A BLUETOOTH HOME DESIGN @ NZ

Four Smartness

Olaf Diegel, Grettle Lomiwes, Chris Messom, Tom Moir, Hokyoung Ryu , Federico Thomsen, Vaitheki Yoganathan, Liu Zhenqing

Massey University, Auckland, New Zealand

Abstract: Much of the work in the smart house technology has been done on individual technologies, but little has been done on their integration into a cohesive whole. The Bluetooth house project at Massey University in New Zealand, which was initiated in 2002, embraced a systems engineering approach to design a usable smart house, aiming at a complete and integrated solution, which can be customised, based on individual needs, to give elderly people independence, quality of life, and the safety they require. This paper presents how the Massey Bluetooth smart house design project has been carried out and what the smart home may look like in the near future. Considering current technical feasibility and the advances in other research, it is suggested that for a house to be considered as truly 'smart', four levels of smartness are imperative: *smart sensors*, *smart management*, *smart control*, and *smart appliances*. The Bluetooth house at Massey University incorporates these four smart technologies and allows all these individual technologies to be integrated into a seamless whole. For smart sensing, the project employed Bluetooth technology to connect the whole house, and to locate the user's position. In order to coordinate all the technologies, a smart management system was developed, that is capable of coordinating the information for commands, feedback from smart appliances, and user's location information. It can make intelligent decisions on what to do, or relay necessary information to individual intelligent devices throughout the house. In addition, the medium of communication with the house must be as natural as possible, in order to make it as easy as possible for the occupants of the smart house to interact with and the various smart appliances. A voice-activated universal remote control and a new microphone system are being developed to this end. Finally, the smart house has to provide an enjoyable experience that can promote the uptake of smart house technology by users in the future. An interactive TV environment is being developed to this end. The Massey Bluetooth house project is not so much aimed at a cutting-edge technology in smart house design, but at integrating technologies into a seamless, cohesive whole through the application of four levels of smartness.

A. Sloane (ed.), *Home-Oriented Informatics and Telematics*

1. INTRODUCTION

Since Mark Weiser of PARC has coined the phrase 'ubiquitous computing', there have been great advances in this research. Much of the enabling technologies in this area, as predicted in his visionary paper (Weiser, 1991), are now to some extent available. For instance, Global positioning systems, Personal Digital Assistants, Bluetooth networks and Radio Frequency Identification networks are all applicable in realising the concept of a ubiquitous computing environment.

It is noted that these technologies have been great successes in each of their individual consumer worlds. A smart home (or smart house), however, asks them to be integrated to a level where the technologies and appliances in the house help make life easier, safer and more enjoyable for the occupants (Rogers and Mynatt, 2003). It poses the three important issues in that a systems engineering approach is needed to make all areas of the smart house work together seamlessly (Jacko and Sears, 2003); the smart house should be transparent to the people in the home (extended from Norman, 2001); and finally multidisciplinary cooperation is required to achieve these goals. It is also note that much work has been done on individual technologies that can be of help in caring for the frail and elderly, but little has been done on their integration into a cohesive whole. The Bluetooth house project at Massey University, which was initiated in 2002, follows this systems engineering approach to develop usable smart house technologies in New Zealand, with collaboration between engineers from electronics, robotics, telecommunication technologies, and psychologists.

Apart from the academic interest, the political and social aspects of New Zealand are also considered in this project. In 2002, the authorities of New Zealand Health sector initiated their strategic approach to provide appropriate health care to the elderly population in New Zealand (Health Sector Strategic Report 2002). The report concluded that New Zealand has a high and increasing elderly population ratio without any support from the other family members and suggested that rest homes with monitoring facilities would be very effective in taking care of this population segment.

The goal of the Massey Bluetooth home project is thus to create a complete and integrated solution, which can be customised, based on individual needs, to give elderly people independence, quality of life, and the safety they require.

