

# **Distributed Support for Intelligent Environments**

A thesis submitted for the degree of  
Doctor of Philosophy at The Australian National University

**Teddy Mantoro**



**Department of Computer Science  
The Australian National University  
ACT 0200, Australia  
24 April 2006**



## Declaration

I declare that the research described in this thesis is my own original work during my PhD study under the supervision of the members of advisory panel, i.e. Assoc. Prof. Christopher W. Johnson (chair and main supervisor), Assoc. Prof. Bob Kummerfeld (co-supervisor) and Dr. Ken Taylor (co-supervisor), except where otherwise acknowledged in the text.

Teddy Mantoro  
April 2006

## Publications

### Journals:

1. Mantoro, T., and C. W. Johnson, **Fusing Sensors to Enabling Intelligent Responses in an Active Office**, Submitted to the Journal of Pervasive and Mobile Computing (PMC) by Elsevier, ISSN 1574-1192, December 2004.
2. Mantoro, T., and C. W. Johnson, **Instance-Based Learning Methods for the Best Estimation of Topological User Location in Pervasive Environments**, Submitted to the International Journal of Mobile Computing and Communication Review (MC<sup>2</sup>R), ACM SIGMOBILE, May 2005.
3. Mantoro, T., and C. W. Johnson, **Location Based User Activity in a Pervasive Computing Environment**, Submitted to the International Journal of Pervasive Computing and Communication, ISSN (Online): 1742-738X - ISSN (Paper): 1742-7371, June 2005.

### Conferences:

1. Mantoro, T., and C. W. Johnson, “**Design Space: Enabling ‘Unregistered User’ to Access His Own Content.**” The Seventh International Conference on Ubiquitous Computing (UbiComp'05) Workshop 6 - The Spaces in-between: Seamless vs. Seamless Interactions, Tokyo, Japan, 11-14 September 2005.
2. Mantoro, T., and C. W. Johnson.  **$\eta k$ -Nearest Neighbour algorithm for Estimation of Symbolic User Location in Pervasive Computing Environments.** Accepted to the IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), Taormina, Italy, 13-16 June 2005
3. Mantoro, T., “**Understanding User Activity in Distributed Intelligent Environments**”, Proceeding of the Third IEEE Conference on Computing and Intelligent System (Kommit'04), ISSN-1411-6286, Jakarta, Indonesia, 14-25 August 2004.
4. Mantoro, T., and C. W. Johnson, **DiCPA: Distributed Context Processing Architecture for an Intelligent Environment**, Proceeding of the Western

- Multiconference (WMC): Communication Networks And Distributed Systems Modeling And Simulation Conference (CNDS'04), San Diego, California, 19-22 January 2004.
5. Mantoro, T., and C. W. Johnson, **User Mobility Model in an Active Office**, LNCS 2875, Proceeding of the European Symposium on Ambient Intelligence (EUSAI'03), Eindhoven, The Netherlands, 3-4 November 2003.
  6. Mantoro, T. **User Location and Mobility for Distributed Intelligent Environment**, Adjunct Proceedings, The Fifth International Conference on Ubiquitous Computing (UbiComp'03), Seattle, Washington, USA, 12-15 October 2003.
  7. Mantoro, T., and C. W. Johnson, **“Location History in a Low-cost Context Awareness Environment”**, Workshop on Wearable, Invisible, Context-Aware, Ambient, Pervasive and Ubiquitous Computing, Australian Computer Science Communications, Volume 25, Number 6, Adelaide, Australia, February 2003.

## Acknowledgement

The ANU department of Computer Science has provided me with a great atmosphere for my PhD research for the past three years. It has been a great privilege to be surrounded by so many excellent computer scientists, both theoretical and experimental, particularly under the supervision of Assoc. Prof. Chris Johnson who brought me to the research and community of Smart Internet Technology. Discussion with him has been a time of great privilege for me and seemingly endless enthusiasm and imagination generated new perspectives: his honest critiques came in the form of deep and inevitably challenging questioning. He is my mentor whose approach is defined by the words of Glaser (1995), who said: “*Grab one corner of the problem and go! Start doing it!*”. For such a rich and overwhelming introduction to the world of research I am deeply grateful. I am also grateful for my advisory panel who gave me a lot of invaluable feedback, i.e., Assoc. Prof. Bob Kummerfeld from the University of Sydney and Dr. Ken Taylor from the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

