PART I

SMART TECHNOLOGY FOR AGING, DISABIITY, AND INDEPENDENCE

CHAPTER 2

HOME AUTOMATION AND SMART HOMES TO SUPPORT INDEPENDENCE

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2.1 INTRODUCTION

Home automation is a concept that has been explored frequently at world's fairs, expositions, and exhibitions. The 1933–1934 Chicago World's Fair featured the "House of Tomorrow," designed with 12 sides, 3 stories, and a wedding-cake shape.[1] It was unique for the time, in both design and technology, which included a built-in dishwasher, electric lights with dimmer switches, central air conditioning, and an electric garage door opener. It used passive solar heating, one of the first homes in the United States to do this. The garage was built to hold the family car and airplane, which futurists predicted each family would one day own. At the 1939 New York World's Fair, television and other now-everyday appliances were predicted to be in all homes of the future. The first TV set was sold in 1938, a year before any programs were broadcast.

At the 1964–1965 World's Fair in New York, several exhibits presented visions of the future. "Futurama," by General Motors, and "Space City" reached by the "Magic Skyway" by Ford suggested that future generations would live in cities consisting of very tall skyscrapers connected by tunneled highways and elevated walkways and highways, with computer-controlled vehicles. Futurama also predicted an underwater city 10,000 feet beneath the sea, where workers mined minerals, drilled for oil and gas, and farmed the sea. The underwater city also featured a resort called the Hotel Atlantis.[2] We now have Jules Undersea Lodge in Key Largo, Florida (http://www.jul.com/), and in Dubai a 220-suite underwater hotel will open in 2006. Named Hydropolis, this Dubai hotel will resemble a giant submarine, and guests will enter through a tunnel to a waterside reception area http://travel.guardian.co.uk/news/story/0,7445,1018216,00.html). Predictions at the 1964 the World's Fair included sending a man to the moon and widespread use of personal computers. Today, we take for granted many of the technological advances featured at these not-so-long-ago events.

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More recently, technological advances have been applied to providing supportive environments and tools to support older people in their homes. We begin this chapter on home automation and smart environments by answering the question, "What is a smart house?" We follow this with the author's vision for smart homes of the near future (5 years from the publication of this book) applied to the needs of people as they age. The vision is based on current research and development on smart home technology, which is described following this view of the future.

What Is a Smart House?

As we age, we face declining abilities from age-related diseases and the aging process itself. Our home can assist or hinder our ability to complete self-care and household activities. In Chapter 9, we discuss ways to modify the structure, furnishings, and lighting of a home to optimize our ability to complete everyday tasks independently. In this chapter we focus on the very latest technology, as well as future technology, that can and will assist us in living independently at home into our very oldest years.

There is growing interest in the concept of "smart houses." We begin this chapter by discussing smart house functions—what is it that a smart house actually does, or offers to its residents? Table 2.1 summarizes the following discussion of smart house functions, organizing these functions into "levels" based on complexity and how long the function has been available; in some cases they are not yet available in product form.

Smart House Level I: Offers Basic Communications Level I technology is necessary for a smart house, but simply having level I technology does not alone make it a smart house. At Level I, technology relates to communications, providing residents with the means to communicate with and receive communications from others beyond the home. Telephones represent one example of communications technology—one that has been available for over 100 years, providing voice communication with others who have the same technology. Today, especially with mobile phones, they exist almost everywhere.

The telephone is especially important for older persons with disabilities. Almost one-third live alone, and for those with limited mobility, the telephone provides opportunities for socialization. In a study of older adults living in rural areas, frequent loneliness was found to be associated with frequent use of the telephone.[3] The telephone also provides a mechanism for calls for help. Many older adults also use the telephone for shopping, banking, and arranging other personal services.

Today mobile phone manufacturers are merging other technologies into the same "box" with the phone. Consider the Sony-Erickson P900 "superphone," which offers traditional voice communications, internet access for web browsing and email, digital camera (and you can send your pictures with this device to others over the internet), MP3 player (and you can download songs from the internet), and all the functions of a personal digital assistant (such as contact list and scheduler).

Not everyone owns a "superphone" with internet access like the Sony Ericsson P900, but in the United States almost 75% of homes now have internet

TABLE 2.1 Smart House Functions

Level 1: Offers Basic Communications

Offers interactive voice and text communication (phone and email)
Provides link to World Wide Web
Offers TV (full range of stations) & radio (AM and FM)

Level 2: Responds to Simple Control Commands from Within or Outside the Home

Unlock / lock door
Check for doors / windows open or unlocked
Turn on lights
Check for land-mail
Get help (in the case of a fall or other problem)

Level 3: Automates Household Functions

Air temperature, humidity
Lights on/off at predetermined times
House made secure at certain times
Music, TV on/off at certain times

Level 4: Tracks Location in the Home, Tracks Behaviors, and Tracks Health Indicators

Determines activity patterns
Determines sleep patterns
Determines health status (vital signs, blood glucose, weight)

Level 5: Analyzes Data, Makes Decisions, Takes Actions

A. Issues alerts
- *A1. To resident*
  - Mail has been delivered
  - Person (name given, or stranger stated) at door announced
  - Water leaks
  - Stove has been left on
  - Door is unlocked
- *A2. To distant care provider*
  - Altered, problematic activity or sleep pattern, or health problem
- *A3. To formal service provider*
  - Health alert

B. Provides Reports
To resident, care provider, and formal service provider on status

C. Makes changes in automated functions based on learned preferences
- Adjusts lights, temperature, music to resident's use patterns—can be overridden easily

(Continued)

TABLE 2.1 *Continued*

Level 6: Provides Information, Reminders, and Prompts for Basic Daily Tasks

Notification mail has arrived, someone is at the door, stove was left on
Medication reminder
Hydration reminder
Meal reminder
Task prompting

- Washing, grooming
- Dressing
- Toileting/hygiene
- Exercise
- Meal preparation
- Social contacts (e.g., "call. . . . ")
- Household cleaning

Level 7: Answer questions

"Have I . . . (brushed my teeth, taken my medications, put all the ingredients in the dish I am preparing"
Orientation—time, day, month, year, season
What is happening today?
General information (any question that could be searched on Google)

Level 8: Make household arrangements

Schedule maintenance and repair visits
Order medications
Prepare grocery lists and send to grocery for delivery
Prepare meals
Handle house cleaning

access (retrieved 8-5-04-http://www.websiteoptimization.com/bw/0403/, as of February 2004). Internet access is an important communication technology, essential if a home is to be considered "smart." And for optimal use of the internet in a smart house, high-speed access is very important. Over 48 million adult Americans have broadband connections at home, which provides high-speed access (4-19-04-http://www.pewinternet.org/PPF/r/121/report_display.asp retrieved 8-5-04)

Television and radio offer additional communication, although traditionally the communication has been one-way. This is also changing. We have Web-TV, an inexpensive way of turning a TV into a web device. TVs are being sold as components; for example, a flat screen monitor hanging on a wall can display TV or input from a computer. Traditional TV, along with other electronic entertainment, is being designed in smart homes as multimedia centers, offering a range of options for media based entertainment (music, movies, television, pictures) and methods for control.

Smart House Level 2: Responds to Simple Control Commands from Within or Outside the Home At this level, anything in the house that uses electrical power can be "operated" without having to use a switch or control button attached to, or wired into, the appliance or device. Examples of household items that could be controlled include: door locks with an electronic mechanism to set the bolt; lights; small appliances; thermostats; and mechanically controlled curtains and windows.

Ideally, voice commands would provide the simplest way to issue the commands. Most systems currently sold use a remote control device similar to a TV remote. Many systems also allow distant operation through a phone.

Smart House Level 3: Automates Household Functions Heating and air-conditioning systems that use a thermostat automate air temperature in the house. Keep in mind that the first thermostat for controlling room temperature was invented in 1885, and the first home air conditioners appeared in 1928. Today, for the most part, we take automation of our air temperature for granted.

It has been possible to automate other aspects of our home such as when lights go on and off, when music or television is turned on, when the security system is set, and when our lawn sprinklers go on and off. Today we have products that offer more flexibility or features in this level of automation. Computer-based smart home products allow more easy setup for the on–off cycle, and different scenarios can be programmed for different periods, such as "weekends at home," "vacation mode traveling," and "work-week mode." In some systems, the preset cycles can be broken or interrupted easily, either in the home or through a phone call.

Smart House Level 4: Tracks Location in the Home, Tracks Behaviors, and Tracks Health Indicators A number of university and corporate labs are working on development of systems to track where a person is located in their home. If the home "knows" where you are, it can take appropriate actions in that room or area. For example, if the smart house is going to issue a reminder (time to take medications) or alert (someone at the front door), it can provide the reminder or alert in the exact location where the resident is sitting or standing. If the resident falls, an alert can be issued stating just where the person is located in the home.

The smart house can also track behaviors, such as trips to the bathroom, visits to the kitchen and refrigerator, tossing and turning in bed, and time spent sleeping, sitting, or exercising. Tracking health indicators could include taking measurements of vital signs and weight.

