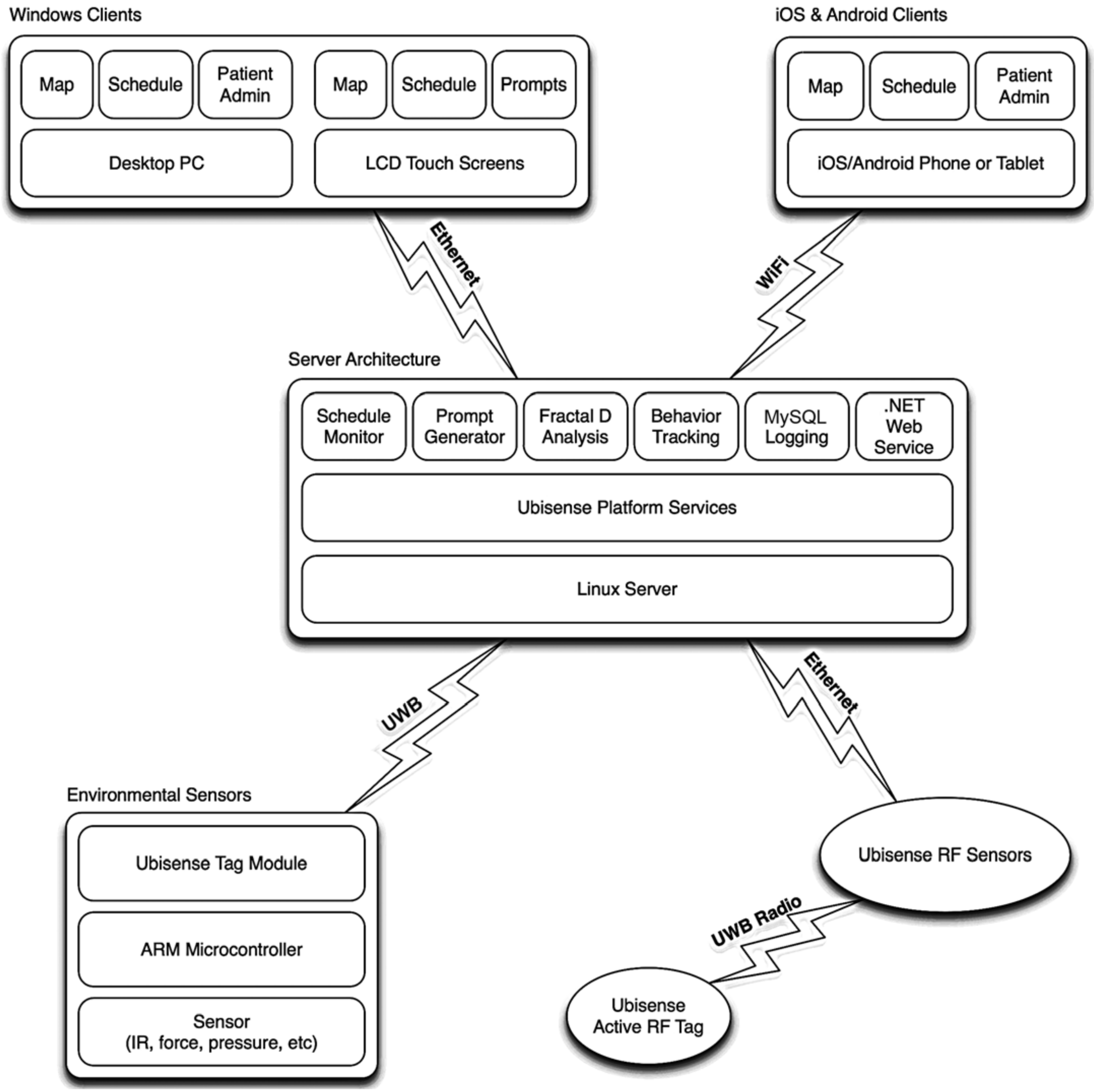

Figure 1.
Smart home architecture. Combination of environmental and location sensors connected to Linux server running Ubisense core platform services (Ubisense Ltd; Cambridge, England) as well as custom smart home applications for behavior monitoring, prompting, and data analysis. End user applications run on Windows (Microsoft; Redmond, Washington), iOS (Apple, Inc; Cupertino, California), and Android (Google, Inc; Menlo Park, California) devices. Admin = administration, Fractal D = fractal dimension, IR = infrared, LCD = liquid crystal display, PC = personal computer, RF = radio frequency, UWB = Ubisense wireless backchannel.

requires a special firmware for sensors and tags to increase the discrete channels in the 6 to 8 GHz band.