I would like to thank Prof. Matthew James, as the Head of the Department of Engineering (2001-2002), who supported me at the beginning of my study by allowing me to continue working part time as a computer system administrator in the Department while I pursued my studies and for providing me with a fee-waiver scholarship from March 2002-Oct 2002; Prof. Michael Cardew-Hall, as the Head of the Department of Engineering (2002-present) who continuously supported me during my studies and Rob Gresham my supervisor in the Department of Engineering who is very supportive and understanding, he did everything he could to make sure it would be easier for me to do my job.

The community in which I have worked throughout this PhD has been extremely generous, both with knowledge and money, i.e.,

Smart Internet Technology – CRC (<http://www.smartinternet.com.au>), especially Prof. Darrell Williamson as CEO of SIT-CRC, has provided me with financial support for my PhD from January 2003 to June 2005 (2.5 years) and give me the opportunity to participate in a series of SIT-CRC conferences and to publish my work.

Faculty of Engineering and Information Technology (FEIT) – ANU, through the Faculty Grant Research Scheme (FRGS), that provided me with a one year grant for research support (January-December 2004)

ANU National Institute of Engineering and Information Sciences (NIEIS) through its NIEIS travel award has provided me with travel support for a conference (January 2004).

Department of Computer Science, especially Assoc. Prof. Chris Johnson as its Head of Department, and Department of Engineering, both have provided me with varying financial support, especially travel support to conferences.

I also would like to thank several people especially Dr. Eric McCreath and Prof. John Lloyd for valuable discussions in the area of machine learning, several SIT-CRC PhD scholars especially Adam Hudson, Dan Cutting, David Carmichael, Mark Assad, Michael Avery and Derek Corbett from the University of Sydney, with whom I shared experiences when visiting Media Lab–MIT, Max Planck Lab, Saarland University, and

DFKI Lab in Germany, as well as the DTG lab, Cambridge University UK (October-November 2003).

Very special thanks to Andrew Wilkinson who become my partner in discussing technical experiments with several fixed and precise sensors and Kanwar Sidhu, both my colleagues as Computer System Administrators in the Department of Engineering along with my PhD study.

I would like to express my very special thanks to several of my very good friends who voluntarily helped me with English grammar, to John Shelton and Albert Deme for their early help of publishing conference papers, to Else Sugito for my early thesis draft and conferences paper, to Tony Flynn for his invaluable effort in making my thesis more readable, especially with English grammar and usage, punctuation, voice and tone and to Dr. Michelle McCann during my thesis revision.

Finally, I would like to thank my real live team: Media, Mamo and Yutta who sacrificed countless weekend hours for me during this PhD. This work is dedicated to them.

## Glossary of Abbreviations

AmI	Ambient Intelligence
AI	Artificial Intelligent
ANN	Artificial Neural Network
ANU	The Australian National University
AP	Access Point
API	Application Program Interface
ASR	Automatic Speech Recognition
Aura	An Architectural Framework for User Mobility in Ubiquitous Computing Environments. Carnegie Mellon University: “Distraction-free Ubiquitous Computing”
BDA	Bluetooth Device Address
Bluetooth	Short distance wireless cable replacement technology
Bluejacking	The sending of unsolicited message over Bluetooth to Bluetooth-enabled devices, such as mobile phones, PDAs Smart Phones or Laptops
BT	Bluetooth
CAIP	Centre for Advanced Information Processing
CIPE	Crypto Internet Protocol Encapsulation
CLIPS	C Language Integrated Production System
CMU-TMI	Carnegie Mellon University – Triangulation Mapping Interpolation
CS	Computer Science
CSIT	Computer Science and Information Technology
DB	Database
DCS	Department of Computer Science
DHCP	Dynamic Host Configuration Protocol
DHT	Distributed Hash Table
DiCPA	Distributed Context Processing Architecture
DNS	Domain Name Server
DSTO	Defence Science and Technology Organisation
ECIS	European Conference on Information Systems
ECSE	Experimental Computer Science and Engineering
Ekahau	Commercial software which has capability to locate location in wireless (IEEE 802.11) local area network environment.
ESPRIT MUSiC	European information technologies (IT) programme (ESPRIT) Measurement of Usability in Context
FEIT	Faculty of Engineering and Information Technology
GPRS	General Package Radio Service
GPS	Global Position System
GSM	Global System for Mobile Communications
HCI	Human Computer Interaction
HTTP	Hypertext Transfer Protocol
ICMP	Internet Control Message Protocol
ID	Identification
IE	Intelligent Environment