Smart House Level 5: Analyzes Data, Makes Decisions, Takes Actions Knowing typical patterns for the smart home's resident, deviations from this pattern could be indicators of a problem, and the smart house could check with the resident, or a family member, to be sure the person was well. Likewise, if a person was losing too much weight, they could be alerted, or a care provider could be notified.

The smart house is also capable of compiling health status reports for the resident, for a family care provider, or for a formal service provider such as a physician. Tracking key health information related to the resident's condition on a daily basis can lead to quickly identifying deviations from what is normal for that person.

The smart house can also learn the resident's preferences in such areas as lighting, temperature, and music. The smart house will then either directly make adjustments (such as raising the temperature in the home just before the person gets out of bed) or "ask" the resident if they would like the adjustment made.

Smart House Level 6: Provides Information, Reminders, and Prompts for Basic Daily Tasks The smart house will "know" when mail has been delivered, when someone is at the front door, when the stove has been left on too long, or when the resident has gone too long without a drink of water or has forgotten to take medications. It will prompt the resident that the mail has arrived, to take a drink of water or medications, or that it is time to have dinner.

For someone with more significant cognitive impairment, who has difficulty even with basic daily tasks such as dressing and grooming, the smart house will prompt the person with voice and visual cues through each step in the activity.

Smart House Level 7: Answer Questions Those of us who regularly use the internet appreciate the ease with which we can get answers to almost any question—typically we use Google or some other internet search engine. For questions that go beyond the resident's individual experience, the smart house, with a voice recognition interface, will accept questions, go to the web to seek the answers, and respond with an answer back to the resident. For more personal questions, such as "Have I taken my medications this morning?" the smart house will search its own database and respond appropriately.

Smart House Level 8: Make Household Arrangements The smart house will know when the furnace filter needs to be cleaned and when medications should be ordered, and it will handle all details of those transactions. The smart house will track food consumption, seek input from the resident on the menu for the next several days or more, prepare grocery lists, order the groceries, and arrange for deliveries. When an appliance requires repairs, the smart house will recognize the need and arrange for someone to come to the home to make the repair.

2.2 VISION OF THE NEAR FUTURE: A DAY IN MRS. SMITH'S SMART HOME

After the following introductory paragraph, we present an edited version of an article by William Mann and Sumi Helal that appeared in the *Journal of Certified Senior Advisors* in 2003.[4]

The story takes place in the year 2010—that is, 5 years from the publication of the present book. Some of the smart house features described below were available while the book was being written, whereas others were in the research and development stage. In 2010, all are available in product form. The University of Florida Research and Development team, working with several university and corporate partners, created a flexible package called the Gator Tech Smart House system.

Mrs. Smith is an 87-year-old widow who lives alone. She no longer drives because her vision is moderately impaired, and arthritis makes it difficult for her to grasp the steering wheel. She is also a bit forgetful, but still plays cards regularly with a group in her community. Her daughter, Sally, who lives 12 miles away, assists with trips to the grocery store and doctor, while Mrs. Smith's friends and neighbors help with trips to church and the community center where she plays cards. Mrs. Smith had a fall 2 years ago which resulted in a hip fracture, but she recovered well and walks slowly with a cane. Mrs. Smith's son, Tommy, lives 800 miles away, but has kept in close touch by phone and visits at least every 3 months. Sally and Tommy recently assisted Mrs. Smith in a move from her large two-story home of 52 years into a smaller ranch style home set up as a smart house.

Bathroom and Bedroom

When Mrs. Smith gets up in the morning, the time is tracked. If it is significantly earlier or later than normal, the smart house notes this. She goes to the toilet—a smart toilet. In the early 2000s the Japanese company Matsushita Electric Industrial Co. designed a toilet that can determine a person's blood pressure, temperature, and blood sugar. This information can be analyzed by the smart house to determine if there is a need to electronically transmit an alert to Sally or Tommy or Mrs. Smith's family physician, Dr. Jones.

Mrs. Smith completes her other basic activities of daily living (ADLs)—taking a shower, combing her hair, getting dressed. While her "forgetfulness" is not severe, the smart house is ready to help with prompting through these activities, should Mrs. Smith need help in the future. Monitors and speakers in the bathroom and bedroom provide auditory and visual prompts for brushing teeth, combing hair, bathing, and dressing. The smart house "remembers" if these activities have been completed. If Mrs. Smith cannot remember if she brushed her teeth, she can ask the smart house: "Have I brushed my teeth, already?" She will get an appropriate reply. Should she go back to brush her teeth a second time, without having consumed food, the system will politely remind her that she has already brushed her teeth.

Hall

After completing these basic morning ADLs, Mrs. Smith goes to the kitchen to prepare her breakfast. On the way from the bedroom her movement is tracked by a number of sensors. Should she stop and stand in one place, or fall, speakers close to where she is standing will ask her if she requires assistance. She can respond that she has stopped to look at some pictures, and the smart house will "know" she is safe. The movement tracking system is also able to ascertain if she has fallen and will ask her if she needs to have a call placed for emergency assistance. She could respond that she fell but did not hurt herself and is able to get up, and there is no need for a call. Alternatively she could instruct the smart house to place the call. If she does not respond at all, the smart house places calls in this order: first to Sally, but if she does not answer, second to a Personal Emergency Response System (PERS) operator for emergency assistance. The smart house tells either Sally or the PERS operator that Mrs. Smith has fallen and she is not verbally responding to questions. Mrs. Smith does not fall today, but feels much more secure knowing that if she falls, the smart house will find her help. When she fractured her hip two years ago, she lay on the floor 4 hours before her daughter came to the house—her daughter had become concerned because her mother had not answered her morning phone call.

Mailbox

On the way to the kitchen the smart house tells Mrs. Smith that the morning newspaper has been delivered to her mailbox.

Kitchen

The smart house offers a number of features for Mrs. Smith in the kitchen. Like her bedroom and bathroom, the kitchen has flat screen monitors hanging on the wall, along with small speakers unobtrusively placed on the walls. Mrs. Smith can call on the smart house for suggestions for breakfast—providing a menu based on the diet recommended by a nutritionist who works with Dr. Jones. Today she decides she is going to make instant oatmeal, using her smart microwave oven. The smart microwave oven recognizes what Mrs. Smith is preparing from an electronic tag on the package, and it automatically sets up the appropriate time and power. This microwave oven is also able to determine if the food or object is not safe—that is, if it contains a substance that could cause an allergic reaction. Mrs. Smith drinks a glass of orange juice and slices a banana into her oatmeal. The smart house tracks the food that Mrs. Smith is eating for breakfast.

Mrs. Smith takes four medications, one of which she takes in the morning and evening; the other three are taken just in the morning after breakfast. Today a half hour after eating breakfast, she is still enjoying the morning newspaper and has not yet taken her morning medications. The smart house reminds Mrs. Smith that it is time to take her morning medications. She has a medication caddy that is designed to dispense the appropriate medications, at the appropriate time, into a small dish. After she takes her morning medications, the smart medication caddy recognizes that Mrs. Smith's arthritis medication is down to a 4-day supply, so a message is sent to the pharmacy regarding the need for a refill. Mrs. Smith receives a call later in the morning from the pharmacist, asking her if she would like the refill, and, if so, would it be convenient to have it delivered by Joe, the delivery man, in about 1 hour. When Joe arrives, the doorbell rings through the speakers in the kitchen, where Mrs. Smith is still reading the paper. She looks up at the monitor and recognizes Joe. The security camera at the front door is also part of the smart home system. She instructs the smart house to "open the front door," and Joe comes in, greets Mrs. Smith, and places her arthritis medication in her medication caddy. When Joe leaves, the smart house locks the door behind him. The smart house tracks all visitors, so Joe's visit is noted.

Laundry Room

After reading the newspaper, Mrs. Smith decides to wash some clothes. She has a combination washer/dryer—the same machine both washes and dries her clothes, saving her the extra step of transferring the washed clothes to the drier. The smart washer/drier alerts Mrs. Smith that her clothes have completed the wash/dry cycle through the monitor/speaker system in the living room where she is now seated. The automatic tracking system always knows where Mrs. Smith is in the house, and it can send the messages to the speakers and monitors specifically to the room she is in. Should she need it in the future, an advanced option for the smart house is to have speakers and monitors on every wall, so that the verbal and auditory messages come through on the monitor she is facing. Mrs. Smith goes to the laundry room, folds her clothes, and takes them to her dresser and closet. The smart house notes that these tasks have been completed.

Living Room

The living room has an entertainment system that is also integrated into the smart house. This system includes music (CD player and AM/FM tuner), video (VHS, DVD, and cable TV), internet access, and integration with files stored on her computer, including her digital picture collection. Today she sits on her couch and verbally instructs the entertainment system to turn to FM 88.7 and she listens to National Public Radio. With classical music in the background, she reads a novel that Tommy had given her on his last visit. The smart house notes this.

Beyond the House: Getting Out

At noon, Mrs. Smith prepares a light meal. Smart house interaction/involvement is very similar to breakfast. Following lunch, Mrs. Smith's next door neighbor stops by to give her a ride to the community center, where she plays cards for the afternoon, followed by dinner out with her bridge partner. The smart house records her lunch, the visit of her neighbor, the departure time of Mrs. Smith, and her arrival time back at the house.

