



UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN EMBEDDED SMART HOME SYSTEM

THINAGARAN PERUMAL

ITMA 2006 3



DEVELOPMENT OF AN EMBEDDED SMART HOME SYSTEM

By

THINAGARAN PERUMAL

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in
Fulfilment of the Requirement for the Degree of Master of Science**

July 2006



Dedicated to,

My Family



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DEVELOPMENT OF AN EMBEDDED SMART HOME SYSTEM

By

THINAGARAN PERUMAL

July 2006

Chairman: Associate Professor Abdul Rahman Ramli, PhD

Institute: Advanced Technology

Smart home systems are expected to become key research area for ubiquitous and embedded system computing in coming years. In this thesis, a new scheme in smart home systems technology using embedded system for providing intelligent control of home appliances is proposed. An embedded system act as protocol glue that incorporates wired and wireless option such as Short Message Service (SMS) router with wireless local area network (WI-FI) for intelligent automation and higher speed of home appliances connectivity. The system is implemented in 2 tier models. First-tier model consist of incorporated design of SMS Router and Wireless Access Point. Wireless local area network (WI-FI) is selected as mechanism due to its transmission range within 100m which suits the smart home requirement for automation and control, justifies the Personal Area Network (PAN) for mobile device connectivity. Second tier model consist of remote application server systems, which cater a conceptual model between embedded hardware and software integration of appliances in smart home. This interface model will be between in house networks and external communication environment,



whereas embedded system acts as storage media and server for information interchange between systems especially with mobile devices within a smart home. Embedded system sits at the core of the home network, acts as residential gateway and enables bi-directional communication and data transfer channel among networked appliances in the home and across the Internet. On the other hand, client-side application provides a user-friendly Graphic User Interface (GUI) to enhance the usability of the system. The proposed embedded system has been implemented and verified that the system can be a core device for smart home environment functionality.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN MODUL TERBENAM UNTUK RUMAH BESTARI

Oleh

THINAGARAN PERUMAL

Julai 2006

Pengerusi: Profesor Madya Abdul Rahman Ramli, PhD

Institut: Teknologi Maju

Sistem rumah bestari di jangka menjadi topik penyelidikan utama dalam bidang pengkomputeran merata dan sistem terbenam dalam tahun yang akan datang. Dalam tesis ini, satu skema baru dalam teknologi sistem rumah bestari menggunakan sistem terbenam untuk kawalan cerdik peralatan rumah dicadangkan. Sistem terbenam berfungsi sebagai penggabung protokol antara wayar dan tanpa wayar dengan menggunakan perkhidmatan pesanan ringkas (SMS) and WiFi untuk automasi dan rangkaian pantas alatan rumah. Sistem ini diimplementasikan dalam 2 aras. Aras pertama merujuk kepada gabungan perkhidmatan pesanan ringkas (SMS) dan titik capaian tanpa wayar. Wi-Fi dipilih kerana penghantaran normal 100m yang memenuhi keperluan sistem rumah bestari untuk kawalan dan automasi, sekali gus menepati kehendak rangkaian kawasan persendirian (PAN). Aras kedua merujuk kepada aplikasi pelayan jauh yang mewakili konsep antara sistem terbenam dan integrasi perisian



peralatan rumah. Sistem tersebut berpusat di antara rangkaian rumah dan luaran di mana modul terbenam bertindak sebagai storan media dan pelayan untuk pertukaran maklumat di antara peranti bergerak dan sistem rumah bestari. Sistem terbenam akan menjadi penghubung utama rangkaian rumah, sebagai ruang akses, membolehkan komunikasi dua hala dan saluran pemindahan data di antara peralatan rumah dan Internet. Selain itu, aplikasi antara muka grafik pengguna (GUI) yang mudah diguna telah menambah keberkesanan terhadap sistem operasi. Sistem terbenam yang di uji telah menunjukkan bahawa sistem ini boleh menjadi teras untuk persekitaran rumah bestari.



