

SmartCare: an Introduction

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Abstract—This paper introduces SmartCare, a project revolving around a smart environment especially built to enable aging in place. The paper describes the vision behind SmartCare as well as its translation into a deployed system. The physical incarnation of SmartCare is the SmartCare apartment, an actual apartment in a retirement community. We provide a description the technologies that are deployed in the SmartCare apartment. This paper does not introduce novel algorithms for smart environments, rather it provides an architectural system description of a real smart environment that was designed to enable aging in place.

Keywords—*smart environments, health technologies, aging in place, health self-management,*

I. INTRODUCTION

Progress in medicine and changes in lifestyles in developed countries over the last decades resulted in a significant increase of life expectancy and with this an overall aging of the population. In the United States, for example, average life expectancy has increased from 70 years in the 1970s to 78.8 years currently [21]. Along with the increase in age, however, comes a higher prevalence of chronic health conditions, such as high blood pressure, congestive heart failure, diabetes, or arthritis. In the US population, for example, 80% of individuals over 65 suffer from at least one chronic condition. This increasing prevalence of chronic conditions, in turn has significant impact on the quality of life, the requirements for health care services, and the cost of the health care system. In the U.S., for example, health expenditures have increased from 13% of GDP in 2000 to currently 17% of GDP and are projected to exceed 20% of the GDP by 2022 [22]. To address these costs, improve quality of life even at an advanced age, and to address the common desire to remain independent as long as possible, it is essential that chronic conditions can be detected and diagnosed as early as possible, that diagnosed conditions can be monitored efficiently, and that treatment can be effectively self-managed. Pervasive sensor and information processing technologies promise to be an important component in facilitating this by enabling non-intrusive at-home monitoring, providing diagnostic support, and assisting in self-management in the context of complex treatment plans.

Over the last decade, a range of smart home and intelligent environment technologies have been developed, aimed at providing information regarding the behavior of inhabitants in a home. Many of these projects were initially developed to facilitate in-home automation but have recently changed focus to investigating their potential impact on aging-in-place

applications. At the same time, a range of component technologies have been developed aimed at the monitoring aspects important to health, including: i) telemedicine devices that allow collection of medical information (e.g. heart rate or blood pressure) at a high frequency without the need for a visit to the doctor's office; ii) overall behavior assessment technologies detecting changes in coarse behavior patterns; iii) technologies to facilitate remote doctor/patient interaction.

In this paper we describe SmartCare, a pervasive, integrated hardware/software/communication infrastructure aimed specifically at studying the utility of holistic technologies for early diagnosis support, smart, non-intrusive health monitoring, and self-management assistance in home settings. SmartCare uses unobtrusive sensing technologies that do not impede on the privacy of the inhabitant and that do not require any specialized user interactions to perform health monitoring and assessment in the context of common daily living activities. This not only reduces the white coat effect (which leads to erroneous data when individuals are aware that they are providing health data), but also permits continuous monitoring and reduces the burden on the individual which, in particular in the context of the growing potential of mental deficiencies in older individuals, can also lead to a more reliable and regular source of information. These sensing abilities are integrated with modern communication technologies and intelligent algorithms to facilitate individualized monitoring without focusing on individual conditions but rather addressing a more holistic context, covering all areas of life, including nutrition, overall activity, exercise, and physiological health factors. Moreover, SmartCare is also concerned with the integration of the intelligent environment system with the broader care system by investigating connections to care providers through diagnosis support and treatment adherence support components. The SmartCare system prototype described here has been deployed in an independent living apartment at the Lakewood Village Senior Living Community where it permits testing and evaluation of the technologies in a real elder care environment with the target population. The live-in SmartCare laboratory consists of a complete (~800sqft) one-bedroom apartment which includes an exercise room. Next to the apartment is a separate control room (~100sqft) used to: i) house the control and data collection/evaluation infrastructure; ii) allow for demonstrations; iii) supervise the system; iv) allow data access without the need to enter the apartment.

