DEVELOPMENT OF A NOVEL INTELLIGENT WIRELESS SENSOR ACTOR NETWORK FOR AGRICULTURAL APPLICATIONS

by

Naseer Sabri Salim

(0940210430)

A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

School of Computer and Communication Engineering

UNIVERSITY MALAYSIA PERLIS

2013

UNIVERSITY MALAYSIA PERLIS

DECLARATION OF THESIS

Author's Full Name	:	Naseer Sabri Salim
Date of Birth	:	16. Oct. 1969
Title	:	DEVELOPMENT OF A NOVEL INTELLIGENT WIRELESS SENSOR ACTOR NETWORK FOR AGRICULTURAL APPLICATIONS
Academic Session	:	2010/2011

I, hereby declare that this thesis becomes the property of University Malaysia Perlis (UniMAP and to be place at the university library. This thesis is classified as:

☐	CONFIDENTIAL	(contains confidential information under the Official Secret Act 1972)*
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done)
■	OPEN ACCESS	I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to University Malaysia Perlis to reproduce this thesis in whole or in part of the purpose of research or academic exchange only (except during a period of .... years, if so requested above)

Certified by

....	....
SIGNATURE	SIGNATURE OF SUPERVISOR
0940210430	Prof. Dr. Syed Alwee Aljunid
(PASSPORT No. / NEW IC NO.)	NAME OF SUPERVISOR
Date:..............................	Date: ....

NOTES: * If there is CONFIDENTAL or RESTRICTED, please attach with letter from the organization with period and reasons for confidentially or restriction.

ACKNOWLEDGMENTS

"***It is not possible to prepare anything without the assistance of Allah (SWT); my welfare is only in Allah***"

Firstly and foremost, special thanks should be given to **Allah,** the most gracious, the most merciful, who guides me in every step I take. On the very outset of this report, I would like to extend my sincere and heartfelt obligation to all the people who have helped me in this endeavour. Without their active guidance, help, cooperation and encouragement, I would not have made headway in this research.

I am ineffably indebted to my supervisor, **Prof. Dr. Syed Alwee Aljunid,** for his conscientious guidance and encouragement to accomplish this assignment. I extend my gratitude to **University Malaysia Perlis** for giving me this opportunity. I am extremely thankful to co-supervision of **Prof. Dr. R.A. Badlishah**, **Prof. Ir. Dr. R. Kamaruddin** and **Dr. M.F. Malek** for their valuable support in the completion of this research. I am also grateful to **Eng. Hisham** and the UniMAP greenhouse campus for their advice and assistance.

I also acknowledge with a deep sense of reverence, **my family**, who have always supported me morally. I have extreme gratitude for my brother and his family, for their support and patience.

Last but not least, gratitude goes to all of my friends who directly or indirectly helped me to complete this project. Any omission in this brief acknowledgement should not be taken as a lack of gratitude.

Thank You

Naseer Sabri Salim

1 June 2013

To whom I belong,

To the Spirit of the Martyr

Dr. Safaa Sabri Salim

TABLE OF CONTENTS

CHAPTER FIVE AGRICULTURAL CONTROL SYSTEM BASED ON WIRELESS SENSOR NETWORK: POWER MANAGEMENT PERSPECTIVE

CHAPTER SIX WIRELESS SENSOR NETWORK WAVE PROPAGATION IN VEGETATION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	Analog-To-Digital Converter
AES	Advanced Encryption Standard
AI	Artificial Intelligence
ANN	Artificial Neural Networks
ASEN	Active-Sensor
CCA	Clear Channel Assessment
CFM	Cubic Feet Per Minute
CPU	Central Processing Unit
CSMA/CA	Carrier sense multiple access with collision avoidance
DC	Direct Current
DCI	Dynamic Check-In Interval Technique
DOM	Degree Of Membership
DSP	Digital Signal Processing
DSSS	Direct Sequence Spread Spectrum
ED	Energy Detection
FFD	Full Function Device
FHSS	Frequency Hopped Spread Spectrum.
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Controller
FPGA	Field Programmable Gate Arrays
FSPL	Free Space Path Loss
GA	Genetic Algorithm
GH	Greenhouse