ACKNOWLEDGEMENTS

First of all, I would like to express my utmost thanks and gratitude to my family for giving me the support to finish this thesis successfully. The author gratefully wish to express his profound appreciation and gratitude to his supervisor, Associate Professor Dr. Abdul Rahman Ramli, for his supervision, ultimate guidance, morale support and constructive suggestions and comment throughout the duration of the project till completion. The author would like to express high regards and thanks to Dr. Kenneth Wacks, Chairman of ISO SC 25 Home Electronic System and MIT Media Lab Researcher, for his material contribution and some guidelines on research project implementation.

The author also extends appreciation of his supervisory committee, Pn. Siti Mariam Shafie@ Musa for her guidance and valuable assistance during this period. Appreciation also to the assistance rendered by the respective lecturers, ITMA Science Officers especially Puan Juraina Md Yusof, Puan Rosiah Osman and En.Mohd Saufi, technicians of ITMA for providing the facilities required for undertaking this project.

Finally, the author would like to acknowledge and express highest regards to Ministry of Science, Technology and Innovation (MOSTI) for funding this project under The Intensified of Research and Development in Priority Areas (IRPA) program, titled Embedded Multimedia Interface Module for Smart Home Environment (04-02-04-0799-EA001)



I certify that an Examination Committee has met on 4th July 2006 to conduct the final examination of Thinagaran Perumal on his Master of Science thesis entitled “Development of An Embedded Smart Home System” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Yusof bin Sulaiman, PhD

Professor
Institute of Advanced Technology
Universiti Putra Malaysia
(Chairman)

Mohammad Hamiruce Marhaban, PhD

Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Samsul Bahari Mohd Noor, PhD

Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Kaharudin Dimiyati, PhD

Associate Professor
Faculty of Engineering
Universiti Malaya
(External Examiner)

HASANAH MOHD GHAZALI, PhD

Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:



This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

Abdul Rahman Ramli, PhD

Associate Professor
Faculty Engineering
Universiti Putra Malaysia
(Chairman)

Siti Mariam Shafie@Musa

Lecturer
Faculty Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD

Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:



DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

THINAGARAN PERUMAL

Date:



TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xvii
CHAPTER	
1 INTRODUCTION	1
1.1 Smart Home	1
1.2 Embedded System in Smart Home	3
1.3 Problem Statements	5
1.4 Research Scope and Contribution	6
1.5 Research Objectives	7
1.6 Thesis Organization	7
2 LITERATURE REVIEW	9
2.1 Introduction	9
2.1.1 Smart Home Environment	9
2.2 Embedded System in Smart Home	13
2.2.1 Characteristics of Embedded System in Smart Home	14
2.2.2 The Current Problem and Related Research Work	16
2.3 Smart Home Technologies	18
2.3.1 Wired Protocols	19
2.3.2 Wireless Protocol	27
2.4 Smart Home Standards	38
2.4.1 European Home Systems	38
2.4.2 BatiBUS	39
2.4.3 European Installation Bus	40
2.4.4 Konnex	41
2.4.5 Home Plug	41
2.4.6 Home Electronic System	42