2. CHALLENGES IN MASSEY BLUETOOTH HOME DESIGN

The Massey Bluetooth home project, presented here, offers a potentially high opportunity to demonstrate a basic level of smart house technology, focusing on two challenging issues: Integrity and Usability.

2.1 Integration

It can be seen that the key success factor of smart house technology is how well the individual technologies can be integrated to provide a comfortable life in the home. Integration is thus what smart house researchers are ultimately aiming at. The current technologies available still need to be reconfigured for this objective, as there are many interdependency issues that arise as the individual technologies are integrated into a cohesive working application. For example, the Aware Home project at Georgia Tech (see more details in http://www.cc.gatech.edu/fce/ahri) and the project Aura at CMU (see more details in http://www-2cs.cmu.edu/%7Eaura) also focus on the integration of the individual technologies.

The Massey smart house team's approach is thus to identify the opportunities and limitations of current technologies in the home and to introduce a plausible solution for their integration through the use of a Bluetooth network. Some technologies are also being developed to ensure the integrity of low cost smart house technology in order to meet the market's demands.

2.2 Usability

In the context of work, the key components of usability are recognized as task fit and ease of learning. Current smart houses are often designed from a mechanical view so that poor ease of use and task fit are major barriers to the uptake of such ubiquitous computing technology.

Whilst conventional concepts of usability are equally important, they miss something about the nature of smart home environments, specifically, activities in the home. Smart house researchers presume that many activities in home do not have a clear aim or task objective and may be done simply for the enjoyment they provide. Thus, in the smart house the criteria for usability have mainly to do with the user's experience rather than the user's ability to complete some task (from personal communication with Monk, 2003).

The approach of the Massey Bluetooth home project is thus to identify design principles for ease-of-use and ease-of-learning, previously developed and applied in the workplace, to the problem of configuring and re-configuring networks of devices in the smart house. At the same time new concepts of usability will be identified, building on the work on this topic currently going on in the other ubiquitous computing projects at Massey.

The following sections discuss how these aims are being investigated in this project.

3. THE MASSEY BLUETOOTH HOME DESIGN

Considering current technical feasibility and the advances in other research, e.g., MIT Oxygen project, Home Automated Living and DELTA project, it is presumed that for a house to be considered as truly 'smart', it requires four things:

- Smart sensors: it needs to know who is in the house, where in the house they are, and what special needs or preferences they may have.
- Smart management: it needs a central management system, which is based on the occupants identities and locations, can coordinate all the smart appliances and devices in the house to best fit those occupants' needs.
- Smart control: a speech recognition system that allows the users to communicate with the house in a natural manner, without having to wear headsets or consciously have to activate a microphone, etc.
- Smart appliances: to be a smart home environment, it needs some smart appliances that have enhanced capabilities of the conventional home appliances. For instance, Internet-connected appliances are now within the financial reach of the ordinary consumer, resulting in a range of new services to enhance our lives. At the application level, what sort of smart appliances would be useful in the smart home environment is also an important concern.

The Massey Smart House incorporates these four core technologies to allow all these individual technologies to be integrated into a seamless whole. The following outlines the details of each sub-project.

3.1 Bluetooth Network with Bluetooth Watch

There are many workable networks in the smart house design, e.g., Wi-Fi, GPS, RFID and Bluetooth. One requirement in connecting the house is that the network has the ability to detect where users are within the network. That

is to say, the house needs a dynamic network throughout the house that allows devices to communicate with the house management system that coordinates the information within the house, and the occupants of the house, based on the location of the occupants. This can be achieved through a variety of means including the technologies mentioned above. The indoor tracking system developed by AT&T Laboratories in Cambridge, for example, uses a network of ultrasonic modules to keep track of the users (Harter et al., 1999). The disadvantage with such a system is that the house will only react to occupants wearing the appropriate ultrasonic transmitters.