The SmartCare system integrates a number of pervasive, environment-embedded sensor technologies, including a SmartFloor for overall behavior and specific gait analysis, Z-wave based device control for monitoring of inhabitant interactions with appliances and devices in the home, motion

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detectors for coarse behavior and presence information, a smart mirror for unobtrusive health data acquisition, instrumented exercise equipment, sleep monitoring pressure mats, and automation components for window blinds and curtains. Data from these sensor systems is integrated through a communication infrastructure into a computing system which permits data analysis, monitoring, visualization, decision support, and outside integration. Through this, the deployed system provides a means for testing and evaluation not only of the integrated components but also for new technologies which can be integrated incrementally through the uniform architecture, and for which the existing components can provide ground truth information to facilitate more effective evaluation (e.g., wearable sensor systems).

The rest of the paper is organized as follows. Section II presents the overview of the SmartCare infrastructure and its architecture. Section III introduces the sensor and actuator components. Section IV provides an overview of related projects with a focus on other intelligent environments for aging-in-place. Section V concludes the paper.

II. THE SMARTCARE INFRASTRUCTURE

As indicated, the goal of the SmartCare system infrastructure is to provide a holistic, integrated hardware/software framework that addresses individualized early detection of health changes, diagnostic support, health condition monitoring, and self-management and treatment adherence support in the context of aging-in-place and in-home monitoring. Underlying the design of the SmartCare system are a number of core principles, including that i) systems should be unobtrusive and preserve privacy, ii) data analysis and support should be individualized, and iii) the system should be expandable to include new technologies and analysis capabilities. The first of these has led to the focus of sensor systems that are virtually invisible to the user, and preserve the privacy, leading in part to the absence of cameras throughout the apartment for behavior and activity tracking and the use of more indirect sensing methods (in particular the SmartFloor) to provide relevant information in a less intrusive way. The second principle has led to a focus on adaptive and machine learning techniques for data processing that can automatically adapt to the inhabitant and provide more sensitive and customized monitoring and self-management support capabilities. To address the expandability of the system and the data processing capabilities, the system has adopted a uniform, data-centric architecture for information management and processing that permits the addition of new technologies and processing algorithms without changes to the existing system.

Figure 1 shows an overview of the elements of the architecture of the system. At the bottom of this architecture is the sensor layer containing sensor and actuator components that provide actual data and perform assistive actuations. These components contain their own data accumulation and communication hardware and interact with the data layer of the system. The data layer forms the heart of the architecture. Each of the sensor-layer modules interacts with the data layer through a client-server interface. Through this, acquired data is put in the database and commands are read from the database and sent to the sensor/actuator module. As a result, interaction

between any two modules is strictly performed through the database, leading to a uniform interaction scheme as well as to an infrastructure that facilitates research by maintaining data and allowing re-processing of information independent of the running sensor modules. The analysis layer contains the processing modules. Again, these interact through client-server interfaces with the database, accessing the necessary information and returning processed analysis results to the database for other processes to access. Similarly, the interface layer contains user interface and visualization components.

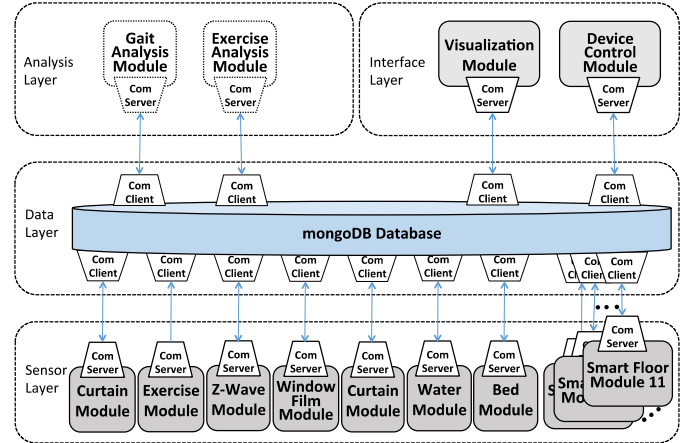


Figure 1 SmartCare System Architecture Overview

The architectural design leads to a modular, extensible system where additional sensor systems and algorithms can be added without disrupting the remaining system. Moreover, this data-centric integration ensures that not only the most recent data item is available but that the system also supports modules that require re-processing of data, such as machine learning algorithms that learn user profiles or self-calibration algorithms that can calibrate sensor readings based on usage data.

