Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
ZigBee-Based System for Remote Monitoring and Control of Switches

A thesis presented in partial fulfilment of the requirements for the degree of
Master of Engineering

at Massey University, Albany,
New Zealand.

© Matthew Lyon
October 2010
Abstract

Home automation technology has existed for nearly four decades, but is nonetheless mostly absent in the average home today. The systems that do exist are often highly customised and expensive, catering to a very niche market, or overly sophisticated and complicated. Many of these also require extensive, dedicated cabling as their communications backbone and as such are only practical to install during the construction of a new house.

The core aims of this project are to develop a cheap and simple home automation system that can be easily installed in new and existing houses. These aims are achieved by creating a centralised system where most of the intelligence is managed by a PC server and the end nodes are kept as simple as possible.

The server is responsible for basic security, maintaining awareness of the current system state and providing the user interface. At the outer edge of the system is a ZigBee network of wall switches and, in between, a home gateway provides a protocol translation service between the two. The new, “smart” switches are designed to be entirely compatible with existing wall switches in terms of their mounting and wiring requirements, and so ZigBee is chosen to provide a reliable wireless communication channel between the end nodes and the gateway.

Development of the system is undertaken in three stages; design of the server software (including the user interface and server processes), design of the home gateway embedded software, and design of the hardware and embedded software of the switches.

The end result is an effective, entry-level system that provides the benefits of remote management without the need for a costly or complex infrastructure.
Acknowledgements

A number of people have made a valuable contribution to this thesis through their support, guidance and help with various technical problems.

Many thanks are extended to Jamie McIntyre for his assistance with the use of Altium, and sound advice during the design and production of the switch hardware.

I also gratefully acknowledge Reece McCarthy, long-time friend and electrician, for lending his knowledge and experience in mains wiring and existing smart house products.

To my parents, many thanks for your endless motivation and support, especially in the final stages.

And finally, this project owes much of its success to the support and guidance of supervisor, Dr Tom Moir, whose direction throughout the process of developing and writing has been hugely appreciated.
# Table of Contents

Abstract ...................................................................................................................................... 2  
Acknowledgements .................................................................................................................... 3  
List of Tables ............................................................................................................................. 8  
List of Figures ............................................................................................................................ 9  
1 Introduction ...................................................................................................................... 10  
   1.1 Project Overview ....................................................................................................... 10  
   1.2 Design Specification ................................................................................................. 11  
      1.2.1 Requirements ..................................................................................................... 11  
      1.2.2 Constraints ......................................................................................................... 13  
   1.3 Thesis Outline ........................................................................................................... 13  
2 Literature Review ............................................................................................................. 15  
   2.1 Problems Facing the Home Automation Industry ..................................................... 15  
   2.2 Existing Technologies ............................................................................................... 16  
      2.2.1 X10 and INSTEON ............................................................................................ 16  
      2.2.2 CEBus and C-Bus .............................................................................................. 16  
      2.2.3 Vantage .............................................................................................................. 17  
      2.2.4 Control4 ............................................................................................................. 17  
      2.2.5 KNX ................................................................................................................... 18  
   2.3 Research Approaches ................................................................................................ 18  
   2.4 Standards ................................................................................................................... 19  
      2.4.1 OSGi .................................................................................................................. 19  
      2.4.2 ZigBee ................................................................................................................ 20  
   2.5 Summary ................................................................................................................... 21  
3 System Design .................................................................................................................. 22  
   3.1 Project Framework .................................................................................................... 22
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1</td>
<td>Remote Switching Process</td>
<td>23</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Local Switching Process</td>
<td>23</td>
</tr>
<tr>
<td>3.2</td>
<td>Communication Protocol</td>
<td>24</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Command Messages</td>
<td>25</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Data Messages</td>
<td>25</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Notification Messages</td>
<td>25</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Acknowledgement Messages</td>
<td>26</td>
</tr>
<tr>
<td>3.2.5</td>
<td>Server Disconnect Signal</td>
<td>26</td>
</tr>
<tr>
<td>3.2.6</td>
<td>Command Mode Protocol</td>
<td>26</td>
</tr>
<tr>
<td>3.2.7</td>
<td>Communication Overview</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>Server Design</td>
<td>28</td>
</tr>
<tr>
<td>4.1</td>
<td>User Interface</td>
<td>28</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Security</td>
<td>28</td>
</tr>
<tr>
<td>4.1.2</td>
<td>User Authentication</td>
<td>29</td>
</tr>
<tr>
<td>4.1.3</td>
<td>Control Centre</td>
<td>30</td>
</tr>
<tr>
<td>4.1.4</td>
<td>Switchboard</td>
<td>31</td>
</tr>
<tr>
<td>4.1.5</td>
<td>Alert Boxes</td>
<td>33</td>
</tr>
<tr>
<td>4.1.6</td>
<td>System Management</td>
<td>33</td>
</tr>
<tr>
<td>4.1.7</td>
<td>Event History</td>
<td>36</td>
</tr>
<tr>
<td>4.2</td>
<td>Database</td>
<td>37</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Users Table</td>
<td>37</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Devices Table</td>
<td>38</td>
</tr>
<tr>
<td>4.2.3</td>
<td>History Table</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>Home Gateway Design</td>
<td>42</td>
</tr>
<tr>
<td>5.1</td>
<td>Programming the Microcontroller</td>
<td>42</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Microchip TCP/IP Stack</td>
<td>42</td>
</tr>
<tr>
<td>5.2</td>
<td>TCPhandler Module</td>
<td>42</td>
</tr>
</tbody>
</table>
List of Tables