Mrs. Smith always carries her smart phone with her when she leaves the house. Until the recent significant upgrades in voice recognition technology, the smart phone served as the primary interface for human interaction with the smart house. While traveling outside the home, the smart phone tracks her location and can provide assistance if she requires it, as well as make traditional voice calls. When she returns home, information about her trip outside the home will be sent (using Bluetooth wireless) to her computer. Before Mrs. Smith stopped driving 3 years ago, her smart phone interfaced with her car and, through sensors in her car, was able to alert her if she was driving too slowly or perhaps swaying from lane to lane. It was based upon feedback from this smart phone/car system that she decided it would be best to stop driving.

Back Home for the Evening

Arriving home after dinner, Mrs. Smith is reminded by the smart house to take her evening medication. She then watches the news for an hour, completes her nighttime ADLs, and retires to bed at 9 P.M. The smart house notes all of this. Before she retires to bed, Mrs. Smith asks, "Are all doors and windows locked?" The smart house quickly checks and gives her an accurate security report. Mrs. Smith's bed includes biosensors that track her body temperature, heart rate, breathing rate, and movement while sleeping. The smart house notes these measurements.

Data Analysis and Reports

An important aspect of Mrs. Smith's smart house is its capability to interpret data, including movement patterns. If Mrs. Smith "tosses and turns" every night, then this is not unusual behavior and probably not a reason, at least by itself, to send an alert to Sally or Tommy. On the other hand, if Mrs. Smith typically sleeps calmly but on one night is tossing and turning and is also up from bed several times during the night, then Sally will receive a call. Likewise, if Mrs. Smith were sedentary (she is not) and gets up from bed late, remains in her bathrobe all day, eats little, and stays seated in the living room, then the smart house would alert Sally.

Sally can get a daily, weekly, or monthly report of her mother's health and behavior through a secure internet site. She checked the report of this "day in the smart house" and learned that her mother had slept well, was up at her normal time, had two good meals at home, did the laundry, was out in the afternoon and for dinner (which she knew was appropriate because she plays cards on this day), had taken her medications, and had had a medication delivery. Since her mother moved into the smart house, Sally has felt much less stress and worry—much of the burden of care giving had been lifted. Sally still calls her mother each day, but she no longer feels she is being intrusive with asking many questions—she knows how her mother is doing before she places the call.

When Mrs. Smith visits Dr. Jones, he has available, through the internet, a summary of her vital signs and her sleeping, eating, and activity patterns. The large amount of data is analyzed and summarized for Dr. Jones, who receives a one-page summary with clearly marked alerts for any potential health problems. Should Dr. Jones need more information, he can request more detailed reports. He has had several patients with this smart house technology and has been able to identify early symptoms of depression and dementia and thereby provide appropriate treatment.

2.3. THE UNDERLYING TECHNOLOGY OF THE SMART HOUSE

In the previous section, we discussed components of a smart house in terms of functions, with some mention of the underlying technologies, such as sensors. In this section we discuss the ***underlying technologies*** of the *Gator Tech Smart House*, which include (1) sensors, (2) computers, (3) software, (4) user input devices, (5) user output devices, (6) mechanical hardware, (7) wireless technology, (8) batteries and other power sources, (9) the internet, (10) indoor location tracking technology, (11) smart appliances, (12) other related technology, and (13) human-based service providers. Each will be described below.

Sensors

There are a large number of sensors that can be used in a smart house. Each determines something about Mrs. Smith or her house. Information from sensors is sent to the data storage or data analysis unit—the computer. Specific sensors can detect temperature, moisture, movement, light, sound, acceleration, odors, and much more. Several types of sensors that are being used, or could be used in a smart house, are described below.

Environmental Sensors These sensors can be placed around the house, or on under furniture and appliances, or on floors and walls. Power consumption is usually less of an issue than with personal, wearable sensors, but it may not be possible for these sensors to determine who is being monitored when more than one person (or person and pet(s)) are present.

Passive Infrared Sensors These sensors can track movement. Several investigators have used such sensors to study person-movement within living spaces such as homes, nursing, and hospital rooms.[5]

Fiber-Optic Floor Vibration Sensors Alwan, Dalal, Kell, and Felder describe the use of these sensors in a lab setting to successfully differentiate step count, cadence, pace, and step duration as well as to successfully differentiate among normal gait, limping, and shuffling gait.[6] Furthermore, the sensors can detect falls. The sensors detect gait at distances over 8 feet and work on carpeted, concrete, and wooden floors. Each sensor costs less than $100 and can transmit data wirelessly. Such sensors could be useful in determining general movement in a home (is the person up and doing well), and they can track progress in walking following knee or hip surgery.

Personal, Wearable Sensors These sensors can be attached to jewelry such as rings,[7] pendants, and watches,[8] or they may be attached directly to the body. While it is possible to collect more basic physiological data with wearable sensors, they have more limitations than environmental sensors: need for power; possibility of not being worn correctly or at all; need for great durability; may be intrusive and potentially uncomfortable or unsightly.

Kinematic Sensor A recent study demonstrated that body postures (lying, sitting, standing) could be detected with >99% accuracy using a kinematic sensor attached to a person's chest.[9]

Piezoelectric Sensor These sensors are worn by the person, with voltage produced by body movement.[10]

Computer

A personal computer with an internet connection provides the "smart" (or intelligence) for the smart house.

Software

Several types of software are needed for the smart house. A database program stores the information from all the sensors and commands from Mrs. Smith. An analysis program "digests" the data and sends reports and alerts. Speech recognition software allows Mrs. Smith to give instructions to the smart house simply by speaking them. Many small programs, called "applets," handle sensor and activity specific needs.

User Input Devices

The major input method for the smart house is through voice commands, which require microphone arrays placed around the house (and the speech recognition software). Mrs. Smith can also control many functions in her home using her smart phone, which was the major input device before speech recognition reached its Year 2010 level of sophistication. Occasionally Mrs. Smith, who is an excellent typist, will use a "*projection keyboard and mouse*" to type emails to her family and friends, but her use of these is being superseded by super-reliable voice input.

User Output Devices

The two major output channels for the smart home are video and audio (e.g., flat screen monitors and speakers). Mrs. Smith receives voice messages from her smart house, supplemented by visual messages (video, images or text) on her flat screen monitors. If Mrs. Smith is out gardening (no monitors available), the message is relayed to her phone screen and she receives audio from her phone speakers.

Mechanical Hardware

Some of the devices in Mrs. Smith's home require a mechanical system. These include the door lock, the automatic window opener/closer, and the automatic shades and drapes opener. These devices have been available for several years, but are now integrated into the smart house and can be controlled with voice input.

Wireless Technology

Wireless technology provides an invisible connection between devices. Earlier-generation smart houses typically relied on X-10 technology that used household AC power lines to transmit messages. These systems were often unreliable, as messages could only be sent one way. For example, if the computer sent a message to turn the lights on at 9 P.M., and one light did not go on because the light bulb burned out, the computer would not know this. The advantage of getting a message back to the computer is that it gives the computer the opportunity to take some action, such as alerting Mrs. Smith or the housekeeper, turning on a different light, or adding light bulbs to the shopping list—perhaps all three.

The most common use of wireless technology is for cell phones. We also have wireless systems for connecting our computers to the internet; wireless keyboards and mouse devices; and wireless sensors. The great advantage of wireless technology is the elimination of the need to have a cable or wire between devices, which permits a very high level of mobility. The major downside is that wireless devices require power, usually batteries, which have a limited life between replacement or recharge.

Cell phones use a type of wireless technology that covers a very wide area. The technology continues to advance, and we hear terms like 2G, 2.5G, 3G, and so on, which refer to the generation of the technology. Most digital cell phones in 2001 used either 2G Second Generation Wireless technology or 2.5G. 2G systems for wireless communications offer digital voice and data at low speeds, with limited data connectivity. Some 2G technologies also have low-speed, WAP (defined in next paragraph) mini browsers for access to the internet. Our digital cell phones (standard wireless phones that convert sound into data bits which are then transmitted via radio or microwaves) use 2G.

2.5G provides faster data speeds than 2G. It offers what is called Packet Radio Services with data speeds of 28 Kbps and in some cases higher. Each generation provided a higher data rate and additional capabilities, and 3G (introduced in 2003) offers data speeds up to 384 kbps. A fourth generation (4G) of technology was in the planning and research stages in 2003.

WAP is an abbreviation for Wireless Application Protocol. Internet communications and advanced telephony services to digital phones and other wireless terminals are provided through WAP. WAP is a worldwide standard that operates on any platform providing services that reformat content of internet communications to fit the display screen of the wireless device. This service also supports web browsing, enabling people to search the internet and send messages from a wireless phone. Through the development of WAP, service providers can implement wireless services through a single standard.