A. Sensor Layer Modules

The sensor layer contains modules that handle the data acquisition and pre-processing for different sensor systems. In the deployed SmartCare system these components are i) SmartFloor pressure floor modules, each covering a region of the floor, ii) ZAPS [20]: a Z-wave component which handles information coming from all Z-wave devices, including lights, outlets, motion sensors, door sensors, cabinet door and drawer sensors, and temperature sensors, iii) an exercise equipment module which handles data from the exercise bike, iv) a window film module which controls the dimmable window film used, v) a curtain module which controls the actuation of the curtains, vi) a bed module that handles data from the bed mat sensors, and vii) a water flow and automatic shutoff module to measure and control water flow in the apartment.

Each sensor module contains a data acquisition, communication, and data management processor that handles data pre-processing and implements a server to which the data layer client connects to acquire data and send control commands. BeagleBone Black (BBB) embedded computers (hidden in the walls of the apartment) are used to build the communication platform. All sensor modules are integrated into the environment in a way that minimizes their visibility to

the user, leaving the overall environment as undisturbed as possible; Figure 2 shows the living-, kitchen, bed-, and exercise-rooms.



Figure 2 Rooms in the SmartCare Apartment

B. Data Layer Components

The data layer contains the main database and client processes for each of the sensor modules as well as for each of the analysis layer and interface layer components. These client processes connect to the corresponding server when it is available and manage transfer of the data from and to the main database. This database is at the core of the data layer and uses mongoDB (a no-SQL database) to store the incoming data and commands and to provide efficient access to this data. This database ensures that data is available of on-line as well as off-line analysis and handles all data exchange between modules.

C. Analysis Layer Components

The analysis layer contains the data analysis and decision support algorithm components. As in the case of the sensor layer, all analysis components are integrated in a modular fashion with each module containing a server process to which a corresponding client process in the data layer connects. In this way, analysis modules can be added efficiently, have access to data in the way they need (e.g. real-time versus historic data), and can provide their results in a way that can be used by other modules such as the visualization module. The analysis modules developed so far have been for specific experiments, encompassing a simple gait analysis module as well as a simplistic exercise analysis module. As these are not actual deployment components, they are shown here with dashed outlines. Development of analysis modules will be the main focus of future work in the SmartCare project.

D. Interface Layer Components

The interface layer contains visualization as well as controller interfaces. As in the case of the other modules, the visualization and device control modules each contain a server to which a corresponding client in the data layer connects.

The visualization module used in the SmartCare system (VISMA) [20] allows to both visualize the current state of the apartment in real time or to re-visualize past data for later analysis. This is an important functionality to allow health professionals to re-investigate data in situations where a decision support module has detected anomaly or an indicator of a negative health event. VISMA can also be used to control

various actuators in the SmartCare apartment. Figure 3 shows a screenshot of VISMA and the actual control room.



Figure 3 VISMA and the SmartCare Control Room

III. SMARTCARE COMPONENTS

In a previous paper [20] we provided a brief description of the z-wave control component (ZAPS) and the visualization software (VISMA - written around the Unity game engine). In this section we briefly describe the SmartFloor; then we detail the z-wave based components as well as the other smart environment components.

A. SmartFloor

Here we only provide a brief description of the SmartFloor; a more detailed description is beyond the scope of this paper. Our primary goal with the SmartFloor is to constantly measure gait and balance parameters of inhabitants (in addition to being able to have frequent access to weight measurements). Camera based systems are relatively inexpensive, however they need sophisticated vision algorithms and people find them invasive in their home. Capacitive floors are merely good to detect the presence of an object above them, not the pressure they exert. Gait analysis is usually done by pressure sensitive floor mats but the price of these high resolution mats makes a global apartment-wide deployment infeasible.

The SmartCare SmartFloor is a pressure sensitive floor. We set a goal to have a resolution of about one pressure sensor per square foot (about 10 per square meter). Our choice for pressure sensors is the Tekscan FlexiForce pressure sensor. SmartFloor is built on these disc-like sensors deployed in a one foot (~30cm) side-length square matrix configuration. On top of these sensors we have a click-together ceramic tile rigid flooring structure that can bend along the tile lines. Thus, each tile is floating over four Tekscan sensors in the sensor-matrix. These tiles are rigid enough to take the weight of people and objects usually encountered in a home and do that by being supported only by their corners. With the SmartFloor it is then possible to determine the center of mass (in 2D) over each tile and thus we are able to measure balance and gait characteristics. The floor is built in 4ft by 8ft sections, and each section has a custom designed acquisition board recording the readings of 32 sensors at 50Hz. Data from the acquisition boards is relayed BBBs deployed in the walls of the apartment, which in turn preprocess and relay the data to the central server using Ethernet. The central SmartCare server (magoo) is responsible for making sure that all SmartFloor acquisition boards and their controlling BBBs are running and that the BBB-s have the appropriate servers running.

