

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.

Automated Wireless Greenhouse Management System

A Thesis submitted in partial fulfillment of the

Requirements for the Degree of

Master of Engineering

In

Electronics and Computer Systems

By

Quan Minh Vu



MASSEY UNIVERSITY

SCHOOL OF ENGINEERING AND ADVANCED TECHNOLOGY

MASSEY UNIVERSITY

PALMERSTON NORTH

NEW ZEALAND

June 2011

ABSTRACT

Increases in greenhouse sizes have forced the growers to increase measurement points for tracking changes in the environment, thus enabling energy saving and more accurate adjustments. However, increases in measurement points mean increases in installation and maintenance cost. Not to mention, once the measurement points have been built and installed, they can be tedious to relocate in the future. Therefore, the purpose of this Masters thesis is to present a novel project called “Automated Wireless Greenhouse Climate Management System” which is capable of intelligently monitoring and controlling the greenhouse climate conditions in a preprogrammed manner.

The proposed system consists of three stations: Sensor Station, Coordinator Station, and Central Station. To allow for better monitoring of the climate condition in the greenhouse, the sensor station is equipped with several sensor elements such as CO₂, Temperature, humidity, light, soil moisture and soil temperature. The communication between the sensor station and the coordinator station is achieved via ZigBee wireless modules and the communication between coordinator station and the central station is achieved via long range RF modems.

An important aspect of designing a wireless network is the reliability of data transmission. Therefore, it is important to ensure that the developed system will not lose packets during transmission. An experiment was carried out in one of the greenhouses at Plant and Food Research Ltd, New Zealand in order to determine the functionality and reliability of the designed wireless sensor network using ZigBee wireless technology. The Experiment result indicates that ZigBee modules can be used as one solution to lower the installation cost, increase flexibility and reliability and create a greenhouse management system that is only based on wireless nodes.

The overall system architecture shows advantages in cost, size, power, flexibility and distributed intelligent. It is believed that the outcomes of the project will provide the opportunity for further research and development of a low cost automated wireless greenhouse management system for commercial use.

ACKNOWLEDGMENTS

A journey is easier when you travel together. Interdependence is certainly more valuable than independence. This thesis is the result of work whereby I have been accompanied and supported by many people. It is a pleasant aspect that I have now the opportunity to express my gratitude to all of them.

I would like to express my gratitude to my supervisors, Senior Lecturer Dr. Gourab Sen Gupta and Associate Professor Dr. Subhas Mukhopadhyay, who have given me encouragement and assistance to complete my Masters Project.

I am indebted to Dr. Gourab Sen Gupta for his continuous support and supervision of my research work and providing me with valuable advice and expert guidance, and above all his technical feedback. Without his help and support this work would not have been possible. I sincerely thank Dr. Subhas Mukhopadhyay for his valuable advice, and numerous helpful suggestions. Many thanks to Colin Plaw, Ken Mercer, Anthony Wade, Kerry Griffiths and John Edwards for their help and support on technical matters, and invaluable comments to improve the experimental work in the laboratory.

I would like to thank the New Zealand Institute for Plant & Food Research Ltd for providing me with helpful information on greenhouse related matters and necessary testing environment for the developed prototype.

I would like to thank my friends: Ryan Thomas, Peter Barlow, Ian Bayliss and Mark Seelye for their help and support, and the occasional beverages which have made my Masters year enjoyable and memorable.

Last but not the least, my gratitude goes to my family for their love, support and encouragement during all my studies. Most of all I would like to thank my mother for all the sacrifices that she has made to allow me to achieve my goal. I thank you from the bottom of my heart