2.5	Software Platform for smart home systems	43
2.5.1	Symbian OS	43
2.5.2	Palm OS	43
2.5.3	Java Micro Edition (J2ME)	44
2.5.4	Microsoft Mobile Device Platforms	44
2.5.5	Real-Time Operating System (RTOS)	44
2.6	Conclusion	46
3	METHODOLOGY	48
3.1	Introduction	48
3.2	Operation Mechanism	50
3.3	System Architecture of Embedded System for Smart Home	51
3.4	Operation Modes of Embedded System in Smart Home	53
3.5	Hardware Integration	53
3.5.1	Mobile Device as Remote Terminal	53
3.5.2	User interface and input capabilities	54
3.5.3	Habitual presence	55
3.5.4	Wireless network diversity	55
3.5.5	Mobility	55
3.5.6	Personalization	56
3.6	System Implementation	57
3.7	Embedded Computer	58
3.7.1	Configuring Embedded Computer as Remote Application Server	59
3.8	Network Interface Control Server Programming	60
3.9	SMS Module	65
3.10	Switching Module	66
3.10.1	Microcontroller Programming	72
3.10.2	Signal Translation	74
3.10.3	Error Recovery and Fault Detection	75
3.11	Client Software Application Development	78
3.11.1	Client-Side Development	78
3.11.2	System Integration of Embedded System in Smart Home	80
3.11.3	Optimization of Embedded System Programming	82
3.12	Conclusion	86
4	RESULT AND DISCUSSION	87
4.1	Operation Results	87
4.1.1	Monitoring and Control Using SMS	93
4.2	Respond Time	94
4.3	Data Transformation	97
4.4	Discussion	106
4.4.1	System Efficiency	107
4.4.2	System Stability	108



4.4.3	Security Concern	112
4.5	Conclusion	114
5	CONCLUSION AND RECOMMENDATION	115
5.1	Conclusion	115
5.2	Advantages of Embedded System	118
5.3	Recommendation and Future Work	119
	REFERENCES	120
	APPENDICES	129
	BIODATA OF AUTHOR	217



LIST OF TABLES

Table		Page
2.1	House Codes and Device Codes	23
2.2	Key Differences between the IEEE 802.11 Extensions	34
3.1	Some of the protocol API for network control server	61
3.2	Examples of SMS Command Used For Triggering the Switching Module	66
3.3	Relay control codes for switching module	67
4.1	Type of network connection	95
4.2	Descriptive analysis of connection types in embedded system	96
4.3	Minimum and maximum value derived from descriptive analysis	96
4.4	Test of Homogeneity Variances	97
4.5	ANOVA table for each connection types	97
4.6	List of feedback signal corresponding to the relays status in switching module	106
4.7	Types of testing method for system operation stability	109
4.8	Security checklist of embedded system	112
4.9	Protection methods of security risk	113



LIST OF FIGURES

Figure		Page
2.1	Embedded System Functional Requirement in Smart Home Environment	15
2.2	X-10 Transmitter and Control Pad	20
2.3	A sine graph showing the zero crossing points	21
2.4	X-10 Transceiver Architecture	22
2.5	The BatiBUS System	40
2.6	Architecture of Real-time-operating-system (RTOS) for SC 12	46
3.1	Flow chart of design and development methodology of the system	49
3.2	Operation Mechanism of Embedded System	50
3.3	Embedded System Architecture in Smart Home Environment	52
3.4	Process of Server Implementation	57
3.5	Embedded Computer EB3820	58
3.6	Internet Information Service Management Console for server setup	59
3.7	Pin configuration of SC 12	60
3.8	Flow chart of the mechanism of TCP server (continue)	63
3.9	Flow chart of the mechanism of TCP server	64
3.10	GPRS/GSM Enfora1218A Modem Quad band	65
3.11	System architecture for switching module	67
3.12	Interactive mechanism of I/O interface and switching module	68
3.13	Mechanism of signal switching control in switching module	69
3.14	Mechanism of synchronous triggering method	70



3.15	Mechanism of asynchronous triggering	70
3.16	Flow Chart of System Program	72
3.17	Task of signal converter	73
3.18	Mechanism of error recovery associated with the strong coding selection and data integrity	75
3.19	Mechanism of run-time system failure detection	76
3.20	Standard IDE of Embedded Visual Basic	79
3.21	Logical linking and system operation between embedded computer and switching module	80
3.22	Mechanism of error checking to trap system failure	82
3.23	Embedded System Functional Model in Smart Home	85
4.1	Deployed user interface of client-side application in O2XDA11 Pocket PC	88
4.2	Main program of client side application	89
4.3	Establish connection from client-side application to TCP server	90
4.4	The operation of triggering first relay	91
4.5	Result of all relays are triggered ON in switching module	92
4.6	Result of all relays are triggered OFF in switching module	93
4.7	Login screen of telnet client when started to establish a connection to the telnet server	98
4.8	Connection detection result on monitoring terminal	99
4.9	Data obtained by remote application server to trigger on the first relay	100



