ABSTRACT

Middleware is a software that separates the hardware and application layer. In Radio Frequency Identification (RFID) environment, middleware faces many challenges in adaptation to multi readers, multi applications, and changes in readers or applications environment. Different readers may cause RFID middleware not to work properly during runtime if previous configuration does not match with the current one. Some changes such as adding a new reader or applications could also disturb the operation of RFID middleware. Hence adaptive components in RFID middleware could provide a solution for the problem. This research proposes an RFID middleware architecture that provides two adaptive components; reader detector and message adapter. Reader detector allows the middleware to communicate with multi readers. One unique feature of the reader detector is its ability to autodetect the presence of multi readers and the changes occurred in the reader environment. Reader detector gives response as a reaction to the changes to ensure RFID middleware performs correctly in runtime. Message adapter detects new application, resolves each application name to its IP address, and checks its activity in distributed network. To validate the proposed adaptive middleware, the architecture and adaptive components are tested using various RFID readers with short, medium and long range signal readers. Furthermore, the functionality and performance of the message adapter are tested on several applications developed such as the Operation Theater Tracking (OTT), Integrated Facilities and Asset Maintenance Management System (IFAMMS), and E-Point of Sale (ePOS) that utilize different manufacturer and specification of RFID readers. The results show that during runtime, the proposed architecture has succesfully detected different readers and various applications automatically and are able to adapt to changing situation in the reader or application environment.

ABSTRAK

Perisian tengah adalah perisian yang memisahkan lapisan perkakasan daripada aplikasi. Di persekitaran *Radio Frequency Identification* (RFID), perisian tengah menghadapi kekangan untuk disesuaikan dengan pelbagai pembaca dan aplikasi serta perubahan pada persekitarannya. Pembaca yang berbeza menyebabkan perisian tengah RFID tidak berfungsi dengan betul pada masa larian jika konfigurasi awal tidak sepadan dengan yang terkini. Beberapa perubahan seperti penambahan pembaca atau aplikasi baru juga menganggu operasi perisian tengah RFID. Komponen mudah suai yang merupakan sebahagian daripada perisian tengah RFID boleh membantu menyelesaikan masalah. Kajian ini mencadangkan suatu senibina perisian tengah RFID yang menyediakan dua komponen mudah suai; iaitu pengesan pembaca dan penyesuai mesej. Pengesan pembaca membenarkan perisian tengah berkomunikasi dengan pelbagai pembaca. Salah satu ciri unik daripada pengesan pembaca adalah kemampuannya untuk mengesan secara automatik pelbagai pembaca dan perubahan yang terjadi pada persekitaran pembaca. Pengesan pembaca memberikan maklumbalas sebagai tindakan kepada perubahan yang berlaku untuk memastikan perisian tengah RFID berfungsi dengan betul pada masa larian. Penyesuai mesej pula mengesan aplikasi baru, menentukan setiap nama aplikasi dengan alamat IP, dan menyemak aktivitinya dalam rangkaian teragih. Untuk mengesahkan senibina perisian tengah mudah suai yang dicadangkan, ujikaji dijalankan dengan menggunakan pelbagai jenis pembaca RFID seperti pembaca jarak dekat, sederhana dan jauh. Seterusnya fungsi dan prestasi penyesuai mesej telah diuji ke atas beberapa aplikasi seperti Penjejakan Teater Operasi (PTO), Sistem Kemudahan Berintergrasi dan Pengurusan Penyelenggaraan Aset (SKBPPA), dan Terminal Jualan secara Elektronik (TJE) yang menggunakan pembaca RFID daripada pengilang dan spesifikasi yang berbeza. Hasil ujikaji menunjukkan bahawa semasa larian, senibina yang dicadangkan telah berjaya mengesan pelbagai pembaca dan aplikasi secara automatik dan mampu menyesuaikan perubahan situasi dalam persekitaran pembaca serta aplikasinya.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		**ii**
	DEDICATION		**iii**
	ACKNOWLEDGEMENT		**iv**
	ABSTRACT		**v**
	ABSTRAK		**vi**
	TABLE OF CONTENTS		**vii**
	LIST OF TABLES		**xi**
	LIST OF FIGURES		**xii**
	LIST OF ABBREVIATIONS		**xv**
	LIST OF SYMBOLS		**xvi**
	LIST OF APPENDICES		**xvii**
1	**INTRODUCTION**		**1**
	1.1	Problem Background	1
	1.2	Problem Statements	2
	1.3	Objectives of the Research	3
	1.4	Scope of the Research	3
	1.5	Significance of the Research	4
	1.6	Thesis Outline	5
2	**LITERATURE REVIEW**		**6**
	2.1	Middleware Technologies	7
	2.2	RFID Middleware Architecture in the Previous Research	9