Another form of wireless technology is used for communication among devices in much smaller areas such as a home. There are two major types of "small area" wireless technology: Bluetooth and 802.11. Bluetooth is a low-cost short-range wireless radio link that supports communication among portable devices, enabling exchange of information between devices within a small area. This connection is wireless and therefore is not dependent on the use of connecting cables. This technology is also worldwide, uses low power, and operates with minimal interference. In 2003, Bluetooth Home Networking applications included "The Three-in-One Phone" and "The Universal Remote." "The Three-in-One Phone" is a standard cell phone, a wireless service provider, and a cordless phone for use within the home that uses the wired telephone system for service (without the use of a carrier). All of these options are available through the use of "one telephone, one number" regardless of location. "The Universal Remote" refers to the use of Bluetooth devices (PDA, smart phone, etc.) to inquire about and control other devices and appliances equipped with Bluetooth interfaces. Examples are notifications that the clothes are dry or that the dishwasher needs to be run. For devices that are not equipped with Bluetooth interfaces, control of devices via physical interfaces that communicate through a Bluetooth capable home gateway can be used.

802.11 wireless technology operates very similarly to Bluetooth. In 2003, there were three specifications in the 802.11 "family": 802.11a, 802.11b, and 802.11g. The

802.11g offers wireless transmission over relatively shorter distances at very fast speeds: up to 54 megabits per second (Mbps) compared with the 11 Mbps of the 802.11b standard. 802.11a offers the highest speed of 100 Mbps but covers the shortest distance of all 802.11 family. The 802.11b standard is currently considered the most widely used standard in this family and is often called Wi-Fi.

Power Line Communication Networking

The use of household electric lines to carry the same signals as an Ethernet-cabled or wireless computer network has been shown to be possible.[11] While use of these cables had previously been considered too "noisy" to carry data packets, technology advances have made it possible. Thus, appliances could "communicate" over the same lines that provide them power.

Batteries and Other Power Sources

All electronic devices require some type of power. Many of the sensors in Mrs. Smith's *Gator Tech Smart House* system are in a fixed place and rely on the home's AC power source. Others, such as her smart phone, move with her. In 2003, cell phone batteries lasted about a day, and this varied with amount of use.

The Internet

The internet is an important component in the smart house for two reasons: (1) as a pathway for messages and reports and (2) as a source of information and services to the home.

Indoor Location Tracking Technology

The house can be much smarter and much more useful to Mrs. Smith if her location in the house is known at all times. Similarly for Mrs. Smith, it may be important to know where certain objects are located (e.g., a TV remote or her smart phone). Several indoor location tracking technologies have recently emerged including infrared-based, ultrasonic-based, vision-based, and motion detection and point of presence-based. Some of these technologies require that Mrs. Smith wear some identification elements (e.g., a digital tag).

Smart Appliances

Many appliances are now getting smarter and will be part of the smart house. In Mrs. Smith's smart house, the oven will speak out warning Mrs. Smith of a hot surface when she approaches the stove top, or it will call her on the house speaker phone or her smart phone when her food is cooked and ready to be taken out of the oven. Microwave ovens will program themselves to cook frozen food packets. The home theater system will mute when the phone is ringing.

Ambient Intelligence

This term is now being widely used in research and development settings and by technology companies. The idea is that the technology disappears and user needs are met. It incorporates all of the other components described above, with the added aspect of "intelligence." In a home, a system with ambient intelligence is able to discreetly collect relevant information about the occupants, learn their preferences, anticipate their needs, and control their environment with minimal user effort and ease of interaction for user-issued commands.

Other Related Technology

Mrs. Smith's smart house also uses the following technologies, which are a combination of software and hardware.

Feature Recognition A camera-type device is used to scan a person's face and match to an existing database to correctly identify the individual. This is an important component of Mrs. Smith's security system. When someone rings the doorbell, the person appears on one of her monitors, but with her declining vision she has the extra protection of the smart house "announcing" the person, if the person's face is in the database.

Object Recognition Object recognition is used to recognize items that might be moved within a home, such as furniture and small appliances. The new location can be noted and used in tracking a person's use of household items. Object recognition methods are considered too slow to use for person tracking.[12]

GPS: Global Positioning System

This is a component on Mrs. Smith's smart phone that provides her with information on where she is and how to get to where she wants to go. Sally can also locate Mrs. Smith when she is outside the home through this system.

Digital ID

Digital ID is a high-tech version of the barcode reader technology. Digital ID is a technology innovated by 3M that offers a variety of products based on radio-frequency identification (RFID), or the transmission of signals between information stored on a "smart tag" and a "reader." The use of digital identification technology requires neither direct contact with a reader, as does magnetic strip technology, nor a direct line of sight with a reader, as does bar code technology. Smart tags contain memory and a dormant memory emitter. When beamed by a reader, the dormant emitter is charged enough to send the memory contents to the reader. Mrs. Smith's smart microwave oven is able to identify food packets with this technology. Should Mrs. Smith's vision decline to where she can no longer select her clothes, this technology could be used in the smart house for her to get a verbal description of a selected clothes item from her closet.

Human-Based Service Providers

The technology requires support. In Mrs. Smith's smart house, the technology is "almost" bug-free, but a technician visits every 6 months to check battery power and to update system components. Technology will never be a substitute for human interaction. Mrs. Smith has a number of supportive people in her life that assist with transportation, shopping, and leisure activities. She has 24/7 human backup support in the event of an emergency. She has delivery people, medical people, friends, and family. Sally, Tommy, Joe, and Dr. Jones are just a few of the people that technology cannot replace; however, smart house technology can make each of them more effective in assisting Mrs. Smith to remain independent.

2.4 OVERVIEW OF THE STATE OF THE SCIENCE IN SMART HOMES AND SMART HOME COMPONENTS AND RELATED ISSUES

This section begins with a description of commercial smart house ventures—that is, actual housing that has been built using current smart house approaches. This is followed by descriptions of non-university-based and university-based demonstration/model home/labs where prototype smart home components are being developed and or demonstrated. Several individual smart home components are grouped in a section on individual smart home devices and components. User interface research and development is then described, followed by a discussion of research and development on the actual home designing process.

Commercial Ventures Using Smart Home Technology

We discuss three commercial residential smart house projects in this section.

Village at Tinker Creek, Roanoke, Virginia In April 2003, residents began moving into the first community of smart homes in this country, in Roanoke, Virginia.[13] While not specifically designed for people with disabilities, but providing a high level of control, residents can control lighting, air conditioning and heating, and security system from anywhere they have an internet connection—in the home or away from home. A unique feature of the home is the use of web cameras throughout the house. With these cameras, residents can, for example, check to see if the garage door is closed—many people worry that they may have left the garage door open after driving out. The system will not only provide a real-time view of the garage, but will allow the resident to close the door, even if miles away. Another potential use of this system is for security. It can be set up so that police in a patrol car, following notification of an unapproved entry, could observe an intruder in the house via the web and the cameras—even while they drive to the home. In addition to home monitoring for security and control, residents can track community events and news from the Web. For some people, including older people and people with disabilities, the use of cameras in these homes could seem invasive, especially if they are being monitored for safety reasons. Less invasive approaches to monitoring are described in this chapter.

The homes are being built by Commonwealth Builders. The system used in the home was developed by IBM in partnership with CP Technology in His-Chih, Taiwan, and General Electronics in Shanghai. The gateway for the system, called CP Technology Residential Services Gateway, supports OSGI (Open Services Gateway Initiative), so as new applications are developed, they can easily be added to the system. Some of these applications could be downloaded directly from the internet. Smart appliances could be added to the system, offering such features as automatic notification of repair and maintenance providers. The community of 170 homes, costing about $200,000 each, was established with 20 of these smart houses, and the system was offered as an option for other home buyers at a cost of approximately $3500. IBM envisions the system that will eventually to be able to offer self-reading meters, and it also envisions appliances that alert the homeowner in the event of a potential shutdown or failure.

IT Condominiums, Ringblomman, Stockholm, Sweden e2Home, partnering with construction (Skanska) and telecom companies, designed and built 59 condominiums in Stockholm.[14] The "smart" condominiums address home management, family management, and condominium administration communication. Home management includes security and safety services such as detection and reporting of fires, water leakage, and intruder alarms. Alerts can be issued on site, through phone messages to the occupant when they are away, or directly to an appropriate service provider (fire company, police). The condominiums use an electrical locking system. Family management includes a common family calendar for scheduling activities of all family members. Family management also offers a platform for food management, including shopping and meal preparation. Applications are controlled by an "appliance terminal" with a touch screen, or a personal computer, typically placed in the kitchen or office. Applications can also be controlled remotely via the internet. At present, the home offers greater user control at home or away, energy efficiency, lower insurance premiums, and improved security.

Netherlands Demonstrations Van Berlo discussed smart homes in the Netherlands at ICADI.[15] They have established a demonstration project with 55 residents in 20 apartments. Major applications in the smart homes address security, care, and comfort, including: access control using a camera, chip card, electronic lock, caregiver access, and an intruder alarm; an active emergency alarm, a passive alarm, and a smoke alarm; automatic lighting; gas stove and gas detector; water-flow meter to determine inactivity; central switch above the bed, automatic curtain closures, and movement detectors for lighting at night. Cost is estimated at a monthly service charge of 15 Euros per month. Setup costs were estimated at 5000 to 8000 Euros per house (3–5% of total house cost). While some residents initially had difficulty with the features of the smart house, all were pleased to have the added safety and security it provided. However, several mentioned that they did not require all the functions the house offered. There were also a significant number of problems with false alarms in the first days of use.