Bluetooth has the advantage of being an almost ubiquitous technology used in many common appliances such as cell-phones, PDAs, and more, giving it the advantage of having an already available range of transmitters, allowing the smart house to react to a wider range of people. Bluetooth has a range of around 10 meters, which is adequate for certain forms of communication. In contrast, RFID is capable of covering only a relatively short range (around 1 meter,) which is entirely dependent on the radio frequency and the power, but its speed of communication is faster than that of Bluetooth. The Massey smart house adopted Bluetooth as the communication technology in our project, because it allows devices to automatically talk to each other when they come within a certain range, at a relatively reasonable cost, and it is relatively easily extendable to allow communication throughout the entire house, e.g., up to 1000sqm.

Figure 1. Massey Bluetooth watch

In parallel with the Bluetooth network, a small Bluetooth device embedded in a watch satisfies the requirement of locating the user's position within the network. The project includes the development of a Bluetooth enabled watch/blood pressure monitor as depicted in Figure 1, as well as the

design and construction of the Bluetooth ubiquitous network, and the network software.

The Bluetooth network consists of the Bluetooth watch and several small reduced-range Bluetooth transceiver modules that are attached to the ceiling of the room or house to form a grid of linked modules (see Figure 2). The modules are spaced 2 meter apart and each module is set to have a range of 2.4 meters. The grid is connected to a computer running software to deal with the information received from the network. This software includes the ability to track the user over a map of the house, and display the personal data contained in the users watch. As smart appliances, e.g., interactive TV, then begin to be developed and integrated into the system, this information can then be used to intelligently control the appliances.

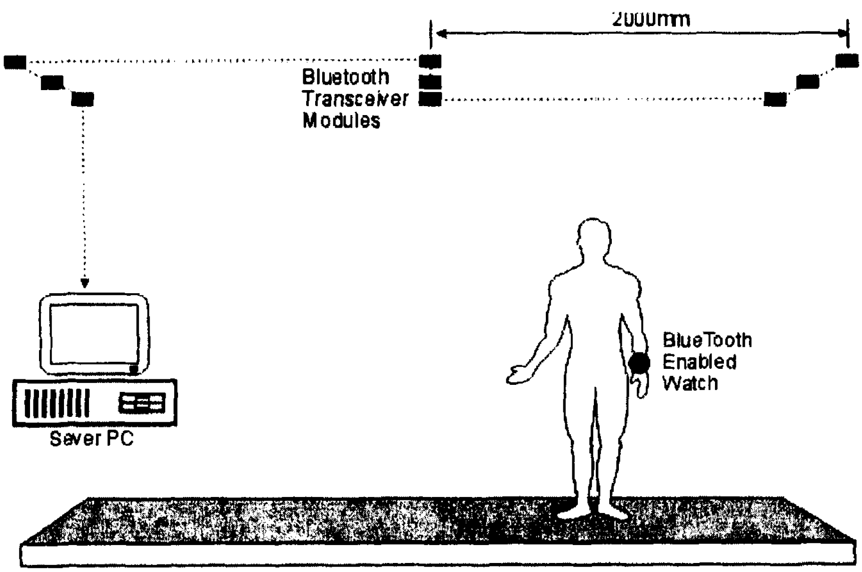

Figure 2. The Massey Bluetooth network

The Bluetooth-enabled watch is loaded with the users' personal data, and it has a range of 2.4 meters. As the watch is generally between 500mm to 2000mm from the floor (depending on the user's arm position), it is always within range of at least one receiver module but never in range of more than 4 receiver modules. It then becomes simple geometry to determine the location of the user relative to either one, two, three or four modules. This is well within the capabilities of Bluetooth, which is capable of communicating simultaneously to up to seven devices. An additional

advantage of using Bluetooth is that standard Bluetooth enabled devices, such as cell-phones, can be used in tracking visitors in the house.

3.2 House Management System

In order to function efficiently and to avoid the duplication of much of the technologies being developed, the house requires a central computer and software package capable of using the information from the speech recognition system for commands, feedback from smart appliances, and user location information. Based on this information, the house management system makes intelligent decisions on what to do, or relaying necessary information to individual intelligent devices throughout the house.