Table 4.1: MySQL description of auth_users table .................................................................37
Table 4.2: MySQL description of devices table .................................................................38
Table 4.3: MySQL description of history table .................................................................41
Table 5.1: LED variable assignments .............................................................................44
List of Figures

Figure 3.1: Project framework ............................................................................................................. 22
Figure 3.2: server_listener output ......................................................................................................... 24
Figure 3.3: Space-time diagram of system communications ................................................................. 27
Figure 4.1: Main MAMP window ......................................................................................................... 28
Figure 4.2: Certificate Warning (Internet Explorer 8) ............................................................................. 29
Figure 4.3: Address bar indications for certificate error and secure browsing (Internet Explorer 8) ........ 29
Figure 4.4: Login window ..................................................................................................................... 30
Figure 4.5: Control centre options for admin user .................................................................................. 31
Figure 4.6: Typical switchboard display ................................................................................................. 32
Figure 4.7: Offline switch indication ....................................................................................................... 32
Figure 4.8: JavaScript alert box .............................................................................................................. 33
Figure 4.9: System management page ..................................................................................................... 34
Figure 4.10: Devices table with completed form data ............................................................................. 34
Figure 4.11: JavaScript confirmation box ............................................................................................... 35
Figure 4.12: Users table .......................................................................................................................... 35
Figure 4.13: Event history page .............................................................................................................. 36
Figure 5.1: LEDs located below the LCD display ..................................................................................... 44
Figure 5.2: LCD display at start-up ......................................................................................................... 47
Figure 5.3: Gateway architecture ........................................................................................................... 48
Figure 6.1: Mounting box ....................................................................................................................... 49
Figure 6.2: PCB layout of first switch ....................................................................................................... 50
Figure 6.3: Completed hardware assembly of first switch ......................................................................... 53
Figure 6.4: General architecture of second switch ................................................................................ 57
Figure 6.5: PCB layout of second switch .................................................................................................. 58
Figure 6.6: Circuitry removed from PowerTech Plus Plugpack ............................................................... 58
Figure 6.7: Various assemblies of the second switch ............................................................................. 59
Figure 7.1: Logical system architecture ................................................................................................. 62
Figure 7.2: Physical system architecture ............................................................................................... 63
Figure 7.3: Project setup ........................................................................................................................ 64