Demonstration/Model Homes—Non-University-Based

In this section, we describe Microsoft's EasyLiving project, Honeywell's Independent LifeStyle System, and the Varmdovik Project in Stockholm, Sweden.

Microsoft's EasyLiving The EasyLiving project at Microsoft, described in 2001, featured a high-technology living room.[16] The project team worked on developing the software (prototype architecture) and related technology for supporting an intelligent environment that could be used in such places as smart houses. The research team identified key areas of the research and development as (1) perceiving people in context, (2) perceiving objects in context, (3) perceiving people for a user interface, (4) perceiving objects for a user interface, and (5) privacy. The first area, perceiving people in context, avoided use of automatic person recognition, as the team felt this could be intrusive or an invasion of privacy. The user must indicate to the system who he or she is, and the system then responds to preset or learned preferences in its responses (such as selection of music, or level of lighting or temperature). The system tracks where people are located and determines the activities in which they are engaged, so that appropriate assistance can be provided in the appropriate place. The second area, "perceiving objects in context," relates to first recognizing objects, tracking them (where things such as furniture and keys are located, even if moved). The third area relates to having the person serve as the user interface, through such means as gestures, pointing, gazing, or, perhaps most easily, speech. For people with severe speech limitations, gestures, pointing, and gazing would offer excellent possibilities for user control of the system. The fourth area, "perceiving objects for a user interface," relates to such now-common devices as hand-held remote control units, as well as such advanced prototypes as Microsoft's XWand. XWand is a wireless device that includes sensors, in the shape of a wand, and can determine its orientation within a room, allowing it to control most devices in the home. The final area of research in this project focused on privacy, ensuring that no unauthorized person had access to any of the electronic information the house gathered.

Independent LifeStyle Assistant™ (ILSA) ILSA is an intelligent home automation system designed to enable older adults as well as younger people with disabilities to live independently and safely at home. The system is designed to increase social contact and information exchange between the residents and care providing family members. Miller, Wu, Krichbaum, and Kiff described the design principles for ILSA at ICADI.[17] They include the following: (1) use of nonintrusive components; (2) limiting of interface to telephone and web pad; (3) system should generate data on resident's status rather than require self-report; (4) system should require minimal effort for setup and use. Implementation of these principles resulted in such actions as: (1) removal of LED indicators on motion sensors; (2) avoidance of use of interactive switches; (3) resident is not constantly provided with reports of their status, but the resident can initiate an inquiry; (4) medication reminders are provided only by telephone (no alarms); (5) clients were not called and asked questions, but use of phone and web pad were tracked to determine cognitive status; (6) to change settings such as medication regime and sleep time, clients request assistance from caregivers. Justiss, Mann, Helal, Dasler, and Kiff described at ICADI the outcomes of beta-testing ILSA in the homes of four older persons with disabilities in northern Florida.[18] Kiff and Plocher described the technology issues with ILSA at ICADI.[19] They state: "Significant issues were encountered at each stage of development and deployment. Barriers to the commercial deployment of an ILSA-like system include ease of installation and maintenance, development of adequate monitoring centers, successful integration with third-party providers, and accurate sensing of significant events in the home." ILSA had not yet been commercialized at the time of publication of this book.

Varmdovik Project, Stockholm, Sweden e2Home, working with JM, built a smart house to be used as a demonstration home and as a model for additional smart homes that will be built and sold in Sweden.[20] One unique aspect of this smart house is the interface, called "Screenfridge," a touch screen built into to the refrigerator, supplied by Electrolux. This smart house includes (a) automation for lighting, (b) control and monitoring of electricity, water use, and air temperature, and (c) control of window coverings.

Oatfield Estates, Milwaukie, Oregon Oatfield Estates is an assisted living facility, designed to incorporate the latest technology. All resident rooms have a touch-screen computer with a high-speed internet connection. Residents and staff wear a small locator badge clipped to their clothing. This badge has a call button and is also used as a room key. The location of residents and staff is tracked using both infrared and radio frequencies and is recorded by computers. Tracking of the time it takes staff to respond to resident calls helps ensure timely responses. Residents' weight and sleep patterns are monitored using sensors placed under the bedposts. Twelve residents reside in each housing unit, with three staff members. Individual residents pay approximately $4000 per month, and couples pay $5000 (*Business Journal Portland*, 2003).[21]

Research Lab/Demonstration Homes—University-Based

Most smart home research labs are university-based, with the major ones at MIT, Georgia Institute of Technology, the University of Virginia, and the University of Florida. Most are used for demonstrating and testing the specific aspect of technology they are developing. Only two (MIT and University of Florida) conduct experiments where people live in the smart house for some period of time. These labs are described in this section.

University of Florida Smart House Lab This lab, described in ICADI, builds on the concept of pervasive computing to assist older people with disabilities to live independently.[22] Initially, the lab-home was designed to use the smart phone as a universal interface in the home (1) for the resident to instruct the house to do certain tasks (unlock door, check security, turn on lights, control the entertainment system) and (2) for the house to assist the resident (issue medication reminders; alert the resident that mail has been delivered; track the user's movement throughout the home so that if the user fell, an alert could be issued). The above are examples of more than 15 applications that have been developed and successfully tested in the Smart House Lab. More recent advances are enabling the resident (Matilda, a robotic device) to interact directly with the Smart House through voice commands, and they enable the house to communicate with Matilda through speakers in each room and through flat panel LCD displays in each room. With the ultrasound tracking system, the house knows which monitors and/or speakers to use to communicate with Matilda—the house knows where Matilda is in the house and only uses the monitor and speakers in the room, and on the wall when walls have multiple monitors, where she is seating or moving about. Yet more recent experiments in tracking systems are exploring the use of (a) pressure sensor pads under the carpet and (b) vibration detecting sensors in the floor. Successfully tested Smart House Lab applications are moved to the Gator-Tech Smart House, a free-standing smart home, where older people with disabilities live with and use the applications for further user/application refinement.

University of Virginia Medical Automation Research Center (MARC) The MARC center has been developing a number of components for the smart house of the future. We discussed their use of optic-fiber vibration sensors earlier. Alwan, Kell, Dalal, Turner, Mack, and Felder described at ICADI an in-home monitoring system they are developing that includes low-cost sensors, data logging, and a communications module with a web-based data management server. The system is able to track and infer activities based on "spatial temporal relationships between sensor firings." Current activity, a log of activity, and trends can be accessed through the internet by care providers. The activity tracking system was successfully tested against user activity logs, which were also automated on a self-report system they developed for a PDA. The system provides a time and date stamp for each entry in the activity log for increasing reliability over paper and pencil self-reporting. Recent work has focused on development and testing of a system for an assisted living facility that would also include real-time alerting for staff. Other work includes a low-cost approach to measuring sleep quality, using a number of sensors for body temperature, sleeping position and movement, and breathing and heart rate. Many of these sensors are embedded in a mattress pad that can sense subject position, body temperature, breathing, pulse, and room light level. Yet another system is being developed that analyzes meal preparation patterns. Activity patterns, such as those involved with preparing a meal, are much more difficult to determine than simple physiological signs like heartbeat and body temperature. This system is able to show consistent patterns of breakfast and dinner preparation. Such a system could be integrated into a smart house to determine if the occupant has varied from the normal meal preparation routine and may not be getting meals due to illness or a more gradual loss of appetite, which could lead to malnutrition.

University of Texas at Arlington MavHome Cook, Das, Gopalratnam and Roy described the MavHome at ICADI (http://ranger.uta.edu/smarthome/).[23] Their research and development centers on a prototype for a home health monitoring system that will also assist in basic daily activities. MavHome sensors track vital signs, movement patterns, medicine taking schedules, and interaction with devices in the home. MavHone can determine water usage in the home, temperature settings, weight of the resident, movement in the home, prescribed and actual medication schedule, use of food items in the kitchen, and time duration and intensity of exercise.

University of Rochester Center for Future Health Pentland and Philippe described at ICADI a multi-campus effort to develop a technology-based personal health system.[24] The goal of this effort is to use technology to move from a disease treatment, hospital-based "health system" to home and community-based health promotion. While at this point the system is proposed as a model, developed, and implemented, it would identify diseases early through sensors in the home, provide health management tools for promoting independence in the face of chronic conditions, and provide emergency response services. The system would work both in the home and community.

Georgia Institute of Technology Aware Home Abowd, Bobick, Essa, Fisk, Mynatt, and Rogers described at ICADI an "Aware Home for Aging in Place."[25] The Aware Home was built to meet the design and functional requirements of a home that someone could live in, and it also has facilities for instruments. Each room has sensors and displays to facilitate interactions between the house and residents. A major focus of work has been on applications for supporting persons with cognitive impairment in daily activities and communications. Sensing equipment includes cameras, microphones, infrared, sonar, and tactile devices. Tracking people throughout the home is done with a range of sensors from RFID to computer vision systems. The Aware Home also has an activity recognition system to track the activities engaged in by residents. Specific applications under development include a blood glucose monitor aid, a memory aid for use in the kitchen, and a unique system called "digital portrait," which assists family members in tracking the status of the resident.