B. Smart Outlets

Every 120VAC outlet in the SmartCare apartment is equipped with an AEON Labs smart energy switch (MSES: DSC26103-ZWUS) which is placed in the outlet box right behind the power outlet (a total of 44 MSESs). These z-wave devices can be remotely turned on and off; they provide instantaneous power and accumulated energy readings over to the main z-wave controller and the ZAPS software. ZAPS runs a server process on a Windows machine. A client process on magoo connects to ZAPS and retrieves the state, power, and energy usage of the MSES switches, which are then placed in the mongo database. Each BBB's power supply is also controlled by one of these MSES switches, enabling an easy remote cycling of the power to the BBBs.

C. Smart Lighting

Every light and fan in SmartCare is also connected to a AEON Labs micro smart dimmer switch MSDS: DSC27103-ZWUS (a total of 13 MSDSs). The MSDS-s are controlled similarly to the MSESs, with the exceptions that MSDSs are also connected to regular light switches that can trigger them and that they have power control (dimming) capabilities.

D. Water monitoring and shutoff

We believe that water usage monitoring could provide value added input to activity recognition. Thus in SmartCare all water sources are measured. In addition we wanted to have the capability to shut off each water source in case any of them are accidentally left running. Thus after each water valve (two for the kitchen sink, one for the dishwasher, two for the tub, two for the bathroom sink, one for the toilet and one for all hot water) we have installed an additional ball valve with a servo motor controlled shutoff, and a water flow meter.

The water flow sensors are Uxcell's hall effect sensors (YF-S201 and FS300A for $\frac{1}{2}$ " and $\frac{3}{4}$ " pipes). These sensors need to be powered with 5V and output a conditioned digital signal with the frequency corresponding to the water flow. After level adjusting the signal with CMOS buffers (the BBBs cannot handle signals larger than 3.3V) they are connected to some of the digital general purpose inputs of the BBBs. One BBB can handle six water flow sensors and six shutoff valves. The shutoff valves are BoxLink BL-OC-VAL; Solenoid based shutoff valves could not have maintained the state of the valve in case of a power outage. The shutoffs we are using are mounted on regular ball valves and have powerful servos to turn the valves. They are controlled using H-bridges and MOSFET drivers from the GPIOs of the BBBs.

For the entire water infrastructure of the SmartCare apartment we use two BBBs, one controlling water in the kitchen (3) and one for the rest (6). Each BBB is set up similarly to the BBBs that control the SmartFloor, i.e., magoo has direct ssh access to them. They both have the same software running, that establishes a TCP server socket, and can then send measurement data (ticks/second for each sensor) to connected TCP clients as well as receive "open valve" or "close valve" commands from them. A script on magoo starts and maintains the server processes on the BBBs as well as starting client processes on magoo that control the valves and write data coming from them into the mongo database.

Additionally, the apartment has three z-wave based flood sensors (Everspring ST812-2) placed at strategic locations in the bathroom and kitchen. They send their data through ZAPS to magoo. A client process monitors data coming from these sensors and can instruct any of the active water sources to be shut off to prevent further damage.

E. Smart Window Film

As privacy is as important as convenience, we wanted to provide a window treatment that can be reconfigured automatically. The SmartCare apartment has three double windows and a double patio door facing outside.

After looking at controllable window blinds, we decided to go with an alternate solution: electrically controllable privacy window films. The product we have decided to use is distributed by SmartTint. This film is opaque (providing privacy while still letting light through) when not receiving electric excitation and will turn to its full transparency when applying a proper sine wave to it at $70V_{eff}$. The simplest solution would be to use power potentiometers to step down AC mains but that would be extremely power inefficient and create a lot of heat. Another option is to use power control circuits similar to dimmers, but these TRIAC based setups only clip the mains at different levels and thus do not provide proper sine wave outputs (SmartTint film is very sensitive at sudden voltage drops and increases). Another option is to use toroidal adjustable transformers, but they are too big and are difficult to adjust. We set out to design a proper sine wave generator (power controller) using switching MOSFETs that can be electrically controlled to output a variable amplitude sine wave with high power efficiency. Due to liability and time concerns we have finally decided to purchase the power controller bricks that SmartTint licenses. The unfortunate problems with these modules are that they are rather large (they can provide an order of magnitude more power than our window films are using) and that they come with a manual potentiometer for adjustment. In addition the potentiometer is connected into the feedback loop of the internal switching power supply thus making its replacement with ICs or MOSFETs difficult if feasible at all.