The house management system involves PC based software that, based on the information received from the Bluetooth network, user commands via speech-recognition, and other sensors throughout the house, is capable of making intelligent decisions. Currently, the system is composed of two modules: an expert system to process the received commands and a conversation module that would operate as a 'Chatbot' to converse with the occupants in the home. Further modules such as a visual element to receive some forms of visual communication from the occupants are also envisaged.

Table 1. Massey smart house database.

Table name	Information held	Description
Commands	Command ID Command Degree of certainty	The commands table contains all the possible commands that the house management system can implement within the house. Each command has a unique command ID and a degree of certainty which indicates that the command received may be unsafe or needs to be confirmed.
Devices	Device ID Device	The device tables contains all the devices that may be accessed through the commands given by the user. Each device also has a unique device ID
Room	Room ID Room	The room table represent all the rooms (or physically isolated location) in the house such as kitchen or the garage. Each location also has a unique room ID
Commands-device	Command ID Device ID	The command device table links the commands and the device, i.e., 'light on' command in the universal remote control is linked to the device

Table name	Information held	Description
		'light'
Room-Device	Room ID Device ID	The room device table holds information about the devices that a particular room has within it.

For the working prototype, the house management system is made up of the house database which contains the commands and the rules to operate the devices. The current house database is represented in Table 1. As any process occurs it is checked against the database and the house management system passes the commands to Switching system so as to access appropriate devices.

3.3 Interaction via Speech Recognition

In order to make it as easy as possible for the occupants of the smart house to interact with and the various smart appliances, the medium of communication must be as natural as possible. Other forms of interaction styles, e.g., eye-tracking, may also be applicable for specific appliances or functions, but a good speech recognition system would resolve most of the traditional communication difficulties.

The Massey smart house therefore adopts a speech recognition system, which is capable of analysing spoken language and extracting necessary instructions from it. It involves a speech recognition system that allows the users to communicate with the house management system and a universal remote control for smart appliances, without the need for a headset microphone. The microphone system makes use of beam follower technology (see for details Griffiths and Jim, 1982), and a commercial speech-recognition software is employed, i.e., Dragon™ Naturally Speaking, for a universal remote control that is activated by voice.

3.3.1 Universal Remote Control

Too many remote controls are very problematic in a home, as the user generally intends to control only a particular appliance. That is where a universal remote control comes in. This allows the user to control all their appliances without using separate remote controls.

Yet, from a 'smart' perspective, the current universal remote control still needs to be advanced from its current interaction style based on keypad-input, to a more intuitive style using speech-recognition technology. A universal remote control is being designed, on which all commands can be activated with human speech rather than through the current user's keypad input on the physical remote.

Based on this account, a voice-activating universal remote control is being developed. The control flow in our design of the universal remote control is described as follows: First, Dragon™ Naturally Speaking recognises what the user said. Then, a program written in LABVIEW™ generates the related binary string which is the same as what the normal remote controller creates when it is clicked. Finally through the RS232 port, the binary strings are transmitted to a microcontroller and the corresponding pulses modulated at 38 kHz are propagated through the infrared LED. The schematic of this circuit design is shown in Figure 3.

In order to dim a light, TWS-434, RWS-434 and HT-12E, HT-12D are used as RF transmitter, receiver encoder and decoder, respectively. LS7631 is a dimmer chip which can adjust the fire angle of a Triac. A signal on the Din pin of HT-12D activates the oscillator which is in turn continuously checked by a decoder. The transmission is not valid until the received address is matched with the decoder's local address. The 555 circuit acts as a pulse generator which can generate different pulse widths which are fed to the LS7631. This voice-activated universal remote control is currently being tested in a laboratory environment.