The Windows (Microsoft; Redmond, Washington) client systems fall into two categories: desktop personal computers and wall-mounted liquid crystal display (LCD) panels. The desktop machines run an administration application to add and remove tracked objects, approve locations for patients to enter (check in and out [CICO] system), configure behavioral prompting, and schedule tasks. An interactive facility map displays all tracked objects on the desktop computers. The wall-mounted LCD panels run the administration and map application and a "dashboard" application in the background. The panels activate in the presence of a tag and the dashboard enables access to the administrator application, map, scheduler, and user settings based on rights associated with the user's tag so that patients cannot access the administration application. Additionally, a notification application runs continuously and, when commanded, pops to the foreground of the LCD panel to display prompts and schedule notifications to the patients by an application running on the server.

The iOS client systems are designed for the PTRP staff and duplicate the desktop administration client and map applications on iOS devices. This was accomplished by developing a .NET Web service that wrapped the necessary portions of the Ubisense API, allowing us to create applications to send and receive data from the Ubisense core platform services by using the open standard HTTP REST methods (GET, POST, PUT, and URL Query Strings). The current iOS applications are written using the Unity engine (Unity Technologies; San Francisco, California), which allows use of the same applications on Mac OS (Apple, Inc), iOS, Android, and Windows devices.

PATIENT AND STAFF TRACKING

Using Ubisense Real Time Location System technology to track patients has been validated in several prior studies, which tracked residents in assisted living facilities [28–29]. The system tracks an active radio frequency identification tag using sensors mounted on the walls of the facility. Sensors are grouped into cells covering a segment of the PTRP. The tags broadcast their identification on a 6 to 8 GHz ultra-wideband channel at an adjustable rate (up to 40 Hz) determined by tag location and velocity. The group of sensors within a cell track tag use time-delay-of-arrival and angle-of-arrival methods to determine tag position in three dimensions to within 0.16 m. Each cell's master sensor relays the tag's position to a server, which aggregates the position of all tags within the PTRP. This position information is then made available to each of the applications discussed in the following section.

INTERACTIVE SAFETY AND REHABILITATION APPLICATIONS

The smart home will provide PTRP staff with the means to monitor patient location to enhance overall safety and assist patients reacquire behaviors lost because of TBI. The applications implemented include scheduled reminders, location assistance, and interactive prompts through 65 wall-mounted, touch-screen LCD panels throughout the PTRP. A related application under development for desktop machines and iPads (Apple, Inc) enables the control of context, content, and frequency of messages delivered by other applications.

Patient Safety

Patients with TBI present challenges similar to those with dementia; one challenge concerns unattended exiting or being away without leave. PTRP staff currently use paper-based protocols for CICO. A recently installed system employs two touch screens in the lobby: one for CICO and one at the exit door to prompt the veterans if they attempt departure without interacting with the CICO console. CICO requires the patients to select their destination from a menu and indicate their estimated return time. If veterans forget to check out (or check in upon return), they are reminded to do so. The type of reminder selected by the clinician may be highly specific ("You forgot to check out") or subtle ("Did you forget something?") and may vary as a function of therapeutic progress, but in all cases it urges the veteran to try to remember. The CICO system frees staff members to perform their duties without constantly monitoring the exit, while providing the patients with “gentle” reminders of a required action.

Map and Navigation

The map and navigation application will enable PTRP staff to quickly locate patients who fail to appear for scheduled therapy sessions and meetings using iPads, iTouch/iPhones (Apple, Inc), Android devices, or any locally available wall-mounted LCD panels. This resource quickly gives the veterans’ current location or, if they are not in the facility, the last known location. Veterans and visitors can also use the map for personal navigation by obtaining directions to any office in the PTRP facility.