PlaceLab Intille, Larson, and Tapia described their smart-home-related work at MIT.[26] They have developed a portable kit that includes "tape-on" sensors, which are used to study behaviors in people's homes. At this point the sensors track movement of objects in the home such as furniture and kitchen tools—in one test home they deployed 85 sensors. The authors state that information from the sensors can be used to "help people learn about their own behavior . . . how they use their own homes and how they might redesign them." (p. 10) The system can also track behavior in the home, which in turn can be used to determine when behaviors have changed and whether the resident(s) is experiencing a problem. These same investigators have also developed PlaceLab, "a residential observational facility . . . that will serve as a "living laboratory" to study how people respond to new proactive health technologies." (p. 11)[27] The facility was under construction during ICADI, and it was scheduled to open in 2004. PlaceLab will use low-cost sensors attractively placed in the model home to study people living in the home, thereby focusing on long-term proactive health behaviors.

Adaptive House, University of Colorado The Adaptive House focuses on automation of energy conservation approaches.[28] The research conducted for the Adaptive House is focused on designing a home system that programs itself, based on the lifestyle, needs, and preferences of the residents. The house not only learns their needs, but anticipates them. By observing the residents adjusting the thermostat or turning on certain lights at a certain intensity (for three-way or fully adjustable lights), the intelligence of the home will infer patterns on which it takes actions. The home uses over 75 sensors that monitor air temperature, lighting level, sound, motion, and openings of windows and doors. The learning and prediction capability of the house is based on "neural network" software. With this approach the house can predict when the residents will be home or away, when to start heating or cooling the home to a comfortable temperature, when to lower the water heater when there is a certainty no one will need hot water, and control of lighting—both on and off and intensity, including anticipation of rooms that will be entered so lighting can be set before the person enters. Such a home would not only be more energy-efficient, but would make life more comfortable and easier for its occupants.

Individual Components and Devices within a Smart House, and Related Research

Several research and development teams have focused on individual devices that could be integrated within a smart home. We describe several of them in this section.

Memory Aid for Cooking Tran and Mynatt (2002) report on a prototype memory aid for cooking.[29] The system uses PC cameras located under kitchen cabinets (largely out of sight). The cameras capture hand activities on the stove and kitchen counters. The computers are "hidden" in kitchen counters. Output is provided on an LCD flat panel on one of the kitchen cabinets. A collage of images is presented on the LCD panel as the user cooks. The collage represents the sequence of six previous actions while cooking. As the user completes another action, it is posted on the collage, with the bottom right corner presenting the most recent action. At the point of their report, Tran and Mynatt were using a Wizard of Oz approach to simulate the system. Twelve users (all undergraduate psychology students) tested the system, with an additional five control participants who did not use the system but were given the same recipe (for preparing cookie dough) as the system users. Design challenges were determined. For example, with the system using still images, an image of a person adding a cup of flour does not convey that it is the third or fourth cup—there just isn't enough information. Other systems using video replays have been designed, but the disadvantage is the time it takes to review the video. Another issue not addressed by these investigators relates to the usefulness of such systems for people who are forgetful, such as people in the early stages of Alzheimer's disease. Research on the system with persons with memory impairment would be a logical and important extension of this work.

Carewatch At ICADI, Rowe addressed the issue of sleep for people with Alzheimer's disease and their caregivers.[30] Studies have shown that almost all people with dementia demonstrate abnormalities in sleep–wake pattern when studied in lab situations. These abnormalities include an increase in the number of awakenings and in the time awake. Over 50% of caregivers are impacted by these sleep disturbances. The aim of Carewatch is to develop and test a prototype system to be used by persons with dementia and their caregivers to (a) prevent unattended exits and nighttime injuries, (b) improve caregiver sleep, (c) reduce worry, and (d) potentially decrease the need for nursing home placement. The Carewatch system includes (1) a control panel that is situated next to the caregiver's bed and (2) sensors for detecting motion, door openings, and pressure in bed. When the system detects activity at night, the caregiver is alerted through text, voice, and alert message alarms. The caregiver immediately receives information on the location of the care recipient.

Philips WWICE (World Wide Information, Communication and Entertainment) Philips, one of the world's largest electronics companies, is developing a system in which is embedded what they term "ambient intelligence," which encompasses ubiquitous computing (access to any information source, anywhere, anytime), natural interaction (voice control), and intelligence. Major functions of WWICE is for entertainment and communication.

Microsoft Light Control Study Many aspects of a smart house can be fully automated, only requiring adjustment when the user has exceptional needs. For example, the smart house may be able to predict and set the temperature for the occupants automatically on all days. Yet if the occupants are planning a party with a large number of people and want to "take over" control of the temperature so they can lower it prior to people arriving, they will need the option of issuing commands to the house. What is the optimal, preferred way to issue commands? A group at Microsoft Research studied this for one task—turning lights on and off.[31] They had a study group interact with several (but not all) of eight different switching methods and then rank their choices using a card-sort approach. The switching methods included (1) normal switches, (2) touch lights, (3) hand-clapping-controlled, (4) computer panel (on wall) control, (5) computer tablet (could be moved around the room), (6) speech-operated, (7) speech plus pointing, and (8) automatic sensing, with a computer using intelligence to determine what lighting the person would like. The two speech methods (with and without pointing) were ranked highest. Limitations of the study include a very limited amount of time (a few minutes or less) participants had with each method.

Designing a Smart Home The future of home design and building is also likely to be very different from now, predicts Kent Larson of MIT's PlaceLab.[32] While today home building is largely a local enterprise, large companies not presently in the business will move in, creating competition and innovation. A home, including its smart components, will be designed by its future occupants (in Mrs. Smith's case, with the help of her adult children) using the internet, where they can easily learn about all the options available and select those that match their needs. While there will be much more technology available, cost will actually decline, as mass production and competition in the housing industry come into play. Evidence that this vision of the future has already begun to materialize is found in the creation of a new company, called e2Home, by Ericsson and Electrolux in December 1999. E2Home conducts research, development, and marketing of technology-related services for networked homes, and it is behind two major high-tech building developments in Sweden: IT Apartments and Varmdovik, described earlier in this chapter.

Borodulkin, Ruser, and Trankler stress the importance of an easy-to-use control system for a smart house.[33] They created a graphical interface using 3D programming tools. They base their system on four principals: (1) The user interface should provide a clear graphical "picture" or representation of the home; (2) the system must be easy to set up; as new components are added or removed, the interface should not need major attention; (3) the users should be able to adapt the interface to their own needs and preferences; (4) the system should allow remote (within and away from home) control of the home.

Funded by the European Union's TIDE program, CUSTODIAN (which is an acronym for Conceptualization for User Involvement in Specification and Tools Offering the Delivery of System Integration Around Home) is a personal computer-based system for designing and validating how well a home automation system will work prior to purchasing and installing it. Basically it is a software program, based on Microsoft Vision that assists in the preparation of a flow diagram. The user can design a smart home network by selecting device icons and placing them on a template. The final system will also prepare an item order list and a cost estimate using currently available products.[34]

For a homeowner to set up their house as a smart house, all of the components in their home must be ready to "communicate with each other" and to interact with the homeowner. What if you have a GE dishwasher, a Frigidare refrigerator, and a Sharp microwave oven? Will they all be able to use the same smart house infrastructure? A consortium of companies is working to ensure that it will be possible, through establishment of the Virtual Private Infrastructure, designed to provide guidelines for secure and unified web-based control of appliances and other devices in the home.[35]

Summary Homes can be made smart with today's technology. With advances in the underlying technologies and the development of new applications, we can expect that in the next several years we will have homes that provide very supportive environments for older people with disabilities. New products and systems will be introduced that can be added to existing homes and as options for new homes.

2.5 SMART HOUSE CONSTRUCTION— AN ARCHITECT'S PERSPECTIVE

Concept

A smart house, at its simplest, is any home that has some measure of automation built into it, the concept being that a smart house can "think" for itself. The precise point at which a house is no longer a simple house with a few gadgets, but a smart house, is an undefined threshold. The common understanding may be, however, that any house ahead of the automation curve is a smart house.

Mankind hasn't always lived in houses. Caves—probably the first step toward a controlled environment—came right after sleeping under the stars or in trees. As we've learned to control more and more of our environment, and as the means of doing so has become less and less expensive, the "technology" to do so—from doors to fuel cells—has found, and will continue to find, its way into our homes. Indoor plumbing, which had been used in palaces and grand homes as early as 4000 B.C., didn't find its way into the average home until the twentieth century. In fact, in the early 1900s fewer than 20% of the houses in the United States had a flush toilet. In the mid-1700s, electricity was first thought of as a potential controllable power source, but it wasn't until Edison produced a practical incandescent light bulb in the late 1800s that indoor lighting became reality. In 1890, only a quarter of American homes had running water, very few had electricity, and none had central heating as we know it today. So we can see that the technology curve is very steep indeed.

In the Gator-Tech Smart House, plumbing, electricity, and central air conditioning are all taken for granted. The technology that qualifies this as a smart house is a central nervous system that interconnects various appliances and fixtures and allows monitoring of, and responsiveness to, the occupant.