4.10	Data obtained by remote application server to trigger on the second relay	101
4.11	Result of data transformation to trigger on the first relay	102
4.12	Result of data transformation to trigger on the second relay	102
4.13	The generated feedback signal by switching module responds to trigger ON first relay	103
4.14	The generated feedback signal by switching module responds to trigger ON second relay	103
4.15	The generated feedback signal responds to trigger OFF all relays	104
4.16	Result respond to the event of reset all of the relays	106
4.17	Analytical ambient temperature result in line chart	110
4.18	Analytical unit temperature result in area chart	111



LIST OF ABBREVIATIONS

API	Application Programming Interface
DNS	Domain Name System
DSL	Digital Subscriber Line
GUI	Graphical User Interface
GSM	Global System for Mobile Communication
IP	Internet Protocol
ISP	Internet Service Provider
LAN	Local Area Network
OS	Operating System
PAN	Personal Area Network
PPP	Point-to-Point Protocol
SMS	Short Message Service
TCP	Transmission Control Protocol
TSP	Telecommunication Service Provider



CHAPTER 1

INTRODUCTION

1.1 Smart Home

Internet has revolutionized many new emerging technologies. Rapid spread of Internet use at home inspires a new convenient way for controlling appliances at home thus conceptualised a smarter home. The smart home, the talk of the decade, has been predicted to be the next gigantic leap in the field of remote monitoring, becoming an important research topic in recent years. Research on smart homes has been moving towards applying the principles of ubiquitous computing [1]. The smart home is defined as one that is able to acquire and apply knowledge about its inhabitants and their surroundings in order to adapt to the inhabitants and meet the goals of comfort and efficiency [2]. The smart home may adjust its functions to the home owner's needs according to the information it collects from inhabitants, the computational system, and the context.

The smart home systems industry is gaining significant attention from manufacturers ranging from consumer electronics to computers and communication networks. The potential business value of smart home systems products rivals some of the largest industries in the world, such as automotive. Basically, a smart home systems is a complete enabling system that provides common resources needed for home automation in a multi-product, multi-vendor environment, a system controller, a house wide wiring



network, communications protocols, standard interfaces for connecting other digital consumer products, and basic user controls. Providing complete smart home functionality depends on the addition of other products, such as more complex user controls, home appliances, and application-specific controllers. Designing and implementing smart homes requires a unique breadth of knowledge and not limited to a single discipline, but integrates aspects of machine learning, decision making, human-machine interfaces, wireless networking, mobile communications, databases, sensor networks, and pervasive computing. With these capabilities, the home can control many aspects of the environment such as climate, lighting, maintenance, and entertainment. In this kind of intelligent environment, information processing and networking technology is hidden away, and interaction between the home and its devices takes place via advanced natural user interaction techniques. As the size of computers become smaller and their speeds become faster, they will be embedded in every device, appliance, or even clothing. Embedding intelligence in automation, security and communication systems has become a dominant theme in smart home environment and state-recognition systems for ubiquitous computing. These systems aims to provide more holistic approach to the smart home, directed by centralized controller, and designed to interpret the user's needs in an efficient and well-defined way. Various intelligent appliances such as cellular phones, air conditioners, home security devices, home theatres are set to realize the concept of smart home. Smart home systems can contribute to better comfort levels and at the same time increase safety and security, detecting and signalling emergency and intrusion situations. It can be very helpful to elderly people with disabilities who may have difficulties in moving or executing tasks. While there are as many as 50 standards for smart home systems, only a handful is considered important