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMAP	Internet Message Access Protocol
IP	Internet Protocol
IrDA	Infra-red Data Association
IROS	Interactive Room (iRoom) Operating System
ISO	International Standardization Organization
JESS	Java Expert System Shell
JINI	An open software architecture that enables Java Dynamic Networking for building distributed systems that are highly adaptive to change.
JSAPI	Java Speech Application Program Interface
JXTA	Stands for Project Juxtapose (more simply, JXTA)
$k$ -NN	$k$ -Nearest Neighbour
LCE	Laboratory for Communications Engineering, Cambridge
LDAP	Lightweight Directory Access Protocol
MAC address	Media Access Control address
MCDM	Multiple Criteria Decision Making
MCRDR	Multiple Classification Ripple Down Rules
MIT	Massachusetts Institute of Technology
MRTG	Multi Router Traffic Grapher
NAPTR	Naming Authority Pointer
NAT	Network Address Translation
Nibble	A Wi-Fi location service that uses Bayesian networks to infer the location of a device.
NIS(YP)	Network Information Service (Yellow Page)
ntop	Network TOP – A network traffic probe that shows the network usage
P2P	Peer-to-Peer
PAN	Personal Area Network
PANU	Personal Access Network User
PARC	Palo Alto Research Center (Xerox)
PCA	Principal Component Analysis
PDA	Personal Digital Assistance
POP3	The PPTP server solution for Linux
PoPToP	The PPTP server solution for Linux
PPTP	Point to Point Tunnelling Protocol
PPPd	Point-to-Point Protocol daemon
PURL	Persistent Unique Resolution Protocol
RADAR	A radio-frequency (RF) based system for locating and tracking users inside buildings.
RBAC	Role-Based Access Control
RFC	Request For Comment
ROADMAP	Role-Oriented Analysis and Design for Multi-Agent Programming; a generic meta-model for describing multi-agent systems



RPC	Remote Procedure Call
RFID	Radio Frequency Identification
RJ45	Registered Jack - Type 45
RPC	Remote Procedure Call
RR	Resources Record
SADT	Structured Analysis and Design Technique
SEA	Smart Environment Agent
SNMP	Simple Network Management Protocol
SOM	Self Organising Map
SPA	Smart Personal Assistant
SpeechCA	Speech Context-Aware
SQL	Select Query Language
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
UPnP	Universal Plug and Play
URI	Unique Resolution Identifier
URL	Unique Resolution Locator
URN	Unique Resolution Name
USB	Universal Serial Bus
UWB	Ultra-Wideband
VNC	Virtual Network Computing
VPN	Virtual Private Network
WAAS	Wide Area Augmentation System
WiFi	Wireless Fidelity, the Alliance to certify interoperability of IEEE 802.11
WiMedia	Brand for high data-rate, wireless multimedia networking applications operating in a WPAN
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WVLAN	Wireless Virtual Local Area Network
XDM	X Display Manager (a graphical windows which manage remote X servers and provide login prompts to remote 'X terminals' or to manage the users X session)
X-terminals	A machine with a network connection, keyboard, mouse and monitor, configured to run the X Windows System to connect to an application server on the network
Zigbee	A combination of HomeRF Lite and the IEEE 802.15.4 specification
$\eta k$ -NN	$\eta k$ -Nearest Neighbour



## Abstract

This thesis describes research on methods for Ubiquitous/Pervasive Computing to better suit users in an Intelligent Environment. The approach is to create and equip a computing environment, such as our Active Office, with technologies that can identify user needs and meet these need in a timely, efficient and unobtrusive manner.