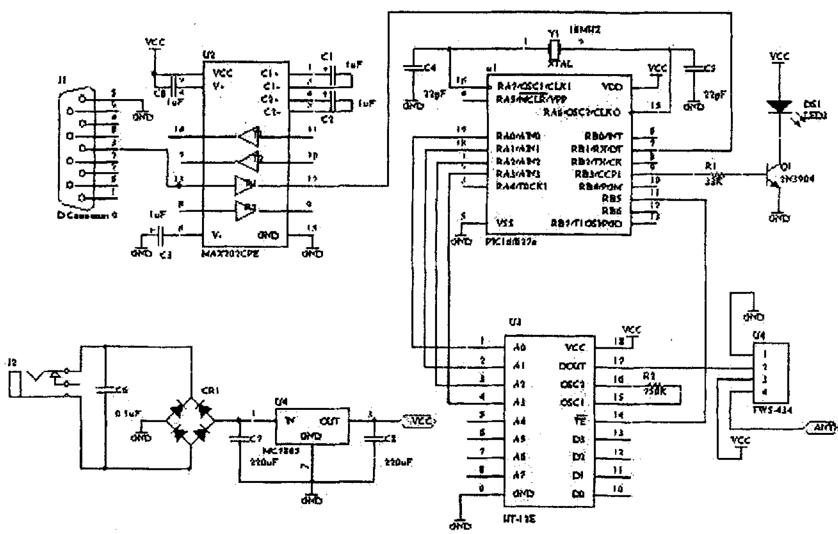

Figure 3. Circuit design of the universal remote control.

3.3.2 Microphone Array Beamformer

The same interaction style used with the universal remote control is also used to analyse the occupants spoken language and extract necessary

commands for the house management system. A simplistic solution to this problem is to use a headset or body worn microphone to acquire the speech from the user. Yet, as the smart house technology is being aimed toward the frail and elderly population, this is not so practical. Furthermore, the majority of the occupants would prefer not to wear a microphone in their house at all times. Therefore, a microphone system is being developed that allows the users to move around freely and interact easily with the house management system by speaking naturally.

Using a directional microphone is a simple solution to this problem, but they seem to fall short of their objectives in adverse environments. The received signal from the microphone might include the desired speech signal as well as the background noise, which can consist of several components propagating from different sources such as computer fans, radio, TV, and other talkers. For the speech recognition system to work efficiently a signal to noise ratio of greater than 20dB is typically required.

Another potential solution to this problem is the use a microphone array, which will give the smart house users the advantage of really being able to move freely around the house. The microphone array makes use of beamforming technology to fight against the effects of the acoustic environment.

The selected adaptive algorithm to be used in the smart house is based on a modified version of Griffiths-Jim beamformer (Griffiths and Jim, 1982), which was originated by Van Compernolle and Leuven (Van Compernolle and Leuven, 1990). This algorithm has been demonstrated to perform well under noisy and reverberant conditions. The algorithm makes use of two adaptive filters based on Least Mean Square (LMS) (Widrow and Hoff, 1960). Since the LMS algorithm has some drawbacks with stability and selection of the step-size the system will instead be using an adaptive filter based on Normalised LMS (NLMS) (Haykin, 2002).

This speech beamformer makes use of two NLMS algorithms. The first NLMS is updated during a speech segment and the second NLMS is updated during the noise segment. The first one acts as an adaptive beam-steering filter and the second one acts as a filter for the noise. Only one of these NLMS algorithms is updated at a given time. The technique also uses a simple voice activity detector to analyse the received speech signal and determine if it is speech or noise. The corresponding NLMS algorithm is updated depending on the result obtained from this voice activity detector. The above algorithm is in the process of being implemented in real-time on a Texas Instruments digital signal processor.

3.4 A Smart Appliance: Interactive TV and User Experience

If, as discussed above, many of the activities in the home are undertaken for the enjoyment they can provide, i.e., watching TV and cooking, then the smart house has to provide an enjoyable experience that can promote the uptake of smart house technology by users in the future.

For instance, new television technology such as digital television might produce more pleasant experiences for housebound, disabled or elderly people, as it would allow them to access richer and more customisable information from their home. In particular, it is noted that the elderly are the biggest current consumers of television in New Zealand, watching on average more than 5 hours a day (National Statistics of New Zealand). This implies that they have less communicative involvement with their neighbourhood, and that they are at risk of becoming socially isolated from their community.