2.3 Commercial RFID Middleware Architecture 11
2.4 Comparative Analysis 12
2.5 Summary 15

3 RESEARCH METHODOLOGY 16
3.1 Operational Framework 16
3.2 Investigating Existing RFID Middleware 18
3.3 Analysis of Standard and Adaptive Architecture for RFID Middleware 18
3.4 Designing Adaptive RFID Middleware Architecture 18
3.4.1 Designing and Developing Mesasge Adapter and Application's Knowledge-based 19
3.4.2 Designing and Developing Reader Detector and Reader's Knowledge-based 19
3.4.3 Designing and Developing Filtering, Rule and Mapping of Reader-Application 20
3.4.4 Designing and Developing Messaging and Repository 20
3.5 Testing, Evaluating and Validating The Proposed Architecture 20

4 ANALYSIS AND DESIGN OF ADAPTIVE ARCHITECTURE FOR RFID MIDDLEWARE 21
4.1 Analysis of Adaptive Architecture in RFID Middleware 21
4.2 Design of Adaptive Architecture in RFID Middleware 23
4.3 Reader Detector Component 26
4.3.1 Reader Parameters 30
4.3.2 Capturing Tag ID 30
4.3.2.1 Various RFID Tag Parameters 32
4.3.3 Reader Detector Framework 36
4.3.4 Algorithm and Flowchart 37
4.3.5 Reader Detector Class Diagram 41
4.4 Reader's Knowledge-Based 41
4.5 Filtering Component 44
4.5.1 Modifying Filtering Algorithm 45
4.6 Rule and Mapping of Reader-Application 47

4.7 Messaging and Message Adapter Component 48
4.7.1 Messaging and Message Adapter Component Framework 52
4.7.2 Message Adapter Component 54
4.7.3 Sender component 58
4.8 Monitoring Component 60
4.9 Repository Component 62
4.10 Development of Multi Applications for Testing 62
4.10.1 Operation Theater Tracking 62
4.10.1.1 Problem Background and Objective of OTT 62
4.10.2 E-Point Of Sales (ePOS) System 65
4.10.2.1 Problem Background and Objective of ePOS 65
4.10.3 Integrated Facilities and Asset Maintenance Management System (IFAMMS) 67
4.10.3.1 Problem Background and Objective of IFAMMS 67
4.11 Summary 68

5 IMPLEMENTATION AND TESTING OF ADAPTIVE ARCHITECTURE FOR RFID MIDDLEWARE 69
5.1 Testing and Validation of Reader Detector 69
5.1.1 Testing Scenarios of Reader Detector 71
5.1.2 Testing of Capturing Various Tags 77
5.1.3 Discussion 78
5.2 Testing of Filtering Component 81
5.3 Testing and Validation of Messaging and Message Adapter Component 82
5.3.1 Testing of Automated Application's Registration and Updating Status 83
5.3.1.1 Automated Registration 84
5.3.1.2 Automated Updating Status 85
5.3.1.3 Automated Reporting Effect 86
5.3.2 Testing Scenario 1: One Application to Multi Readers 94