Schedule and Medication Management

The scheduling system is a core system feature that will work in conjunction with other applications, including medication management. The interface presents a basic calendaring application that allows veterans and staff to set meetings and therapy sessions and provide reminders of upcoming activities. The scheduling information informs the CICO console so that a patient receives reminders to return before scheduled appointments. It also works in conjunction with the mapping application to automatically indicate the patients’ optimal route to their next appointment.

For the medication management application, veterans are categorized into three medication management autonomy levels; each gives the veteran increased control over their medication schedule. The first level requires the veteran to be present at the nurses’ station to receive medication. The second level requires the veteran to be present at the nurses’ station and to indicate the medication type and dosage required before receiving the medication. At the third level, the veteran receives medications in advance and maintains them in a pillbox, which requires forethought to both take the medication and request prescription refills. The system appropriately prompts the patients to perform the activities required by their autonomy level until it detects that the activity has been completed. For example, the system determines the location of the patient and the patient’s instrumented pillbox; when the veteran visits the nurse’s station or accesses his or her pillbox independently, reminders cease until his or her next scheduled medication.

Behavior Prompts

Eligible behaviors for modification are determined by PTRP staff and entered into the behavior management application, which places movement patterns in the context of the veteran’s location. For example, the behavior of taking the kitchen trash to the main trash bin is defined for four actions:

1. Go to trash can in kitchen.
2. Remove trash bag from trash can.
3. Go to main trash bin.
4. Open main trash bin and put trash bag inside.

These events must occur sequentially; the patient’s trash can and the building’s trash bin are outfitted with sensors that report usage. The PTRP staff can program the system to track and prompt these specific behaviors. Several different prompting strategies are amenable to this technology; as early as the 1950s, B. F. Skinner presented research on a technique called “errorless learning,” which used rudimentary mechanical teaching machines [30] (see http://youtu.be/EXR9Ft8rzhk). An advantage of this approach was that it reduced the number of mistakes to a minimum (hence the term “errorless”) and was minimally frustrating to the student, an advantage when working with persons who may have injuries to the brain’s limbic system. Skinner’s protocol presented an entire sentence to be learned and at each step, one or more words in the sentence were systematically faded out until they were eventually invisible. This “stimulus fading” technique ensured that the student could eventually recite long passages such as the Gettysburg Address in its entirety in response to a single cue. With reference to our “take out the trash” sequence, prompt 2 (“Remove trash bag from trash can”) might fade out over days so that fewer and fewer cues are required for the behavioral sequence to be carried out.

Other common behavioral problems that beset patients with TBI and persons with dementia are sleepless episodes and pacing. Veterans with TBI often aimlessly lurk or pace corridors and living spaces. In such cases, they are normally encouraged by staff to do a "more useful" activity. In a smart home, the system can detect pacing and lurking, and when detected, the nearest LCD panel prompts the veteran to perform a useful activity (e.g., "Why not go to the gym?"). The system will also detect sleepless episodes and can alert the night duty nurse who manages such situations.

OUTCOME MEASURES

The smart home uses two classes of outcome measures. First, all current clinical assessments of patient progress and staff assessments determining discharge eligibility are and will continue to be used. Discharge eligibility is based on progress in cognitive, emotional, physical, and social engagement. The current criteria will facilitate the evaluation of the smart home rehabilitation process. The second class is unique to the Tampa Smart Home and makes use of the data generated automatically by the location-aware technology, including estimated distance and rate of travel through the corridors. Perhaps the most interesting is the Fractal D measure of the veterans' movements within the facility and its possible relationship to behavior compliance. Briefly, Fractal D is calculated from the changes in vector of successive episodes of movement as the person ambulates. The lower limit (one) indicates that the patient is traversing a straight path between two places while greater values indicate an increasingly chaotic path with more twists and turns. Higher Fractal D values in elderly persons have been linked to cognitive deficits, including persons clinically diagnosed with dementia [29,31]. In older residents of assisted living facilities, those with increasingly severe cognitive deficits with or without a clinical diagnosis of dementia walk in progressively more tortuous paths, and this tortuosity is significantly correlated with poorer cognitive status on the Mini-Mental State Examination [29]. Polytrauma researchers have long noted behavioral similarities between patients with TBI and dementia patients. The tortuous paths of persons with significant executive impairment caused by TBI may yield a biometric for assessing therapeutic improvement in patients undergoing "smart home therapy" if their paths become progressively less tortuous over time and if Fractal D covaries with other therapeutic indicators in TBI, as has been observed with older persons with dementia.