The critical issues in the Intelligent Environment are how to enable transparent, distributed computing to allow continued operation across changing circumstances and how to exploit the changing environment so that it is aware of the context of user location, the collection of nearby people and objects, accessible devices and changes to those objects over time.

Since the Intelligent Environment is an environment with rapid and rich computing processing, the distributed context processing architecture (DiCPA) was developed to manage and respond to rapidly changing aggregation of sensor data. This architecture is a scalable distributed context processing architecture that provides: 1. continued operation across changing circumstances for users, 2. the collection of nearby people and objects, 3. accessible devices and 4. the changes to those objects over time in the environment. The DiCPA approach focuses on how the Intelligent Environment provides context information for user location, user mobility and the user activity model. Users are assumed mobile within the Intelligent Environment and can rapidly change their access to relevant information and the availability of communications and computational resources.

Context-Aware Computing is a new approach in software engineering for Intelligent Environment. It is an approach in the design and construction of a context-aware application that exploits rapid changes in access to relevant information and the availability of communication and computing resources in the mobile computing environment. The goal of Context-Aware Computing is to make user interaction with the computer easier in the smart environment where technology is spread throughout (pervasive), computers are everywhere at the same time (ubiquitous) and technology is embedded (ambient) in the environment. Context-aware applications need not be difficult, tedious or require the acquisition of new skills on the part of the user. They should be safe, easy, simple to use and should enable new functionality without the need to learn new technology. They should provide relevant information and a simple way for a user to manage.

The Intelligent Environment requires a context-aware application to improve its efficiency and to increase productivity and enjoyment for the user. The context awareness mechanism has four fundamental cores i.e. identity (who), activity (what), location (where) and timestamp (when). Based on DiCPA architecture, the model of user location (where), user mobility (where), user activity (what) and Intelligent Environment response (what) were developed. Prototypes were also developed to proof the Context-Aware Computing concept in the Intelligent Environment.

An Intelligent Environment uses the multi-disciplinary area of Context-Aware Computing, which combines technology, computer systems, models and reasoning, social aspects, and user support. A “good quality” project for Context-Aware Computing requires *core content* and provides *iterative evaluation* processes, which has two types of iteration: design and product iteration of the evaluation. The aim of the development of an evaluation program in Context-Aware Computing is to determine what to test, how to

test and the appropriate metrics to use. This work presents the metrics for a good quality project in the Context-Aware Computing area, which is followed by the evaluation of the prototypes of this work.

## Table of Contents

Declaration .....	ii
Acknowledgement.....	iv
Glossary of Abbreviations.....	vi
Abstract .....	x
Table of Contents .....	xii
List of Figures .....	xvi
List of Tables.....	xviii
Chapter 1 INTRODUCTION.....	1
1.1 General Description of an Intelligent Environment .....	1
1.2 Problem Definition.....	3
1.3 Scope of Study .....	3
1.4 Research Aims .....	4
1.5 Methodology .....	4
1.6 Contributions.....	5
1.7 Outline of the Thesis .....	6
Chapter 2 CONTEXT-AWARE COMPUTING BACKGROUND .....	9
2.1 A Brief of Context.....	9
2.2 Context-Aware Computing.....	10
2.3 Ubiquitous Computing and Pervasive Computing.....	11
2.4 Ambient Intelligence .....	12
2.5 Nomadic Computing .....	12
2.6 Sentient Computing.....	13
2.7 Intelligent Environment .....	15
2.8 Prior and Related Work in an Intelligent Environment .....	18
2.9 Active Office: Action Office for Knowledge Worker .....	19
2.10 Related Work in User Mobility.....	20
2.11 Related Work in User Activity.....	22
2.12 Evaluation in the Context-Aware Computing.....	24
2.12.1 Evaluation for experimental in Context Aware Computing .....	27
2.12.2 Evaluation of the Prototype in Context Aware Computing .....	28
2.12.3 Iterative Evaluation of the Design Process and of the Product/Device ..	30
2.12.4 The Impact of User Factors/Characteristics on Context-Aware Computing Design .....	31
2.12.5 Damaged Merchandise and Discount of Engineering.....	31
2.13 Summary .....	32
Chapter 3 DISTRIBUTED ARCHITECTURE FOR INTELLIGENT ENVIRONMENTS.....	35
3.1 Introduction .....	35
3.2 Merino Service Layer Architecture.....	37
3.3 DiPCA: Distributed Context Processing Architecture.....	38
3.3.1 Intelligent Environments Domain .....	40
3.3.1.1 Intelligent Environments Repository .....	41
3.3.1.2 Intelligent Environments Resolution.....	42