To retain their electrical safety features, we decided to use 0-270 degree servos driving each potentiometer on the SmartTint power bricks. The servos are then controlled by a few add-on components to a BBB's GPIOs outputting PWM signals. We have repurposed a PC case, attaching four window controller bricks, four of their potentiometers, four servos, a six-position relay board, a BBB, a network switch and their power supplies in a cabinet inside the apartment. The BBB can turn individual servos on using the relay board, and issue a PWM signal to them which in turn turns the potentiometers of the controller bricks. The software architecture controlling the window films is similar to that of the water and SmartFloor. There is a TCP server process running on the BBB that gets started by an ssh tunneled command from magoo. An appropriate client on magoo is then started to connect to the BBB and record any settings in a mongo database; this client can take commands from the database as well as establishing its own TCP server to which remote control clients can attach.

VISMA users can click on the windows of the apartment and adjust the transparency level.

F. Smart Curtain

In addition to the privacy film applied to each window, we also have curtains as window treatments, providing the option to darken the rooms. Each curtain is affixed to a BEME erod (ERODCN68-120) remote controllable curtain rod; they are adjustable in size. These curtain rods come with IR remote controls (open, close, stop) so humans can control them conveniently. They have an electronic head unit with a powerful (and heavily geared) motor. Unfortunately, like many “smart home” technologies, they do not provide an interface to advanced users. To be able to control them, we use IR remote controls, where the “buttons” are triggered by the outputs of a BBB (through MOSFETs). However, we also wanted the inhabitants to be able to use the remote controls that come with these units. Thus in order to know when they have been triggered (and how far they were instructed to pull the curtain) we also need feedback coming from the motors. Originally (in order not to have to hack the electronics) we decided to use optical encoders on the motor shaft; this turned out to be unreliable. Our current design has a small current sensing resistor in series of the motor (inside the H bridge) connected to an H-bridge capable difference amplifier IC, of which the output is fed into an A/D converter pin of the BBB controlling the curtains. This way we have a relatively precise position feedback (after we learn the current drawing characteristics of each motor) on the position of the curtains.

The four curtains thus are controlled by a BBB, using three outputs each to control the curtains and four analog inputs to measure any activation (and thus position of the current). The software architecture is practically the same as the one used for the window film control.

G. Smart Appliances

In this subsection we will share more information with regards to what other technologies are currently deployed in the SmartCare apartment, and what our experience with them has been. In general, there are very few off-the-self “smart home appliances” that provide an API for advanced users. In our experience, companies manufacturing “smart appliances” attempt to market these appliances and then due to low interest from customers, they cease to manufacture them. We have observed this vicious cycle for most of the past two decades.

1) Refrigerator and Range

The fridge we have selected is an LG smartThinQ LFX31995ST. The “smartness” of this refrigerator is in that it has an Android driven touchscreen from which the user can access a few configuration options, and can retrieve basic information from the Internet. In addition the fridge can talk wirelessly to a remote control application as well as to LG manufactured smart ranges (preheat them to the right temperature when a recipe is selected). Unfortunately, there is no easy to use API to access these options from the outside and thus controlling the refrigerator or receiving data from it from/to our own software remains future work.

Similarly to the refrigerator, the range we picked is a “smart appliance” manufactured by LG (smartThinQ

LRE3027ST). This is the model that can actually indeed talk to the refrigerator. Interfacing the stove with our own software remains a task for the future.

2) Faucets and toilet

Both the kitchen faucet and the bathroom sink faucet are Delta Touch2o variants; these faucets turn water on and off when a human touches the faucet body (capacitive sensing). Unfortunately, they do not have any external interfaces; however our water monitoring and shutoff setup can control water. The toilet is a KOHLER Touchless appliance, where flushing is done by waving one’s hand over a battery operated sensor that triggers a motor to pull the flushing flap. Like with the faucets there is no external interface provided to the toilet.