5.3.3 Testing Scenario 2: Multi Applications to Multi Readers 98
5.3.4 Discussion 103
5.4 Summary 105

6 CONCLUSION AND FUTURE WORK 107
6.1 Achievement of Objectives 107
6.2 Research Contribution 109
6.3 Future Work 110

REFERENCES 113

APPENDICES 120
A Publications 120
B Paper1: Comparative Analysis on Adaptive Features for RFID Middleware 121
C Paper2: Multi Readers Detection in Adaptive RFID Middleware 126
D Paper3: Proving Adaptive Characteristics of Reader Adapter for Adaptive RFID Middleware Architecture 132

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Comparison of CORBA, RMI AND DCOM	8
2.2	Comparison of Commercial RFID Middleware Funtionalities	11
2.3	Detail Comparison of The Previous Architectures	13
2.4	Detail Features of The Proposed Architectures	14
4.1	Comparison of the Architectures for RFID Middleware	22
4.2	Reader Parameters	31
4.3	Four Various Tag Parameters	36
4.4	Application Attributes Table:Data of Application's Attributes	57
4.5	Aplication's Knowledge-Based Table:Registering and Monitoring of Application	57
5.1	Results of scenario 1 to 6	75
5.2	Comparison of HTTP and RMI Message Sending	93
5.3	Results of Scenario 1 Summary	97

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
3.1	Flow of Operational Framework	17
4.1	Features Selection	23
4.2	Adaptive RFID Middleware Architecture	24
4.3	Adaptation Scope	29
4.4	Mifare 700 Tag Format	32
4.5	Mifare Tag Data in RS232 Format	32
4.6	GP90 Tag Data in RS232 Format	33
4.7	GP90 Example Tag Data	33
4.8	EVO Mobile Tag Format	34
4.9	UHF2200 Tag Format	35
4.10	Reader Detector Frameworks	37
4.11	Flowchart of Reader Detector	39
4.12	Flowchart of Obtaining Tag ID from Diverse Tags	40
4.13	Architecture of Classes	42
4.14	Look up Table Diagram	43
4.15	The Flow of Filtering Process	45
4.16	Relational Table of Mapping Reader-Application	47
4.17	Tag Data Processing in Filtering	48
4.18	Adaptation Scopes of Messaging Component	50
4.19	Messaging and Message Adapter Component Framework	53
4.20	Message Adapter Framework	54
4.21	Message Adapter Use Case	56
4.22	Application Look up Table	58
4.23	Message Adapter Flow Chart	59
4.24	Sender Component Framework	59

4.25	Flowchart of Sending Message	61
4.26	Capture of OTT Interface	65
4.27	Capture of ePOS interface	66
4.28	Capture of IFAMMS Interface	67
5.1	Communication Model	70
5.2	Result of Scenario 1-Port Detection	71
5.3	Result of Scenario 2-Reader Detection	72
5.4	Additional of New Serial Port	72
5.5	Result of Scenario 3-New Port Detection	73
5.6	Result of Scenario 4-New Reader Detection	74
5.7	Result of Scenario 5-Reader Change Detection	75
5.8	Result of Scenario 6	76
5.9	Chart of Testing Results	77
5.10	Mifare 700 Tag Captured	78
5.11	GP90 Tag Captured	78
5.12	UHF2200 Tag Captured	79
5.13	EVO Mobile Tag Captured	79
5.14	Redundat Tag Occured	81
5.15	Non Redundant Tag Occured	82
5.16	Client-Server Communication	83
5.17	Result of Application Registration	85
5.18	Result of Application Updating Status	86
5.19	HTTP Client without Auto Status Reporting	87
5.20	Chart of HTTP Client Testing without Auto Status Reporting	88
5.21	HTTP Client with Auto Status Reporting	88
5.22	Chart of HTTP Client Testing with Auto Status Reporting	89
5.23	Testing Diagram of RMI Client without Auto Status Reporting	90
5.24	Chart of RMI Client without Auto Status Reporting	91
5.25	Testing Diagram of RMI Client with Auto Status Reporting	91
5.26	Chart of RMI Client witht Auto Status Reporting	92
5.27	One Apllication to Multi Readers	95
5.28	Mapping of Four Readers to OTT Application	95
5.29	Testing Result of Scenario 1:OTT Has Multi Readers	96
5.30	Patient Captured in Holding Bay In	97
5.31	Data Transaction in OTT Table	98
5.32	Scenario 1 Testing	99
5.33	Result of All Readers Detection	100
5.34	Mapping of All Readers to Multi Applications	100
5.35	Reading and Sending Tag ID from COM1 to ePOS	101