The Smart House Movement

The early smart house movement was largely driven by safety and efficiency concerns—safety in the sense that if power to a lamp is turned off in the wall (at the outlet) instead of at the fixture, there is less of a chance of injury to someone plugging or unplugging the lamp or changing its bulb. In practice, one way to accomplish this would be to put a switch behind every outlet. This would of course yield a plethora of wall switches, with a typical living room requiring dozens of switches; more switches would be needed if you wanted to be able to control the outlets from more than a single location. Another way to resolve this would be to provide sensing outlets that could determine whether a lamp required power or not, by checking at high frequency whether the switch on the lamp was closed or open. At such time as the outlet sensed the switch was closed, it would power the lamp.

A simple stereo system is, in many ways, like the electrical system in a house. A single receiver/amplifier can provide music to several sets of speakers, just as the electrical service to a house can provide electricity to numerous outlets and appliances. Consider, however, an installation where a stereo is located in your den and speakers are located in the den, bedroom, dining, and living rooms. Ideally there would be an independent connection run to each of the rooms. This means that there would be many pairs of wires running from speakers back to the den and the stereo. From the stereo in the den, you could select which room or combination of rooms you wanted music to play in. You would have a fair amount of control. If that den later became a nursery, however, the stereo would have to move. You'd be able to plug it in in any room in the house, but all of the speaker lines would need to be re-run.

We have accommodated electrical systems fairly well in our houses. In fact, building codes actually guarantee a minimum level of electrical accessibility, primarily to limit the number of extension cords used and gain a measure of safety from that limitation. Stereo systems are still a young technology, and there are few houses built with central systems that would allow you to move your stereo around freely within the house. There are a couple of reasons for this: One, stereos and speakers have a simple but direct relationship. Whereas the power supplied to most every outlet in a house is a uniform 110 volts, and that is all you require for the lamp or appliance to function as you wish, the speaker output is dependent upon the stereo not just being on, but being tuned to the right source. Were this not the case, you could simply leave the stereo wherever it was first installed, tuned to your favorite radio station, and install a volume control switch on each speaker. This is essentially what is done with electrical power.

The ability to control a speaker from the speaker requires communication between the speaker and the source. It requires a means of transmitting instructions regarding what to listen to, where to listen, and at what volume. The same wires between amplifier and speaker that provide the signal for the speakers output could be used for communication in the other direction of course—as long as the connection at the amplifier side were modified to accept an incoming signal. Ethernet, a network protocol for interconnection of computers, provides a model of this communicating system. The same wires that provide the data stream to the computer also allow the computer to respond to the data source to identify itself and communicate its state—on, off, ready to receive data, and so on. In a simple point-to-point network, a network of peers, two computers are able to share information with one another, and even to control one another.

The progression from lamp to stereo to computer network is one of evolving communication—from a lamp with no communication abilities, only the ability to accept or inhibit input, and the power supply that can also either send or not send; to the stereo, which can send a variety of signals that are interpreted by the speaker to become a variety of sounds; to the computer, which has full communicative abilities enabling it to be operated either locally or remotely—and is seeing a similar parallel in the smart house realm, but is hampered by the vast array of appliances and communications standards produced today. One of the earliest communications standards available to the homeowner is X10. X10 has fairly well captured the DIY end of the home automation market, and today it offers a third-party controller for many consumer devices, from lighting to draperies and security systems. Because of the flexibility of the X10 system, and its ability to be added on after the fact, it provides a suitable means for one to experiment and for the retrofit of existing systems. The X10 is not a full peer-to-peer communication system, but rather a collection of transmitter and receiver modules that communicate via radio-frequency (RF) signals sent over existing AC house wiring. To extend the X10 system beyond the house wiring system, wireless controllers are available that send either RF or IR (infrared) signals to transceiver modules plugged into the power system that translate the signal into an X10 signal to be transmitted over the house wiring. Interfacing this system with a home computer allows complex commands to be sent that can control a number of devices and can time-sequence their operation in order to provide a substantial array of results.

More recently we have begun to see the development of more advanced interconnectivity between devices within the home, much of it centered on the protocol TCP/IP. TCP/IP has advantages over earlier communications systems in that it has essentially developed from the top down. Deployed first on the largest intercomputer network (then Arpanet), it was quickly accepted by those wanting to participate in the sharing of information available on that network. It has since worked its way down from University and Government computing centers to individual computers, and then out to the consumer. Network Control Protocol/Internet Protocol is today's de facto standard for digital networks. While computers were the first devices to make use of the standard, it is quickly gaining in the telephony field, as Voice-over IP (VOIP) takes advantage of existing computer network infrastructure to provide an advanced means of controlling telephone networks within business organizations.

One of the greatest advantages of TCP/IP is the ability to address devices. TCP/IP over Ethernet allows for a simple hub-and-spoke configuration in which relatively inexpensive devices at the hubs direct signals to the appropriate end devices. The X10 communication protocol sends its signal over all branches of the electrical system, and it will trip every device with the same address. Each device on an Ethernet network is individually addressed, and the addresses can be predetermined or assigned.

On the consumer end, we are now seeing the advent of IP entertainment systems featuring music and video streamed over the internet, captured onto massive data storage devices, and played back on demand. Other devices that operate on TCP/IP include video surveillance cameras, email appliances, a wide range of security devices, and, first among common appliances, the refrigerator. IP devices are also prevalent among commercial audio–visual systems, allowing technicians to diagnose or control them remotely. Some will even send out warning messages when they are in need of service.

The opportunity to quickly and easily connect various appliances (refrigerators!) each with the ability to communicate will revolutionize housing as we know it. For a relatively low additional cost, manufacturers can add features that will distinguish their products from the competition. Regardless of how simple it is to program an oven from the control panel, it will inevitably be simpler from a 17-inch touch screen! Especially when, because every appliance in the house is addressable, you'll inevitably have a screen in every room.

Today, however, with all of the various communications needs and the multiple standards supporting them that we find in a house, the question quickly becomes one of where to run a connection, and which connection(s) to run. While there is currently something of a standard for wiring a smart house (typically a pair of coax and a pair of cat 5 cables), the cost of investing in a structured cabling system can be exorbitant—unless you are certain of every exact location you will need to have wired, and certain that you will not be changing your mind later.

Housing Construction

There are, generally speaking, two types of walls within a building: space-defining walls and structural—or load-bearing—walls. Space-defining walls form the boundary between functions, giving shape to rooms. Bearing walls also define spaces, but the primary reason for their existence is support—of floors, ceilings, and roofs. In early home construction, most walls were bearing walls because of limits on the means to span large distances. Today relatively few walls in a house are bearing walls because it is more efficient to minimize their number—to be able to stand the structure of a house and close it in—than to divide up the enclosed space into the desired rooms.

Wall construction also falls broadly into two categories: generally speaking, either solid (monolithic) or hollow. In most modern construction, solid walls are also bearing walls. They tend to be brick or block exterior walls, where the mass of the wall provides benefits beyond structure, such as thermal mass, appearance, or durability. Similarly, the horizontal elements of construction (floors and ceilings), while generally both structural and defining, are also either hollow or solid. Why does this matter? Because as long as the technology brought into our homes requires a conduit—be it pipe, duct, or wire—there needs to be passage for the conduit.

If we look again at electrical and plumbing systems, these are typically run in the cavities that exist within wall, floor, and ceiling construction; and for a one- or two-story home with basement and attic, that is a very satisfactory solution. Pipes and wires can be run during construction, and access for maintenance or modifications can be had via the basement or attic. If the floor is concrete (slab-on-grade), things such as electrical wiring are run elsewhere (walls, attic). Things that rely on gravity to function, such as waste water lines, are often buried in or below the concrete.

In more complex construction such as office buildings, chases are provided vertically through the building to allow the interconnection and distribution of systems. Superducts may carry forced air over many floors, giant cables carry power, and thousands of glass fiber strands carry data and phone signals. When these systems are distributed throughout a floor, they are most often concealed in a plenum space between the ceiling and the floor above. Penetrations between the two levels allow interconnection where they must feed through the floor and "drops" from the ceiling provide the connection when there is a concealing wall or the appearance of a lone conduit is not an issue.

In the last decade, commercial office installations have seen the growth of raised floor systems. Originally used only in data centers, this product is now being found throughout the office, the idea being that with a raised floor system the entire necessary infrastructure required to support a modern office environment can be provided close at hand, without needing to raise the ceiling or to bore through the floor. Raised floor buildings are seen as the way of the future, but they have yet to overcome economic obstacles in many areas.

Like offices, houses are filled with equipment and appliances that are mobile. But whereas the extent of "connected" equipment in an office is often limited to computer equipment—PCs, printers, telephones—the range of fixtures in a house is greatly expanded and, at the smart house, may include wired medicine cabinets, beds, chairs, and motion sensors. This means that for this smart house it is desirable to have the most flexible distribution system possible.

The Gator Tech Smart House

The smart house is a simple house: one story, slab-on grade (no basement—the concrete floor is poured directly on earth—with an attic over the whole). The plan for the house is based on a typical three-bedroom unit for Oak Hammock Retirement Community—the community where the smart house was built.