3) Tub and Water heater

Neither of these units is “smart”, they do not provide any interfacing capabilities. However, the tub is a walk-in “geriatric” tub with a Jacuzzi feature (Meditub 3060wirbd) (we can measure or shut off water to it). The water heater is a Stiebel-Eltron (Temptra 20) tankless electric heater (unfortunately without a computer interface). This heater was added (having had to upgrade the main electrical cabling) to enable inhabitants to indeed enjoy a full tub of hot water.

4) Vacuum cleaner

Our choice for the vacuum cleaner was a Neato Botvac D80. These vacuum cleaners do room mapping in order to be knowledgeable about obstacles and thus know where they cleaned already. They do not provide a native interface but researchers have hacked them previously so that they can be remote controlled. We will apply similar hacks in future work to be able to interface the Neato with our data collection and appliance control.

5) Smart Coffee Table

The coffee table in the living area is a lowered Samsung SUR40 Microsoft PixelSense table; essentially a large (40” – 101cm diagonal) optical-multi-touch tablet. This table will serve as a remote control and health visualization appliance as well as it will host geriatric serious gaming applications currently under development in our lab.

6) Recumbent Exercise Bike

Proper exercise can significantly contribute to an extension of independent living. It is important to be able to provide appropriate exercise appliances and measure their usage. One of the least stress-inducing exercise machines are recumbent bikes. Unfortunately, exercise bikes that provide an open interface are rare. For SmartCare we opted to purchase the Stamina Elite Total Body recumbent exercise bike. In order to be able to interface with it, we connected a BBB’s GPIO input with appropriate signal conditioning to the speed sensor of the bike. (We reused an available pin of a nearby SmartFloor control BBB.) The software architecture of reading from this “SmartBike” is similar to that of the window treatments.

7) Xbox

The inhabitants also have access to an Xbox/Kinect system. A preloaded yoga game (Your Shape: Fitness Evolved), can post data on a Facebook page, from which it could be downloaded into our database. This interfacing is future work.

H. Smart Bed

The queen size bed in the bedroom is 5-way position adjustable on both sides. In addition to this convenience feature, each side of the bed has Vista Medical pressure sensitive sensors under the bedsheet (BodiTrak BT3510). Each of these bedsheets provides pressure images 26 times a second with a resolution of 256x64 “pixels”. Both sensors are USB connected to an Intel NUC i5 (sandman) microcomputer running Windows 8, located under the bed. Our software on sandman establishes a TCP server, reads both the bedsheets, and provides a compressed stream of data to connected clients. Magoo, has a client running that connects to sandman and stores the incoming pressure data in the mongo database. A separate client connected to the mongo database can retrieve the data and estimate sleep parameters of the inhabitants.

I. Smart Mirror

The Smart Mirror is an experimental component under research in our lab and thus is not permanently in the SmartCare apartment. The Smart Mirror is planned to be located in the bathroom vanity cabinet. Interestingly, it is the only component (besides the Xbox) that contains a camera and that camera is indeed in the bathroom. The smart mirror is engineered so that no raw data can be extracted from it and so that any but meta data reading access to the computer requires physical access to the computer. The camera is not visible to the inhabitant as it is behind the mirror. The smart mirror detects anomalies in facial expressions and structures to detect signs of sickness, ailments, mood, and water retention. In addition it can detect hemoglobin and melanin levels and measure pulse.

J. Motion, Temperature, HVAC, Registers

Each room is equipped with one to three z-wave based multisensors (AEON Labs DSB05-ZWUS) monitoring the room. These sensors measure temperature, humidity, and have a passive IR detector on them. As they are z-wave, they interface with magoo through ZAPS. The HVAC unit has been replaced for the apartment with a high efficiency unit (Texas heat). The thermostat is z-wave compatible and thus can be controlled through ZAPS as well. One of our future goals is to be able to set “micro-climates” for different rooms; thus we have z-wave controllable ceiling HVAC inlet registers. This way we can shut off or enable induced cold or hot air from the HVAC unit entering individual rooms.

K. Doors

Each door (entrance, patio door, room doors, even cabinet doors) and drawers have z-wave open/close door sensors attached to them. Data coming from these sensors is recorded by magoo through the ZAPS interface. This data, together with the SmartFloor data are going to be essential components for our activity recognition tasks.