CONTENTS

ACKNOWLEDGMENTS	III
CONTENTS.....	V
LIST OF FIGURES	IX
LIST OF TABLES	XIII
1. INTRODUCTION	1
1.1 GREENHOUSE HISTORY	1
1.2 PROJECT STATEMENTS AND OBJECTIVES	1
1.3 OUTLINE OF THE THESIS	4
2. LITERATURE REVIEW AND MARKET SURVEY	7
2.1 LITERATURE REVIEW	7
2.1.1 <i>Environmental Factors and Plant Growth</i>	7
2.1.2 <i>Wireless Sensor Network (WSN) In Environmental monitoring</i>	11
2.1.3 <i>Wireless Sensor Network (WSN) in Greenhouse management</i>	12
2.1.4 <i>ZigBee Wireless technology applications</i>	14
2.2 MARKET SURVEY	17
2.2.1 <i>Introduction</i>	17
2.2.2 <i>Winland EnviroAlert</i>	17
2.2.3 <i>Watchdog Wireless Crop Monitor</i>	18
2.2.4 <i>Sensaphone alarm Dialer</i>	20
2.2.5 <i>Conclusions</i>	21
3. SENSOR RESEARCH AND EVALUATIONS	23
3.1 INTRODUCTION.....	23
3.2 TEMPERATURE SENSING TECHNOLOGY.....	23
3.2.1 <i>Thermocouples</i>	23
3.2.2 <i>Resistance Temperature Detectors (RTD)</i>	24
3.2.3 <i>Thermistors</i>	25
3.2.4 <i>Integrated Circuit (IC) Temperature sensors</i>	26
3.3 HUMIDITY SENSING TECHNOLOGY	27
3.3.1 <i>Capacitive Humidity Sensors (CHS)</i>	28
3.3.2 <i>Resistive Humidity Sensors (RHS)</i>	29
3.3.3 <i>Thermal Conductivity Humidity Sensors (TCHS)</i>	30
3.4 LIGHT SENSING TECHNOLOGY	31
3.4.1 <i>Photometric Sensors</i>	31
3.4.2 <i>Light Dependent Resistor (LDR)</i>	32
3.4.3 <i>Pyranometers</i>	33
3.4.4 <i>Quantum Sensors</i>	34
3.5 SOIL MOISTURE SENSING TECHNOLOGY	34
3.5.1 <i>Frequency Domain Reflectometry (FDR) Soil Moisture Sensor</i>	35
3.5.2 <i>Time Domain Reflectometry (TDR) Soil Moisture Sensor</i>	36

3.5.3	<i>Gypsum Blocks</i>	36
3.5.4	<i>Neutron Probes</i>	37
3.6	CARBON DIOXIDE (CO ₂) SENSING TECHNOLOGY	38
3.6.1	<i>Solid State Electrochemical (SSE) CO₂ Sensors</i>	38
3.6.2	<i>Non-dispersive Infrared (NDIR) CO₂ Sensors</i>	39
3.7	SENSOR SELECTION	41
3.7.1	<i>Temperature and humidity sensors selection</i>	42
3.7.2	<i>CO₂ Sensor Selection</i>	43
3.7.3	<i>Soil Moisture Sensor and Soil Temperature Sensor Selection</i>	44
3.7.4	<i>Light Sensor Selection</i>	44
3.7.5	<i>Conclusions</i>	45
3.8	SENSOR EXPERIMENTAL SETUP AND RESULTS	45
3.8.1	<i>Introduction</i>	45
3.8.2	<i>SHT75's Characteristics and Construction</i>	45
3.8.3	<i>VG400'S Characteristics and Construction</i>	47
3.8.4	<i>THERM200'S Characteristics and Construction</i>	49
3.8.5	<i>NORP12' Characteristics and Construction</i>	50
3.8.6	<i>TGS4161'S Characteristics and Construction</i>	52
3.9	EXPERIMENT SETUP	59
3.10	EXPERIMENTAL RESULTS AND DISCUSSIONS	60
4.	WIRELESS TECHNOLOGIES	73
4.1	EXISTING WIRELESS TECHNOLOGIES	73
4.1.1	<i>Bluetooth</i>	74
4.1.2	<i>Wi-Fi</i>	75
4.1.3	<i>ZigBee</i>	76
4.1.4	<i>Comparison of ZigBee, Wi-Fi and Bluetooth</i>	77
4.1.5	<i>Conclusions</i>	78
4.2	ZIGBEE WIRELESS COMMUNICATION	79
4.2.1	<i>ZigBee Configuration</i>	79
4.2.2	<i>ZigBee Feasibility</i>	80
5.	SYSTEM INTEGRATION	85
5.1	DESIGN SPECIFICATIONS	85
5.1.1	<i>Central Station Requirements</i>	85
5.1.2	<i>Coordinator Station Requirements</i>	85
5.1.3	<i>Sensor Station Requirements</i>	85
5.1.4	<i>Development Platform</i>	86
5.1.5	<i>Design Constraints</i>	86
5.2	SYSTEM OVERVIEW	86
5.3	OVERALL HARDWARE DESIGN	89
5.3.1	<i>Processing Unit</i>	89
5.3.2	<i>Transceiver Unit</i>	92
5.3.3	<i>Sensor Unit</i>	94
5.3.4	<i>Battery Unit</i>	94
5.3.5	<i>Battery Level Detection Unit</i>	95
5.3.6	<i>Relay Control Unit</i>	98