For the specific purposes of the Gator Tech smart house (Figure 2.1), a few minor modifications were made. The secondary bedrooms were converted to lab space—that is, workrooms for monitoring the smart house and its occupants. Halls and doorways were widened to allow independent wheelchair access. The central coat and storage closets were combined to form a single larger storage closet to accommodate furniture needed for events but not for day-to-day operations. Similarly, the den and dining room were combined to allow for a larger space that can be used as a conference space, as well as a living area. The master suite was given more direct entry, and the master bath was reconfigured to provide a roll-in shower and a wheelchair-accessible toilet. Doors in the master suite were also changed to pocket sliding doors, so that they could be left open to provide the least obstruction of passage, yet be pulled closed when privacy is desired.

The Gator Tech kitchen is perhaps the most pronounced change from the standard unit. Although the plan configuration remains largely unchanged, the specific distribution of appliances, as well as the appliances used, has been changed somewhat. The smart house kitchen cabinets all feature roll-out shelves in the base cabinets, eliminating the need to reach into them. Under-cabinet lights illuminate the work surfaces along the wall; recessed lights illuminate the island and sink area. Upper cabinets are a combination of standard upper cabinets for storage of lightweight and infrequently used items.

Figure 2.1 Gator Tech smart house.

The island provides a wet-work area with a pot-filler faucet, dual dishwasher, and under-counter refrigerator. The refrigerator and freezer are independent units, each located beneath the counter. Both are drawer units that eliminate stacking of items through the depth of a shelf, both drawers are easily accessible from a wheelchair, and because the drawers have sides, they retain more "cool" when left open. The dishwasher is actually a pair of dishwashers stacked one above the other. Each drawer can be run independently, so there is the option of only using the top if need is limited, along with the possibility of living from one unit while loading the other, thereby limiting the need to put dishes away!

The pot filler faucet allows for filling of a bowl, pot, or pan without the need to lift it from the sink when full. Similarly, the oven is mounted at counter height, with a pull-out counter beneath it, so minimal lifting is required as food preparation moves from sink to counter to oven. A side-opening door on the oven also allows the cook to get closer to the oven, without having to reach over a hot door. The cook top unit used in the smart house is a halogen-fired unit with a ceramic top. Not only does the immediate illumination of the halogen burner give a better indication of the burner in use than either a gas flame (which is difficult to see under some lighting conditions) or a standard electrical coil, but the ceramic top does a good job of limiting the spread of heat on the surface and also cools relatively quickly. In addition to being easy to clean, the cook top has a raised lip that will contain overflow or spills up to one-half gallon, which aids general cleanup and enhances safety. Finally the microwave oven—an indispensable appliance in a modern kitchen—is located at the edge of the kitchen, convenient to both breakfast and dining room.

The floor system most readily distinguishes the Gator Tech smart house from any of the other club homes at Oak Hammock. As mentioned previously, the smart house is built—like all of the club homes—slab-on-grade with wood-framed walls and ceiling. The roof bears on the exterior walls and, for the most part, spans the interior members of the roof trusses, leaving little room for negotiation within the attic.

For the club home to be successful meant that it would have to be flexible enough to support numerous experiments—perhaps hundreds—during its life as a working laboratory. The primary concern was the ability to provide wired connections to the various sensors and equipment that would be deployed and redeployed throughout the house.

Standard residential drywall construction is amazingly resilient. There is little to encumber any desired equipment placement, particularly when running vertically within a wall, because the wall is essentially parallel vertical voids separated by wood studs and skinned by drywall. Drywall is easily modified and repaired with simple and inexpensive tools and supplies. Understanding a few basic construction principals allows the average handy individual to creatively solve the problem of mounting equipment precisely where needed. Ceiling placement of equipment is also relatively easy, because the construction is similar, but in this case the ceilings are skinned on only one side and are filled with insulation. They are also accessible directly from the attic. Walls and ceilings then provide a satisfactory environment for a living working home laboratory. Equipped with drywall compound, scraps of drywall, paint, and a few tools, it will be possible to continue to modify the smart house as required for years with no great effort or expense.

The design of residential construction can overcome much of the difficulty that might be expected in repeatedly running wires out to new equipment while maintaining a homey appearance can be overcome. Because the Gator Tech smart house is slab-on-grade, however, one of the best potential routes for accessing the walls—from an unfinished basement below—was not available. With the heat in Florida, along with limited access through the attic, it too was eliminated as anything but an occasional route for accessing the ceiling itself. The solution came from the office model.

There are a number of raised floor solutions available today that are built for remodel and low cable loads. Most are in use in Europe and Asia, but a few are making inroads in the United States. Unlike the higher raised floor systems (those in the 12 to 24-inch range), low-profile floors are not adjustable in height. They install directly over the floor slab, and they follow the contours of the slab. But to their advantage and in part because they are nonadjustable, they are extremely simple to install and lend themselves to this type of an installation.

To facilitate use of motion sensing equipment, there is also a dropped crown molding throughout the house that is fed by conduit from the space beneath the floor (Figure 2.2). The crown has a recessed shelf that can support small cameras, infrared or radio-frequency sensors, and other equipment.

The raised product chosen for the Gator Tech smart house is a low-profile floor made up of PVC and steel. It has a small module, allowing it to be easily tailored to the intricacies of a residential plan. The PVC makeup is also a plus in an environment as humid as Florida's. By using a raised floor throughout the house, cables

Figure 2.2 Dropped crown molding in the Gator Tech house for cabling and sensors.

can be quickly and easily run from the workrooms to any room in the house, and they can be reconfigured as the need arises (Figure 2.3). Once the cables are in the right position along the wall, they can be run up inside the wall to any height necessary. The floor itself is very stiff, because it is supported almost continuously, with the maximum span being only about 5 inches. In addition to the ability to run connections throughout the house beneath the floor, the floor also provides a means of distributing sensors that track movement through the house or of weighing an individual as they walk over an area of the floor.

Modular carpet applied over the raised floor provides a look that is contemporary, yet based on traditional. The carpet chosen is a neutral Berber, with a nondirectional pattern that lends itself well to this application, and is indeed a product that has recently been brought to the residential market by a major commercial carpet manufacturer. Their intended target market: a generation of urban loft-dwellers.

Like the raised floor and carpet, many of the components used in the house have come from the corporate world. The electronic strike on the front door that allows the door to be unlocked remotely is commonplace in office environments. Sensing controls of lights, along with zoned heating and cooling systems, also have been used in corporate environments for some time. Like so much of technology, those things that become accepted by business find their way into our homes as costs come down, and new benefits and uses are found.

There will be changes made to the construction of housing to accommodate integrated technology and also to accommodate changing technologies. Much of the research currently being done into these changes is far-reaching, and not of practical value for immediate implementation. For now, with minor adaptation in the extreme case of the Gator Tech smart house—where technology may be changing

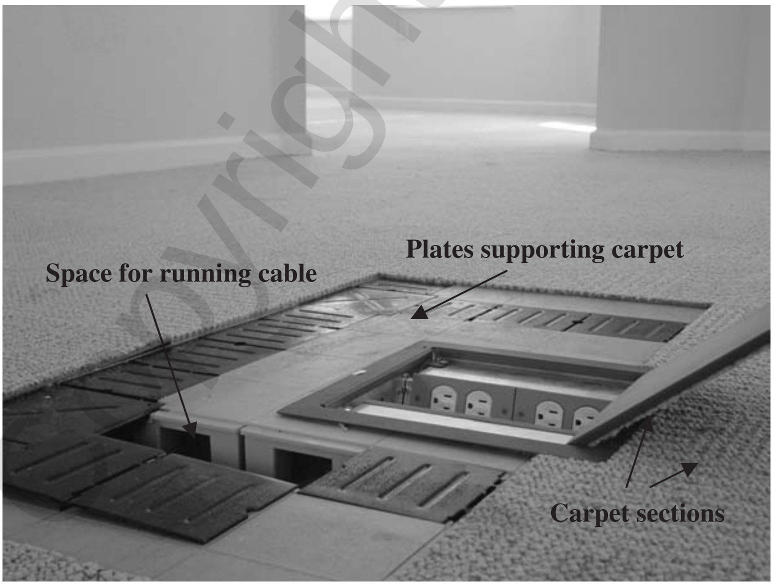

Figure 2.3 Raised floor in Gator Tech house for cabling.

on a monthly basis—current building practices with the simple extension of a raised floor can satisfy the needs of an advanced program.

Whereas the smart house is primarily built on wired technology and that technology is pervasive, houses in the future may see computing environments in which sensors are part and parcel of the materials used in construction—scattered sensor "dust" that respond to a radio signal sweep, carpet that converts fiber motion to energy to power sensors woven into it, paint that uses light as power to mirror the cycle of the day and affect our mood. Until that day, as long as power is wired, communications wiring will play an essential role and will require accommodation in construction. The key to the Gator Tech smart house's success is its flexibility and ability to be adapted. It is already available today to all homes, and as the technology tested at the smart house is proven, it will be able to move directly from the laboratory to our homes.

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