5.36	Reading and Sending Tag ID from COM2 to IFAMMS	102
5.37	Reading and Sending Tag ID from COM11 to IFAMMS	102
5.38	Reading and Sending Tag ID from COM3,4,5 to OTT	103
6.1	Multi Platforms Supported in Enhanced Adaptive Architecture	111
6.2	Ethernet Communication Supported in Reader Detector	112

LIST OF ABBREVIATIONS

RFID	-	Radio Frequency Identification
OMG	-	Object Management Group
CORBA	-	Common Object Request Broker Architecturek
RMI	-	Remote Method Invocation
DCOM	-	Distributed Component Object Model
ORB	-	Object Request Broker
JRMP	-	Java Remote Method Protocol
IDL	-	Interface Definition Language
DII	-	Dynamic Invocation Interface
DSI	-	Dynamic Skeleton Interface
GIOP	-	General Inter-ORB Protocol
IIOP	-	Internet Inter-ORB Protocol
OTT	-	Operation Theatre Tracking
ePOS	-	E-Point of Sales
IFAMMS	-	Integrated Facilities and Asset Maintenance Management System
HTTP	-	Hyper Text Markup Language
ALE-API	-	Application Level Event-Application Programming Interface
XML	-	Extensible Markup Language
	-	

LIST OF SYMBOLS

t0	-	Sending Time
t1	-	Receiving Time
tm	-	Messaging Time

LIST OF APPENDICES

APPENDIX NO.	TITLE	PAGE
A	Publications	120
B	Paper1: Comparative Analysis on Adaptive Features for RFID Middleware	121
C	Paper2: Multi Readers Detection in Adaptive RFID Middleware	126
D	Paper3: Proving Adaptive Characteristics of Reader Adapter for Adaptive RFID Middleware Architecture	132

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Radio Frequency Identification (RFID) middleware faces many challenges regarding its capability to adapt to changes and differences in RFID reader or application environment. Adaptive characteristics of RFID Middleware respond the different situation by modifying its behavior[1] and make the system flexible to any changes. In RFID reader environment, previous researchers have identified the problems and proposed adaptive architectures for RFID middleware. Bo *et al.*[2] proposed the architecture that could deal with some problems in reader environment such as different readers, communication model and connectivity, and the changes of RFID hardware. Furthermore, the architecture also provides a service to integrate the RFID middleware with the backend enterprise applications. Cheong *et al.*[3] proposed the RFID middleware architecture which supports various types of reader including its tag read protocols and allows user to configure, monitor and control all of connected RFID readers. In addition the architecture supports Application Level Event (ALE) compliant for business application using Real-time Business Process Triggering System (RBTS). Other researchers Hoag and Thompson[4] developed the RFID middleware architecture using agent that allows to control the reader to set on, off, and request the message status. Meanwhile the agent also converts each message to XML format and send to the intended applications.

The previous architectures have already overcome the problems stated in RFID reader and applications environment, however the architecture that has capability to detect and identify connected readers and applications automatically was not yet proposed. This architecture enables user just plugs in the reader and application and the middleware will auto-detect and identify. The architecture also has the standard functionalities/features to monitor, filter, save the data in the repository, and deliver the message to the application. Therefore this research is done to investigate the adaptive architecture of RFID Middleware related to multi readers and applications environment; propose the adaptive architecture of RFID Middleware that can detect various readers and deal with the changes occurred in reader's environment, adapt to multi applications; and test and validate the proposed adaptive architecture with the several RFID applications.