5.4	PROTOTYPE HARDWARE DESIGN	99
5.4.1	<i>Introduction</i>	99
5.4.2	<i>Hardware Design of the Sensor Station</i>	100
5.4.3	<i>Hardware Design of the Coordinator Station</i>	106
5.4.4	<i>Hardware design of the Central Station</i>	109
5.5	SOFTWARE DESIGN AND ALGORITHMS	110
5.5.1	<i>Introduction</i>	110
5.5.2	<i>Software Design of the Sensor Station</i>	110
5.5.3	<i>Software Design of Coordinator Station</i>	113
5.5.4	<i>Software Design of Central Control Station</i>	115
5.5.5	<i>Data Acquisition Algorithms</i>	116
5.6	PROTOTYPE FINAL DESIGN	121
5.6.1	<i>Sensor Station Final Design</i>	121
5.6.2	<i>Coordinator Station Final Design</i>	122
5.6.3	<i>Central Station Final Design</i>	123
5.7	GRAPHICAL USER INTERFACE (GUI) FINAL DESIGN	124
5.7.1	<i>MANUAL Mode</i>	127
5.7.2	<i>AUTO Mode</i>	128
5.8	DATABASE	129
6.	CONTROL OF OPERATIONS AND SYSTEM EVALUATION.....	131
6.1	INTRODUCTION.....	131
6.2	DEVELOPMENT OF THE PROPOSED CONTROLLER.....	132
6.2.1	<i>Input and output variables of greenhouse system</i>	132
6.2.2	<i>Control Rules</i>	133
6.3	CONTROL ALGORITHM.....	136
6.3.1	<i>Comparison Algorithm</i>	136
6.3.2	<i>Rule Checking Algorithm</i>	137
6.4	CONTROLLER IMPLEMENTATION AND EVALUATION	137
6.5	SYSTEM EVALUATION	139
6.5.1	<i>Measuring Environment</i>	139
6.5.2	<i>Network Throughput and ZigBee Feasibility</i>	140
6.5.3	<i>Power Consumption</i>	141
7.	CONCLUSIONS.....	143
7.1	FUTURE DEVELOPMENTS.....	145
	REFERENCES.....	147
	PUBLICATIONS	155
A.	PROCEEDING AND CONFERENCE PAPER	155
B.	SEMINAR/PRESENTATION	155
	APPENDIX.....	156

List of Figures

Figure 2-1: Winland EnviroAlert.....	18
Figure 2-2: WatchDog Wireless Crop Monitor	19
Figure 2-3: Sensaphone Alarm Dialer	20
Figure 3-1: Thermocouples.....	24
Figure 3-2: Resistance Temperature Detectors.....	25
Figure 3-3: Thermistors	26
Figure 3-4: Integrated Circuit (IC) temperature sensors.....	27
Figure 3-5: Capacitive humidity sensors	28
Figure 3-6: Resistive humidity sensor	29
Figure 3-7: Thermal conductivity humidity sensor	30
Figure 3-8: Photometric Sensors.....	31
Figure 3-9: Light dependent resistors	32
Figure 3-10: Pyranometers.....	33
Figure 3-11: Quantum Sensors	34
Figure 3-12: Frequency Domain Reflectometry (FDR) Soil Moisture Sensors	35
Figure 3-13: Time Domain Reflectometry (TDR) Soil Moisture Sensors	36
Figure 3-14: Gypsum Blocks.....	37
Figure 3-15: Neutron Probes.....	37
Figure 3-16: Electrochemical CO ₂ Sensors	39
Figure 3-17: Non-dispersive Infrared CO ₂ Sensors	40
Figure 3-18: SHT75 connection layout [51].....	46
Figure 3-19: VG400 soil moisture sensor.....	48
Figure 3-20: THERM200 soil temperature sensor.....	49
Figure 3-21: Graph of resistance as function of illumination (left) and spectral respond (right) [54].....	51
Figure 3-22: NOPR12 electrical characteristics [54].....	51
Figure 3-23: NORP12 light dependent resistor	52
Figure 3-24: TGS4161 construction	53
Figure 3-25: TGS4161 application circuit [57]	54