The main entry door has a Samsung RFID/biometric safety lock (SHS-P718) that can be remote unlocked (by a remote controller). The door handles on this lock mechanism are “intuitive” as pushing it inwards opens the door from the outside while pulling it inward opens the door from the inside. The same door has high-end electronic actuator (DORMA ED100LE) that helps in opening and closing the door.

Our plans include the placement of smaller actuators on each door so a robot can easily traverse the entire area. For this we will also need to add solenoid enabled door strikes (so that doors can actually be unlocked before trying to open them). Although we possess the actuators and strikes, their installation and interfacing is future work.

IV. SIMILAR PROJECTS

Over the last two decades, a wide range of Smart Home and Intelligent environment technologies have been developed, including a number of complete smart home deployments aimed at aging-in-place as well as a wide range of component technologies aimed at health monitoring and aging-in-place services. As the SmartCare system is a holistic approach to health monitoring and aging in place and at providing a testbed for other technologies, this related work will focus on complete Smart Home projects. For an analysis of other smart home component technology research, Morris et al [1] provide a basic overview and analysis of the study results.

A. Smart Home Projects

Over the last decade, a number of integrated smart home laboratories have been built. Many of these projects were initially developed to study behavior and in-home automation, including the Neural Network House [5], the iDorm [3], the Duke Smart Home [10], or the UTA MavHome [6]. While these systems integrated various sensor systems and network and processing infrastructures, they largely focused on the development of learning algorithms but not on aspects of aging and health management. Soon after, however, many of the projects started to refocus on health and aging-in-place applications such as the Georgia Tech Aware home [2], the Gator Tech Smart home [4], or the CASA Horizon house [7], with a small number of larger scale deployments encompassing a significant number of units, such as TigerPlace [8], the ORCATECH Living Laboratory [9], or the CASAS smart home in a box project [19]. The latter two here are distributed smart homes made possible through the deployment of movable technologies to existing homes and do not provide the same infrastructure-embedded technologies as the former projects. While this makes wide scale deployment easier and more cost effective, the resulting environments cannot serve as testbeds for additional technologies as they cannot provide ground truth for many of the measured parameters. The SmartCare system presented here, on the other hand, has been designed specifically for this purpose, making it easily extendable and providing high fidelity ground truth information through the smart floor and other sensing components.

B. Smart Floor Technologies

The smart floor component is the most complex sensor system deployed in the SmartCare system. A number of other smart floor systems have been developed and are in use in a number of research laboratories. However, none of these systems is integrated into a holistic system aimed at health monitoring and self-management support. Existing smart floor technologies broadly use one of three technologies to measure contacts with the floor: i) optical (GravitySpace [11]), ii) capacitive (SensFloor [12]) or iii) pressure (ASU Pressure Mat Floor [13] EMFi Floor [14][15] Future Care Floor [16][17])

CMU SmartFloor [18]). While the optical system in GravitySpace can measure precise contact contours if sufficient pressure is applied, its technology does not allow it to measure actual pressure variations. Similarly, the capacitive technology used in the SensFloor does not allow for the measurement of pressure/force (weight). Existing pressure floor technologies can be divided into three classes. The first, represented by the ASU Pressure Mat floor uses a high density (1cmx1cm) of sensors to cover the floor. While this provides high resolution data, it is very expensive. The second type, represented by the EMFi floor addresses parts of these issues by using a low-resolution (30cmx30cm) sensor film deployed under the floor surface. The third type (Future Care Floor, CMU SmartFloor) is the one most closely related to the smart floor used here and uses a rigid flooring substrate mounted on a set of pressure cells. However, both the Future Care Floor and the CMU SmartFloor are expensive to deploy and do not scale easily to larger environments when retrofitting existing spaces.

V. CONCLUSIONS

In this paper we presented our vision for what technology can do for aging in place. This paper did not focus on algorithmic aspects of smart environments; instead it detailed the engineering work that has been excreted in making a real live-in smart environment for aging in place. We provided descriptions of the data and information infrastructure within SmartCare as well as described every “smart” component currently deployed and identified our future work. Preliminary data collection has begun during the Summer of 2016 in the apartment. We plan on having real inhabitants occupying the apartment for one month at a time starting the late Fall of 2016.

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