3.3.1.3 Resources Manager .....	42
3.3.1.4 Resources Manager Applications.....	43
3.3.1.5 Knowledge-Based Context.....	43
3.3.2 Subject and Environment Role-Based Access Control.....	44
3.4 The Application Scenario.....	45
3.5 Summary .....	47
Chapter 4 LOCATION AWARENESS IN INTELLIGENT ENVIRONMENTS .....	49
4.1 Introduction .....	49
4.2 Location Context Awareness .....	50
4.3 User Location Categories.....	52
4.3.1 Precise User Location .....	53
4.3.2 Proximate User Location.....	53
4.3.3 Predicted User Location (Location Context Aware History).....	56
4.4 User Location Aggregation.....	57
4.5 The Prototype of Location Context Agents Using Speech Recognition.....	58
4.5.1 The Use of Predicted User Location in SpeechCA Commands.....	59
4.5.2 The Finding the Nearest Object Using SpeechCA.....	61
4.6 Location Scalability .....	64
4.7 Discussion .....	66
4.8 Summary .....	67
Chapter 5 INSTANCE-BASED LEARNING METHODS FOR ESTIMATION OF SYMBOLIC USER LOCATION .....	69
5.1 Introduction.....	69
5.2 Machine Learning for Location Awareness.....	71
5.3 Training: The Description of the Learning Process .....	71
5.4 Instance-Based Learning and the k-Nearest Neighbour.....	72
5.5 The $\eta$ k-Nearest Neighbour Algorithm .....	73
5.6 The Algorithm to Evaluate the Training Data Set .....	77
5.7 Discussion .....	78
5.7.1 The Result of the Four Variations of k-Nearest Neighbour Algorithms.....	79
5.7.2 The Boolean MaxMin Algorithm.....	80
5.7.3 Finding the Best k (Maximum Common Value) to Achieve the Maximum Correct Result in the Estimation of Symbolic User Location ...	81
5.8 Evaluation .....	84
5.9 Summary .....	87
Chapter 6 USER MOBILITY MODEL IN AN ACTIVE OFFICE.....	89
6.1 Introduction.....	89
6.2 What is an Active Office?.....	90
6.3 Hotspots and User Mobility .....	91
6.4 The Active Office Area of Study .....	92
6.5 The Pattern of User Mobility Based on History Data.....	94
6.6 Summary .....	98
Chapter 7 USER ACTIVITY BASED ON LOCATION IN A DISTRIBUTED CONTEXT AWARENESS ENVIRONMENT .....	99
7.1 Introduction.....	99
7.2 User Activity Concept.....	100