Figure 3-26: Humidity dependency test (left) and sensor sensitivity to various gases (right)	54
Figure 3-27: Sensor calibration overview	55
Figure 3-28: Sensor calibration setup	56
Figure 3-29: Experimental result of TGS4161 sensors.....	58
Figure 3-30: Manufacturer’s plot.....	58
Figure 3-31: Comparison of the experimental results of the SHT75 temperature sensors results and the BWGasProbe temperature sensor	60
Figure 3-32: Comparison of the experimental results for the SHT75 humidity sensors and the BWGasProbe humidity sensor	62
Figure 3-33: Comparison of the experimental results of the NORP12 light sensors and the JT-06LX Lux meter.....	64
Figure 3-34: Comparison of the experimental results of THERM200 soil temperature sensors and Fluke Temperature Meter.....	66
Figure 3-35: Comparison of the experimental results of the VG400 soil moisture sensors and MO750 soil moisture Meter.....	68
Figure 3-36: Comparison of the experimental results of the TGS4161 electrochemical CO ₂ sensors and BWGasProbe CO ₂ sensor	70
Figure 4-1: Comparison of the complexity for each protocol [68].....	78
Figure 4-2: XCTU Configuration tab	79
Figure 4-3: Components for ZigBee testing	81
Figure 4-4: Testing the strength of ZigBee radio signal with respect to the changes in the displacement between coordinator and end device.....	83
Figure 5-1: System overview	88
Figure 5-2: C8051F020 system overview [70]	90
Figure 5-3: Block Diagram of C8051F020 [70]	91
Figure 5-4: XBee 2mW series 2.5.....	92
Figure 5-5: 2.4 GHz XStream-PKG RF modem.....	93
Figure 5-6: Schematic design of the battery detection unit	96
Figure 5-7: Battery detector simulation	98
Figure 5-8: I/O 24 Relay Output Board	99
Figure 5-9: System block diagram.....	100

Figure 5-10: Sensing Unit schematic design	102
Figure 5-11: Sensing Unit PCB design.....	102
Figure 5-12: XBee electrical connection layout	103
Figure 5-13: REG1117 circuit layout	104
Figure 5-14: LM2594M-5V circuit layout.....	105
Figure 5-15: PCB design of the processing unit	105
Figure 5-16: Final design of the Sensor Station.....	106
Figure 5-17: System data flow of the coordinator station.....	107
Figure 5-18: PCB design of the coordinator station	108
Figure 5-19: Final design of the coordinator-station	108
Figure 5-20: Layout of the central station.....	110
Figure 5-21: Software flow diagram of the sensor station.....	111
Figure 5-22: Algorithm for ADC initialization.....	112
Figure 5-23: UART0 and UART1 initialization.....	113
Figure 5-24: Software flow diagram of the coordinator station.	114
Figure 5-25: Software flow diagram of the central station	115
Figure 5-26: Data acquisition algorithm for analog sensors.....	117
Figure 5-27: Algorithm for start-up sequence	118
Figure 5-28: Start-up transmission output signal.....	119
Figure 5-29: Algorithm for sending command to SHT75	119
Figure 5-30: Temperature command ('00000011')	120
Figure 5-31: Relative humidity command ('00000101').....	120
Figure 5-32: Data acquisition algorithm for SHT75.....	121
Figure 5-33: Final design of the sensor station.....	122
Figure 5-34: Final design of the coordinator station.....	123
Figure 5-35: Final design of the central station	124
Figure 5-36: GUI of the developed system.....	125
Figure 5-37: Real-time data plotting.....	126
Figure 5-38: MANUAL Mode.....	128
Figure 5-39: AUTO mode.....	128
Figure 6-1: Tasks in greenhouse environmental control.....	135

Figure 6-2: Comparison Algorithm	136
Figure 6-3: Rule checking Algorithm	137
Figure 6-4: Case 1-simulation result (invoked control rules: 2, 11, 20 and 29)	138
Figure 6-5: Case 2-simulation result (invoked control rules: 9, 17, 19 and 28)	138
Figure 7-1: Experimental setup.....	139

List of Tables

Table 2-1: Design guidelines for building a WSN for environmental monitoring [19]	12
Table 3-1: Sensor technologies comparison	42
Table 3-2: Temperature compensation coefficients [51]	47
Table 3-3: Temperature conversion coefficients [51]	47
Table 3-4: Calibration result	57
Table 3-5: Sensor evaluation and comparison with calibrated instrument (BWGasProbe Temperature Detector)	61
Table 3-6: Sensor evaluation and comparison with calibrated instrument (BWGasProbe humidity detector)	63
Table 3-7: Sensor evaluation and comparison with calibrated instrument (JT-06LX Lux meter)	65
Table 3-8: Sensor evaluation and comparison with calibrated instrument (Fluke Temperature Meter)	67
Table 3-9: Sensor evaluation and comparison with calibrated instrument (MO750 Soil moisture probe)	69
Table 3-10: Sensor evaluation and comparison with calibrated instrument (BWGasProbe CO ₂ Detector)	71
Table 4-1: Wi-Fi Generations [63]	75
Table 4-2: Comparison of ZigBee, Wi-Fi and Bluetooth [67]	77
Table 5-1: Battery technology comparison [74]	95
Table 5-2: Database field description	129
Table 6-1: Control rules	134
Table 7-1: Network Throughput	140
Table 7-2: Current consumption of the Sensor Station	141