1.2 Problem Statements

This study aims at designing an adaptive architecture middleware that is flexible and adaptable to multi readers and multi applications environment. Therefore, in order to achieve this goal, the following questions have to be satisfied:

(i) What are the parameters that could be potentially affecting the compatibility of the multi readers and multi applications environment particularly in automated reader and application detection?

(ii) How to design the adaptive architecture for RFID middleware that could identify multi readers and multi applications automatically and deal with the changes in both environments?

(iii) How to test and validate the adaptability of the proposed middleware architecture with application to RFID case study?

1.3 Objectives of the Research

The objectives of this research are as follows:

(i) To investigate architecture of existing middleware technology, RFID middleware and adaptive funtionalities in RFID middleware.

(ii) To propose adaptive architecture for RFID Middleware that conforms to multi readers and multi applications using Reader Detector and Message Adapter component.

(iii) To test and validate the adaptability of the developed middleware architecture with several different RFID readers and RFID applications in distributed environment.

1.4 Scope of the Research

The Scopes of the research are as follows:

(i) Serial communication is used for automated reader detection.

(ii) Java technology is utilized for developing adaptive RFID middleware.

(iii) Four RFID readers which have different specifications, frequency, and reading mode (Mifare700, GP90, UHF2200, and EVO Mobile) and three applications involving web and non web application are used to test the proposed adaptive architecture.

1.5 Significance of the Research

The significance of the research are as follows:

(i) Adaptive architecture of RFID middleware that is able to deal with multi readers and multi applications environment.
Differences and changes in RFID environment cause middleware does not work properly without modifies the previous configuration to adapt to current situation. The capability to adjust the configuration automatically needs adaptive architecture of RFID middleware especially to conform to multi readers and applications environment. The proposed adaptive architecture enables user just connects the readers and applications then the middleware detects and identifies them automatically. In addition, the changes or disturbances occurred in reader and application environment can be detected and middleware modifies the configuration/behavior as a reaction in order to conform to such situation so that middleware can work properly using new configuration.

(ii) Reader Detector component with capability to detect and identify multi readers and conform to different situation happened in reader environment such as adding, unplugging, and changing the reader.
To maintain the communication with RFID reader, the middleware should have the component that deals with multi readers with different specification and the event changed in reader environment. Different specification involves the working frequency (low, high, and ultra high frequency), reading mode, read range, tag data format, command, response, and serial parameter aspect particularly in baud rates. Some events in reader environment consist of adding, unplugging/disconnecting, and changing the reader. The Reader Detector component has automated multi readers detection method that detects and identifies the readers connected to middleware, resolves tag ID from various tag data formats, detects the changes, and modifies the configuration to deal with current state.

(iii) Message Adapter component which detects new application server and monitors its aliveness.
To deal with multi applications, middleware has a component namely Message Adapter. The different factors existed in application environment

embrace application ID and name, type of application involving web and non web application, IP address, URL address (web application) and status of aliveness. Message Adapter has several methods comprising automated application detection, automated updating status, and sending data format for web and non web application using HTTP client and RMI client. Automated application detection has functionality to detect all applications connected to middleware and application attributes including ID, name, IP and URL address, and type of application (web or non web) while automated updating status method reports aliveness of application. Sending data format utilizes HTTP client for web application or RMI client for non web application to send the tag data to intended application.

1.6 Thesis Outline

This thesis is divided into six chapters. Chapter 1 presents an introduction describing problem background, problem statement, the objective, scope, thesis outline and the significance of the research. Chapter 2 presents a literature review on related issues of adaptive RFID Middleware. Chapter 3 explains the research methodology of the research. Chapter 4 discusses analysis and design of adaptive architecture for RFID middleware. Implementation and testing of adaptive architecture is described in chapter 5 and chapter 6 presents the conclusion and future work of the research.