7.3 Activity-based Processing Model .....	102
7.3.1 Sensors .....	102
7.3.2 Smart Sensor .....	103
7.3.3 Resolver.....	103
7.3.4 Resources Manager .....	103
7.3.5 Presentation .....	103
7.4 The role of Location to User Activity .....	103
7.5 “Having a Guest” Using Mobile Access Point .....	109
7.6 System Monitoring User Activity in an Active Office .....	112
7.7 Summary .....	114
<b>Chapter 8 PROVIDING INTELLIGENT RESPONSES IN A SMART ENVIRONMENT .....</b>	<b>115</b>
8.1 Introduction .....	115
8.2 Providing Responses in Context-Aware Computing .....	116
8.2.1 Context as Predicate Relation .....	118
8.2.2 Presence.....	118
8.2.2.1 Location Awareness .....	119
8.2.2.2 Activity Awareness .....	121
8.2.2.3 Response Awareness.....	121
8.3 Sensor Management .....	123
8.4 Fusion Sensor Database Design .....	123
8.4.1 A Spatio-Temporal Database for Various Fixed and Proximate Sensor’s Data .....	123
8.4.1.1 Mobile Objects Queries.....	124
8.4.1.2 Patition/Division Spatio-Temporal Database.....	124
8.4.1.3 The Design of the Sensor Database .....	125
8.4.2 Generalisation of the Sensor Data Format .....	126
8.5 Response to User Activity.....	129
8.6 Modelling Social Environments: Responding to User Situations.....	130
8.6.1 When There is a Meeting .....	131
8.6.2 The Automatic Login\Logout in an Active Office.....	133
8.6.3 Response When a User has a Phone Call.....	135
8.7 Monitoring of the Sensor’s Activity .....	136
8.8 Summary .....	138
<b>Chapter 9 EVALUATION STRATEGY IN INTELLIGENT ENVIRONMENTS .....</b>	<b>139</b>
9.1 Defining “Good Quality” Project in Context-Aware Computing.....	139
9.1.1 Evaluation Process for Context-Aware Computing.....	139
9.1.2 Core Content for Context-Aware Computing .....	140
9.2 Evaluation Criteria for Context-Aware Computing.....	142
9.3 Metrics Evaluation for Context-Aware Computing.....	143
9.4 Usability Evaluation for Context-Aware Computing .....	148
9.5 The Evaluation of this Work.....	150
9.5.1 Core-Content of this Work.....	150
9.5.2 The Evaluation of Location Scalability.....	151
9.5.3 Advantage and Weakness in the Partition of the Spatio-Temporal Database .....	156

9.10.4 Evaluation of the Sensor's Activity .....	157
9.10.5 Evaluation on the Modelling of the Social Environment.....	157
9.10 Summary .....	159
Chapter 10 CONCLUSIONS AND FUTURE RESEARCH.....	161
10.1 The 'Proof of Concept' .....	161
10.2 The 'Proof of Performance' .....	162
10.3 Future Research.....	163
10.4 Conclusions .....	164
Bibliography.....	166
1. Cited Bibliography (References).....	167
2. Uncited Bibliography.....	178
Index.....	180



## List of Figures

Figure 2.1 The Relationship between Context and Intelligent Environment.....	15
Figure 2.2 Intelligent Environment Characteristics.....	17
Figure 2.3 Research Categories in the Area of User Activity.....	23
Figure 2.4 Iteration of the Design and Product Evaluation.....	30
Figure 3.1 Merino Service Layer Architecture for the IE.....	37
Figure 3.2 Context Layer Architecture.....	39
Figure 3.3 DiCPA: Distributed Context Processing Architecture for an IE.....	40
Figure 3.4 Block Diagram of Role-based Transactions for a Distributed Intelligent Environment.....	44
Figure 3.5 Making Connection with an Unfamiliar Intelligent Environment Domain....	45
Figure 4.1 Example of Hierarchical Location Structure: Rooms in a Cluster of Buildings.....	51
Figure 4.2 The Example of Sensors to Detect Precise Location and Proximate Location.....	52
Figure 4.3 Device Measurement of WiFi APs' Signal Strengths.....	54
Figure 4.4 An example of signal activity from wireless sensors within 7 hours.....	56
Figure 4.5 Aggregate users' locations in an Active Office.....	58
Figure 4.6 Block Diagram Speech Context Aware Prototype.....	59
Figure 5.1 The Changing of the Signal Strength.....	74
Figure 5.2 The Minimum of the k-Nearest Neighbour.....	79
Figure 5.3 The Minimum of the $\eta k$ -Nearest Neighbour.....	79
Figure 5.4 The Maximum Number of Locations from the Nearest Ten of the k-Nearest Neighbour.....	80
Figure 5.5 The Maximum Number of Locations from the Nearest Ten of the $\eta k$ -Nearest Neighbour.....	80
Figure 5.6 The Arbitrary Six Points at Which Measurements Were Taken in a Building.....	82
Figure 5.7 Fluctuation of the Most Common Value of $k=1, 2, 3, \dots, 11$ , Where Each Process for 14 Hours on the Estimation of User Location Using WiFi Signal Strength and Signal Quality.....	83
Figure 5.8 The Average Estimation of User Location Using the Most Common Value of $k=1, 2, 3, \dots, 11$ from Both, the Noise Zone and the Stable Zone.....	83
Figure 5.9 Normalisation of Signal Strength and Signal Quality Data Using Mean and Standard Deviation of Signal Strength and Signal Quality in the Room Scale.....	84
Figure 6.1 The User's Possible Movements in the WiFi's Hotspot Areas.....	91
Figure 6.2 Three Building at Faculty of Engineering and Information Technology as an Area of Study of the Active Office.....	92
Figure 6.3 The Pattern of User Mobility Based on the Number of Rooms Visited and Time Spent (in Seconds).....	95
Figure 6.4 Pattern of User Mobility using Direct Graph in the Active Office.....	97
Figure 7.1 User Activity Processing Model.....	102
Figure 7.2 Example of tree structure of user activity.....	105
Figure 7.3 Access Zone in the Resources Room.....	107