GPS	Global Positioning System
GSM	Global System For Mobile Communication
GUI	Graphical User Interface
HAI	Humanistic Artificial Intelligent
HVAC	Heating, Ventilation And Air Conditioning
ICS	Intelligent Control System
IEEE	Institute Of Electrical And Electronics Engineers
IGCC	Intelligent Greenhouse Climate Controller
ITU-R	ITU-Recommendation (ITUR) model
IWSAN	Intelligent Wireless Sensor Actor Network
IWSAN-GH	Intelligent Wireless Sensor Actor Network for Greenhouse
LCD	Liquid Crystal Display
LDR	Light Dependent Resistor
LEACH	Low Energy Adaptive Clustering Hierarchy
LOS	Line Of Sight
LQI	Link Quality Indication
MAC	Media Access Control
MED	Weissberger Modified Exponential Decay
MEMS	Micro Electro-Mechanical System
MGHSN	Main Greenhouse Sensor Node
Npck	Total of Transmitted Packets
Nrpck	Total of Received Packets
NS2	Network Simulator 2
OMNET++	Objective Modular Network Testbed
OPNET	Optimum Network Performance Simulation Tool

OQPSK	Orthogonal Quadrature Phase-Shift Keying
PAN	Personal Area Network
PC	Personal Computer
PEGASIS	Power-Efficient Gathering in Sensor Information Systems
PHY	Physical layer
PIC	Programmable Integrated Circuit
PID	Proportional-Integral And Derivative Controller
PWM	Pulse Width Modulation
QoS	Quality Of Service
RAI	Rationalistic Artificial Intelligent
RAM	Random Access Memory
RF	Radio Frequency
RFD	Reduced Function Device
RFID	Radio Frequency Identification
RH	Relative Humidity
RSS	Root Sum Squared
RSSI	Received Signal Strength
RTC	Real-Time Clock
SCK	Serial Clock
SMS	And Short Message Services
SoC	System On Chip
SPI	Serial Peripheral Interface
TDMA	Time division multiple access
THFC	Temperature and Humidity Fuzzy Controller
UART	Universal Asynchronous Receiver-Transmitter

USB	Universal Serial Bus
VDD	Voltage Drain Drain
W2S	Worth-To-Send Technique
WN	Wireless Node
WSAN	Wireless Sensor Actor Network
WSN	Wireless Sensor Network

LIST OF SYMBOLES

T_F	Current temperature °C
T_{set}	Desired temperature °C
Error	Input linguistic variable
P_i	The peak value of i^{th} crisp output fuzzy set.
$\mu(x_i)$	The weighted strengths of each output member function.
$C_{-}out$	Crisp output.
T_{in}	The interior air temperature (^oC).
T_{out}	The outdoor temperature (^oC).
UA	The heat transfer coefficient (W K^{-1}).
V	Volume (m3).
Cp	Specific heat of air.
q_{heater}	The heat provided by the greenhouse heater (W).
Si	The intercepted solar radiant energy (W).
Pr	Received signal powers (W) transmitter and λ is the
Pt	Transmitted signal power (W).
Gt	Transmitter antennas gain.
Gr	Receiver antennas gain.
D	Distance (m).
λ	Wavelength (m).
Ploss	Power loss (dB).
ht	Height of transmitter antenna.
hr	Height of receiver antenna.
L_{PE}	Path loss two ray model
r	Fresnel zone radius
L_{veg}	Excess attenuation due to foliage
d_f	Depth of a deciduous tree (m)

A	Empirically calculated constants
B	Empirically calculated constants
C	Empirically calculated constants
L	Foliage loss (dB)
$P_{Tot-loss}$	Total path loss
P_{FSPL}	FSPL (PEMODEL)
$P_{Env-loss}$	vegetation loss
$R_{sensitivity}$	Receiver sensitivity
$\mathrm{Loss}_{\mathrm{thr}}$	Maximum path loss (dB)
$d_{\max}$	Maximum propagation distance
N_{con}	The number of connected nodes with the main node in the
N_{node}	The total number of nodes
I_x	The instantaneous current in the given state spent
T_{on}	The time spent during operation
T_{off}	Time spent where no drawing current in the cycle of state
T_w	Wake up time taken
T_R	Read data from the sensors.
I_R	Current drawn through read data from the sensors
T_{Back}	Back-off Period
T_{CCA}	CCA Period
I_{Back}	The current drawn
I_{CCA}	the current drawn
T_{Packet}	Data Transmission Period
I_{Packet}	The radio transmitting current
I_{Sleep}	The current drawn during the approximate one minute sleep
T_{Sleep}	Sleep period
I_{av}	Average current
I_{phase}	The current drawn by the node during phase operation
t_{on}	The time consumed during a phase of operation.
Wp	The total charge during all phases except CSMA/CA and
Tp	The total charge of channel sensing and transmission phases.
Sop	The W2S software Solution total charge