SMART HOME CASE STUDY—VETERAN R

Veteran R is a 24-year-old male who experienced multiple injuries as a result of vehicular accident in July 2008. Following initial stabilization of his wounds, veteran R was transferred to the PTRP for additional therapy to address a number of chronic physical and cognitive issues that included moderate brain damage and manifested as problems initiating behavior and remembering appointments and medications. Veteran R volunteered to wear an ultra-wideband transponder tag that allowed us to track his movements throughout the PTRP while the system passively tracked his location throughout the day; however, he received no prompting from the smart home technology. The intent was to produce an empirically derived report on how veteran R moved about the facility, broken down in 30 min intervals. **Figure 2** provides a diagram of the locations in the PTRP in which veteran R moved. An inspection of veteran R's data indicated that April 4, 2010, contained 22,494 location data points spread across 15 rooms within the PTRP in a 24 h period. The results of the data analysis appear in the **Table** and show that from 6:30 a.m. until 7 a.m., veteran R divided his time between his bedroom (room 138), the waiting room (where morning medications are provided), and room 102 (where breakfast is served). Shortly after 7 a.m., veteran R went to room 111 for an early meeting and remained there until 8 a.m. Following that, he went back to his bedroom (room 138) for 1 h before attending another meeting at 9 a.m. in room 112. The **Table** also displays the information concerning the remaining activities performed on that day.

The results of the case study demonstrate that the PTRP sensor system is capable of providing a detailed real-time record of a given individual's location throughout the day. This is an essential component for a system that uses location-aware

Figure 2.
Polytrauma transitional rehabilitation program floor plan, corresponding to activity matrix for veteran R presented in **Table**. The system can also track activities within rooms; it is possible to locate person standing in front of stove or refrigerator or sitting on couch watching television, allowing for varying degrees of temporal and spatial granularity. APT = apartment.

technology to deliver memory prompts and positive reinforcements to facilitate veteran recovery.

DISCUSSION AND CONCLUSIONS

As of the beginning of August 2011, the first phase of the Tampa Smart Home installation (tracking and CICO kiosk) is complete. The second phase, installing 65 interactive LCD panels, is scheduled to begin mid-August 2011. Currently, most patients have volunteered to have their movements tracked. We found very little resistance from patients and clinicians in adopting the system despite some early anxiety about being constantly tracked, whimsically called the "Big-Brother Syndrome." The clinicians within the PTRP can now immediately locate patients and have an instantaneous list of patients who have checked out or returned. Both patients and clinicians have expressed appreciation for the

Table.
Activities for veteran R as observed by smart home sensor system on Monday, April 4, 2010. Values are gross numbers of location data points reported by sensor tag worn by veteran R. Corridor locations (as veteran R moves from one location to another) are intentionally filtered out.