[3]. Some standards are open and many are proprietary. X-10, EIB, Cibus and LonWorks to name a few, act as open standard. These technologies are incompatible with each other. Another rising problem with current technologies is that they do not offer standard approaches to the problem of system design and adaptation to specific home and users. In most cases, the technology introduced meant to be used by technical personnel and not by common or even savvy users. Therefore, and for some technologies, a user cannot change his / her system or upgrade it without contacting a specialized company. The main constraint will be the lack of generic applications for monitoring and controlling a smart home that can accommodate change and allow the user to modify the system behaviour and adapt it to new needs and preferences. The demand for smart home systems is stimulated by invention of affordable products and services. Simply interconnecting existing appliances or control systems is not sufficient. Effective products must make any internal complexity invisible to the user with simple operating procedures and minimal training. As such the design and development of centralized embedded based system with multimedia support are critical for system reliability in smart home environment.

1.2 Embedded System in Smart Home

Embedded system is a customized computer system with both hardware and software, housed with programs embedded and has digital interfaces for several communication modules using mobile devices for appliances connectivity and control. It is the control centre that functions as a bridge and links consumer devices and manages the flow of data, voice and video between the outside world and devices on the network. With the maturing of wireless technology and communication middleware, smart home designers and inhabitants have been able to raise their standards and expectations. The system need to address interoperability requirements, interconnectivity requirements and plug-compatibility requirements of devices and appliances in smart home environment.

Home appliances or information appliances are consumer devices, which offer Internet or network access without using traditional operating system interface [4]. In particular, these devices use a gateway to communicate with each other, sharing data to build a more informed model of the state of the environment and the inhabitants, and retrieving information from outside sources over the Internet or wireless communication infrastructure to respond better in current state and needs. The devices can access information from the Internet such as menus, operational manuals, or software upgrades utilizing a central embedded based system as task distributor. The system sits at the core of the home network, acts as residential gateway and enables bi-directional communication and data transfer channel among networked appliances in the home and across the Internet. Many research findings suggested that these types of module and

residential gateway are expected to become key integrated service enabler in smart home environments.

1.3 Problem Statements

While there are many standards and organization involved in providing smart home backbone, only a small number had wider acceptance. The most common feature of smart home environment, X-10 technology refers to the electrical wiring that exists in the home to provide power for appliances using the existing power outlets available throughout a home [5]. Currently X-10 is used for applications with low data rate requirements such as lighting and appliances networks, and some security applications. Observing current systems and trends, both in research and practice, the following weaknesses emerge: -

- a) Low bandwidth provides low data rate and incompatibility for new consumer electronics devices whereas X-10 transmission rate limited only 60b/s; it is also unsuitable for handling traffic.
- b) No system feedback to check or monitor connectivity, unreliable and no guarantee of reception
- c) Due to many standards available, there is no multi-connectivity support for smart home systems, therefore difficulties and no interoperability between devices
- d) Lack of user interface support in existing modules

An embedded system is needed to act as ‘protocol glue’ that incorporates other wireless options such as Short Message Service (SMS) router and wireless local area network (Wi-Fi) for intelligent automation and higher speed of appliances connectivity. With this system, the system will solve the problem mentioned by providing a single user interface for home dwellers with multi-connectivity support. The system also will solve the X-10 drawback by providing feedback on control event of home appliances and to indicate whether it is successful or not. With this type of system, home appliances control in smart home environment can be enhances and produce efficiency in total management of appliances.

1.4 Research Scope And Contribution

The goal of this research is to show the capability of the embedded system in smart home technology, and to explore the factors in this technology that expands the interoperability. The design and implementation of the system is examined to find ways to provide a reliable interface using wireless infrastructure, improving the connectivity and control of smart home appliances and devices which will likely be required in the future using high-speed and high-precision data communication link. The contributions of this research are illustrated as follows:

- New hybrid module that incorporates wireless technology (Wi-Fi and SMS)
- Provides a single mobile user interface for appliance control in smart home environment