P_Save	The saving percentage.
$Total_p$	The total charge of all phases except sensors charge.
$Senp$	The total charge consumed by sensors.
H_{op}	Hardware solution of total charge
β	Final fuzzy value
α_{max}	Fuzzy firing strength
P_i	Crisp output duty cycle
$\mu(x_i)$	The weighted strengths of each output member function
T_{in}	The interior air temperature (^oC)
T_{out}	The outdoor temperature (^oC)
UA	The heat transfer coefficient (W K-1)
V	The volume (m3),
C_p	The specific heat of air ($1006 JKg^{-1}K^{-1}$)
S_i	The intercepted solar radiant energy (W),
q_{fog}	The water capacity of the fog
λ	The latent heat of vaporization (2257 J/g)
V_R	The ventilation rate (m^3 (air) s^{-1})
w_{in}	The interior humidity ratios
w_{out}	The exterior humidity ratios
Q_c	The size of heating unit required in Btu/hr
U	heat transfer coefficient in $Btu/hr per\ ft^2$
A	The exposed surface area in square feet
ΔT	The difference between the highest temperature to be
T_i	The highest temperature to be maintained in the greenhouse.
T_o	The minimum outside night temperature.
Len	The length of greenhouse factor.
H_{out}	Outside air humidity.
T_{out}	Outside temperature
$TinF$	The feedback signal of temperature.
$HinF$	The feedback signal of Humidity.

Pembangunan Rangkaian Pengesan Pengaksi Tanpa Wayar Pintar Baharu Untuk Aplikasi Agrikulture

ABSTRAK

Pelaksanaan Rangkaian Pengesan Pengaksi Tanpa Wayar, *Wireless Sensor Actor Network (WSAN),* yang baikmemerlukan skim pemprosesan pintar, penggunaan tenaga yang efektif dan hubungan komunikasi yang boleh dipercayai.Di dalam kajian ini satu pembaharuan tentang Rangkaian Pengesan Pengaksi Tanpa Wayar Pintar, *Intelligent Wireless Sensor Actor Network (IWSAN)*, berasaskan Fuzzy Interference System untuk kawalan iklim di rumah hijau dibentangkan.Dua faktor penting yang memberi kesan terhadap iklim rumah hijau ialah suhu dan kelembapan pada waktu siang dan malam.Penggunaan Fuzzy Interference System serta peralatan yang dibeli dari pasaran dan buatan sendiri digunakan untuk mereka bentuk, simulasi dan melaksanakan IWSAN untuk pengawalan iklim di rumah hijau. Selingan pendaftaran baru yang dinamik, *New Dynamic Check-In Interval technique* (DCI), direka bentuk dan dibangunkan untuk memanjangkan jangka hayat rangkaian nod pengesan.Penggabungan kecerdasan buatan bersama WSN pelakon menunjukkan ciri-ciri yang unggul berbanding dengan sistem kawalan berwayar tradisional dan pemantauan dan pelaksanaan rangkaian tanpa wayar yang mudah.IWSAN membuktikan bahawa ia mempunyai kecekapan pengawalan tugas yang agak tinggi iaitu dalam lingkungan ±0.5 dan ±1 dalam penetapantitik, skala, mobiliti dan kos efektif untuk platform buatan tangan dan keupayaan berubah mengikut bidang geografi. Di samping itu, ia juga mempunyai keupayaan memperhalusi keseluruhan sistem untuk tugas-tugas pertanian yang lain. Ia dilaksanakan sebagai perisian tertanam dalam nod pengesantetapi dijalankan sebagai penyelesaian untuk peralatan yang dicadangkan.Pelaksanaan teknik perisian DCI menawarkan 10 hari maksimum dan 367 hari untuk peralatan yang dicadangkan dengan nilai ambang sebanyak 0.5.ISWAN adalah bukan Permulaan bagi topologi rangkaian isyarat dan ia menyediakan jangka hayat selama 1.24 tahun berasaskan tempoh tidur selama 1 minit untuk setiap nod pengesandan ia dijanakan oleh bateri berkuasa 210mAh. Di dalam rumah hijau, ketidakbolehpercayaan kualiti rangkaian of IWSAN boleh menimbulkan kehilangan paket yang tidak menentu yang boleh dianggap sebagai faktor yang patut diberi perhatian dalam mengawal prestasi sistem kawalan. Kebolehpercayaan sistem ISWSAN dalam rumah hijau adalah tinggi dengan kadar kejayaan minimum penghantaran paket sebanyak 85% dan mencapai prestasi yang stabil dalam 1 minggu operasi. Kestabilan prestasi sistem dapat dikurangkan apabila satu atau lebih nod sensor gagal. Isyarat yang kehilanganarah disebabkan oleh tumbuh-tumbuhan di dalam rumah hijau dijadikan model untuk menentukan ketinggian antena, jarak pemisah dan kedalaman rimbunan dedaun, simulasi dengan skim pengagihan grid bersegi dan diprogramkan untuk membantu simulator WSN yang diketahui umum. Jarak pembahagian maksimum untuk komunikasi yang berkesan dalam bidang tumbuh-tumbuhan ditentukan berdasarkan rangkaian MED model tumbuhan yang mana menunjukkan sambungan sempurna 100% adalah daripada kurang 50m dari kedalaman dedaunan tetapi model ITU menunjukkan sambungan tersebut kurang daripada 88%.