Time	Transponder Tag Data Count															Total
	Room															
	102	104	106	108	110	111	112	126	128	131	135	137	138	139	Waiting Room	
12 a.m.	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	3
4 a.m.	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	3
6 a.m.	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	4
6:30 a.m.	252	—	—	—	—	12	—	—	—	—	—	—	444	—	307	1,015
7 a.m.	351	—	—	—	—	494	—	—	—	—	—	—	—	—	87	932
7:30 a.m.	—	—	—	—	—	626	—	—	—	—	—	—	—	—	—	626
8 a.m.	—	—	—	—	—	31	—	—	—	—	—	1	1,364	—	—	1,396
8:30 a.m.	—	—	—	—	—	5	9	—	—	—	—	—	639	—	—	653
9 a.m.	—	—	—	—	—	1	755	—	—	—	—	—	—	—	—	756
9:30 a.m.	—	—	—	—	2	—	926	—	—	71	—	—	—	—	—	999
10 a.m.	—	—	—	—	—	—	—	—	—	665	—	—	—	—	—	665
10:30 a.m.	—	—	—	—	—	—	—	—	—	658	—	—	—	—	—	658
11 a.m.	—	—	—	—	—	—	—	—	—	708	—	—	—	—	—	708
11:30 a.m.	—	—	—	—	—	—	—	—	—	297	—	—	109	—	162	568
12 p.m.	782	—	—	—	—	—	—	—	—	—	—	—	—	—	29	811
12:30 p.m.	336	1	—	—	—	2	—	—	—	—	546	—	129	—	—	1,014
1 p.m.	—	—	—	—	—	—	—	—	—	—	56	—	—	—	—	56
1:30 p.m.	—	—	9	—	—	—	—	—	—	—	—	—	102	—	—	111
2 p.m.	—	—	—	—	—	—	—	747	1	—	—	—	—	—	—	748
2:30 p.m.	—	1,043	—	—	—	—	—	100	—	—	—	—	—	—	—	1,143
3 p.m.	—	178	—	479	—	—	—	—	—	—	211	—	69	1	—	938
3:30 p.m.	—	—	—	—	—	—	—	—	—	—	1,203	—	—	—	—	1,203
4 p.m.	—	—	—	—	—	—	—	—	—	—	892	—	—	—	—	892
4:30 p.m.	—	—	—	—	—	—	—	—	—	—	760	—	—	—	—	760
5 p.m.	—	—	—	—	—	—	—	—	—	—	853	—	—	—	—	853
5:30 p.m.	878	—	—	—	—	—	—	—	—	—	48	—	233	—	—	1,159
6 p.m.	44	—	—	—	—	—	—	—	—	—	777	—	—	—	—	821
6:30 p.m.	—	—	—	—	—	—	—	—	—	—	920	—	—	—	—	920
7 p.m.	—	—	—	—	—	—	—	—	—	—	849	—	—	—	—	849
7:30 p.m.	7	—	—	—	—	—	—	—	—	—	831	—	193	—	—	1,031
8 p.m.	—	—	—	—	—	—	—	—	—	—	—	—	151	—	—	151
8:30 p.m.	—	—	—	—	—	—	—	—	—	—	—	—	26	—	—	26
9 p.m.	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	4
9:30 p.m.	—	—	—	—	—	—	—	—	—	—	—	—	9	—	—	9
10 p.m.	—	—	—	—	—	—	—	—	—	—	—	—	9	—	—	9
Total	2,650	1,222	9	479	2	1,171	1,690	847	1	2,399	7,946	1	3,491	1	585	22,494

Note: Shaded numbers represent raw number of "sightings" transmitted by transponder tag during time interval. Single sighting provides information on tag's location relative to fixed origin located in southwest corner of building (bottom-left side of floor map in **Figure 2**). Each sighting contains *x* value, *y* value, and *z* value (height) measurement expressed in meters. Individual sighting is calibrated to 0.01 m in *x*, *y*, and *z*, but realistically, accuracy of 0.2 m in each dimension is best that has been achieved under normal circumstances. Tag generates more sightings the longer it stays in one area. When tag moves to another room, it generates new sightings in that location. System is precise enough to determine when person is in given location, where he or she goes next, and in what order.

utility, ease of use, nonintrusiveness, and time-saving features of the tracking resource. The next and more challenging phase involves installing the remaining LCD panels and implementing the behavior-prompting system in conjunction with an application that allows PTRP clinicians to define behaviors in the context of specific locations, for which we anticipate completion by the third quarter of 2011. We have planned research to evaluate the effectiveness of the PTRP in facilitating cognitive rehabilitation.

To summarize, we have described a novel application to smart home technologies for the active rehabilitation of patients with TBI along with the progress of the creation of a rehabilitation smart home at the James A. Haley Veterans' Hospital in Tampa, Florida. The smart home technologies address four key areas: (1) patient safety and monitoring, (2) patient checkout and elopement detection, (3) schedule and medication management, and (4) behavior prompting. The smart home acts as a cognitive prosthetic, providing patients with individualized prompts programmed by the PTRP staff. We hypothesize that Fractal D will be a useful indicator of patient progress. If successful, this technology may be deployed to other PTRP facilities within the VA medical system.

Smart cognitive prosthetics, however sophisticated, will not and should not replace human contact [2]. However, technology-based cognitive prostheses as manifested in the smart home concept can play an increasingly important role in delivering cognitive rehabilitation services and become an integral part of clinical practice.

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