It is believed that our smart house, together with new television technology, can help lessen this social problem, as the technology facilitates social interaction in the community. In a similar context, Hampton (2003) has set up a wired community to see how much information and communication technologies facilitates community participation and collective action. Yet, the previous research does not propose the development of applications in the interactive TV environment, thus encouraging elderly people to adopt it. Following this work, the research team aims to investigate what kinds of applications in the interactive TV environment would facilitate interaction with their neighbourhood for elderly people, thus extending the concept of smart home into the smart community.

Based on this understanding, an interactive Java™ TV environment with the voice-mediated technology is being developed. The main functionality of it is to enhance the broadcast and viewing experience by providing such features as programming information and chatting with friends while watching TV programmes. This chatting facility can increase social ties between people, even while they are watching television. A prototype is being designed and implemented.

4. CONCLUSIONS AND FUTURE WORK

This paper presented how the Massey Bluetooth smart house design project has been carried out and what a smart home integrated with these technologies may look like in the near future. Currently, the Massey

Bluetooth house is only working in a laboratory environment. The house management system, the universal remote control, the beamformer microphone and the interactive TV are still being implemented or tested in this same laboratory environment. The evaluation of both the individual systems and the integrated system has been planned.

This paper has not discussed other smart house issues such as accessibility, emotionality, privacy, security, and sociality, along with the technological approach. We did not intend to trivialise these issues; however, as the current project aims at building a physical house for people to use as a model house for future living, the issues were not included in the immediate project, but will be studied as part of future work.

In conclusion, the Massey Smart House is not so much aiming at a cutting-edge technology in smart house design, but at integrating technologies into a seamless, cohesive whole, and drawing a picture of the technological home in the New Zealand environment as well as developing some business ideas with industry partners such as construction companies, appliance companies, and the government. This research is also intended to communicate the concept of the smart house to the public, encouraging people to access our facility, and thus feel the added benefits of integrating smartness into the home. In the end, the main beneficiaries of this project will be our elderly population who want to retain their independence, and their families and friends who can be secure in the knowledge that they are safe, well and comfortable. The health sector will thus benefit by being able to more effectively help and monitor people in their care. There will also be flow-on benefits for the construction industry, appliance industry, and for people who wish to improve their quality of life.

REFERENCES

Griffiths, L. J. and Jim, C. W. (1982) In *IEEE Trans. Antennas Propagation*, pp. 27-34.

Hampton, K. N. (2003) *Grieving for a lost network: collective action in a wired suburb*, *The Information Society*, **19**, 417-428.

Harter, A., Hopper, A., Steggles, P., Ward, A. and Webster, P. (1999) *The anatomy of a context-aware application.*, *ACM/IEEE International Conference on Mobile Computing and Networking*, 59-68.

Haykin, S. (2002) In *Adaptive Filter Theory*, (Ed, Kailath, T.) Prentice Hall, Inc., Upper Saddle River, New Jersey.

Jacko, J. A. and Sears, A. (Eds.) (2003) *"The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications"*, Lawrence Erlbaum Assoicates Publishers, Mahwah, NJ.

Norman, D. (2001) In *Communications of the ACM*, pp. 36-37.

Rogers, W. A. and Mynatt, E. D. (2003) In *"How can technology contribute to the quality of life of older adults?"* (Ed, Mitchell, M. E.), pp. 22-30.

Van Compernolle, D. and Leuven, K. U. (1990) In *IEEE International Conference on Acoustics, Speech, and Signal Processing, 1990. ICASSP-90.* Albuquerque, pp. 833-836 vol.2.

Weiser, M. (1991) *The computer of the 21st century, Scientific American,* **265,** 66-75.

Widrow, B. and Hoff, M. E. (1960) In *IRE WESCON Convention Rerecord,* New York, pp. 96-104.