Figure 7.4 The Possible Connectivities of a Mobile Access Point to File Server.....	111
Figure 7.5 A Sample Snapshot of a User's Current Location and a User's Activity Recognition Window .....	113
Figure 8.1 Triangle Resolutions: User Identification, Device Identification and MAC Address.....	120
Figure 8.2 Smart Sensor Processing From Fixed and Proximate Sensors Server .....	127
Figure 8.3 Fixed Sensor Server. ....	128
Figure 8.4 Proximate Sensor Server .....	129
Figure 8.5 Sensor Server for the Active Office .....	131
Figure 8.6 <i>ir</i> Media Player Monitoring Status.....	136
Figure 8.7 Monitoring the fixed and proximate sensors' activity graph. ....	137
Figure 9.1 Software Quality Metrics of Boehm Model, McCall's Model and ISO/ IEC 9126 .....	145

## List of Tables

Table 4.1	Example of Room Database.....	51
Table 4.2	Example of Signal Strengths and Signal Qualities from Six WiFi Access Points.....	55
Table 4.3	Example of Location History Database .....	57
Table 5.1	The k-Nearest Neighbour Algorithm for Estimating a User Location Valued Function Using WiFi's Signal Strength and Signal Quality.....	75
Table 5.2	$\eta k$ -Nearest Neighbour Algorithm: The Algorithm to Estimate a User Location Valued Function Using Normalisation ( $\eta$ ) of the WiFi's Signal Strength and Signal Quality .....	76
Table 5.3	The Boolean MaxMin Algorithm to Determine the Quality of the Training Data Set.....	78
Table 5.4	The Comparative Results of the Four Algorithms for 14 Hours Measurements .....	79
Table 5.5	Example of the Maximum of the WiFi's Signal Strength and Signal.....	81
Table 5.6	The Boolean MaxiMin and MiniMax for the Analysis of WiFi's Signal Strength and Signal Quality .....	81
Table 5.7	Example of the Minimum of the Normalised WiFi's Signal Strength and Signal Quality.....	81
Table 5.8	The Boolean MaxiMin and MiniMax for Analysis of the Normalised WiFi's Signal Strength and Signal Quality .....	81
Table 5.9	The Difference (in dBm) Between Maximum Signal Strength in the Morning (08.50).....	85
Table 5.10	The Difference (in dBm) Between Minimum Signal Strength in the Early Evening (19.00).....	85
Table 6.1	History Data Summary of a User's Mobility for One Day .....	94
Table 6.2	User Mobility Sample Data with Activities in One Day.....	96
Table 7.1	Resume of a staff member on a Certain Day Activities.....	106
Table 7.2	Possible Activity Based on Location (Room) in the University Organisation .....	108
Table 7.3	SPA Client Location Category.....	112
Table 8.1	Summary of the Context-Aware Concept.....	122
Table 8.2	Sensor Data and the Interpretations .....	128
Table 9.1	Software Quality Metrics of Boehm Model and McCall Model.....	146
Table 9.2	Software Product Quality Metrics for Context-Aware Computing .....	147
Table 9.3	The Evaluation of the Social/Computer Technology Aspects and User/Environment Dimensions of this Study in Context-Aware Computing.....	152