Development of a Novel Intelligent Wireless Sensor Actor Network For Agricultural Applications

ABSTRACT

Deployment of a successful wireless sensor actor network requires intelligent processing schemes, effective power consumption and reliable communication links. A novel intelligent wireless sensor-actor network (IWSAN) based on Fuzzy Inference System for agricultural greenhouse climate control is presented in this research. The two most important mutual effects agricultural greenhouse climate parameters are considered which are the temperature and humidity during diurnal and nocturnal time. Design, simulation and implementation of IWSAN for agricultural greenhouse climate control based on Fuzzy Inference System is outlined both for off the shelf and handmade platforms. The integration of artificial intelligence with WSAN proves superior features in comparison with traditional wired control systems and simple wireless monitoring and acting network. IWSAN proves high efficiency of controlling task of ±0.5 and ±1 tolerance of setting points, scalability, mobility and cost effective of handmade platform, beside flexibility of using the system in various geographical areas besides the capability of tuning the whole system for other agricultural tasks. New Dynamic Check-In Interval technique (DCI) is modelled and developed to prolong the lifetime of network sensor nodes. It is implemented as software embedded in sensor nodes while a proposed hardware solution is conducted. The DCI technique of software implementation offers maximum of 10days while 367days for proposed hardware solution with a threshold value of 0.5. IWSAN of non beacon start network topology provides a 1.24 year lifetime for sensor nodes based 1 minute sleep period and powered by 210mAh battery. In agricultural greenhouse, unreliable link quality of IWSAN may raise unpredictable packet loss that is considered as a factor of more noteworthy effect on the performance of the control system. The system reliability of IWSAN in the greenhouse is high with minimum success rate of packet transmission of 85% and achieves settled performance during one week of operation. The unpredictability in the system performance is minimized when one or more sensor nodes are failed. Vegetation path loss in the greenhouse is modelled as a function of antenna heights, separation distance and various foliage depths, simulated with square grid distribution scheme and programmed to assist nowadays well known WSN simulators. The maximum partitioning distance for reliable communication in vegetation field is determined where network connectivity based on MED vegetation model shows perfect connectivity of 100% of foliage depth less than 50m while ITU model exposes less connectivity of about 88%.

CHAPTER ONE

TOWARD INTELLIGENT WIRELESS SENSOR ACTOR NETWORKS

1.1 Introduction

Nowadays, the agricultural applications are adopting latest new technologies based on large production and multiplicity requirements, also for quality enhancement and market neediness. Hence, advanced technology engineers are acting a crucial role in the improvement of agricultural management fields such as fusion of automatic control, wireless communication and robotic systems that are integrated almost within diverse levels of agricultural productions like cultivation, environment refinement and control, crop harvest, processing, and transportation. The environmental effects and crop quality are encouraging the substantial demands of automatic control paradigms incorporation within the agricultural application fields. Where the objective of these technologies is to continuous monitoring and control of crop environment and growth that targeting the enhancement of productivity and maintain grower requirements.

In precision agriculture, wireless Sensor Actor Networks (WSANs) used to support in field data collection, precise irrigation process, autonomous fertilizer and remote data gathering and analysis (Wang et al. 2006). In greenhouses growers are able to cultivate plants where the environment would otherwise be unfeasible for budding the plants. Therefore, there is an urgent need for new technologies that assist within environment control yielding of optimizing the growth of plants, enhancing the quality and finally increasing the productivity (Bennis et al., 2008; Wang et al. 2006).