

**EMBEDDED TCP/IP-BASED DC MOTOR CONTROLLED VIA LOCAL  
AREA NETWORK**

**NGO CHEE GUAN**

**MAY 2008**

“I hereby declared that I have read through this report and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Power Electronic and Drive)”

Signature : .....  
Supervisor’s Name : .....  
Date : .....

EMBEDDED TCP/IP-BASED DC MOTOR CONTROLLED VIA  
LOCAL AREA NETWORK

NGO CHEE GUAN

This Report Is Submitted In Partial Fulfilment of Requirement for the Degree of  
Bachelor in Electrical Engineering (Power Electronic and Drive)

Fakulti Kejuruteraan Elektrik  
Universiti Teknikal Malaysia Melaka

May 2008

“I hereby declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references.”

Signature : .....  
Name : .....  
Date : .....

To beloved father and mother

## **ACKNOWLEDGEMENT**

I would like to take this opportunity to thank Professor Madya Doktor Zulkifilie Bin Ibrahim, supervisor of Projek Sarjana Muda 1 and Projek Sarjana Muda 2 for his kind and endeavour support along the journey of doing the Projek Sarjana Muda 1 and Projek Sarjana Muda 2. Professor Madya Doktor Zulkifilie Bin Ibrahim has demonstrated a highly professional character in the process of consultation and assistance that not only improve my knowledge on embedded controller and programming skill, but also upgraded my presentation and technical report writing skills. Not to forget to all others that participated throughout the entire development of the project and to those who had given inputs and guidance of this project.

## ABSTRACT

The project title is embedded TCP/IP-based DC motor controlled via local area network. The objective is to design and develops a proportional integral (PI) speed controlled DC motor via TCP/IP network by using rabbit microprocessor and its core module model RCM 3200 and RCM 2100. User Datagram Protocol (UDP) is implemented in this project to link between master controller and slave controller through network. User stay in a location will control the direction and speed of the DC motor at remote site by adjusting the user control system. The user control system is attach to the master controller which PI algorithm is apply to provide a feedback control through networking. The PI algorithm will compare the reference speed from user control system and feedback speed from slave controller and calculate the require duty cycle of PWM signal needed to supply to DC motor driver. The calculated value will be sent to slave controller as datagram by using UDP. After the slave controller gets the value, it will generate appropriate PWM signal for DC motor driver to drive the DC motor at desired speed. Beside that, the slave controller will read the feedback speed from speed sensor and pass the feedback speed to master controller for further processing. The aim of this project is to design a working laboratory scale prototype that can remotely control a DC motor via local area network by using embedded TCP/IP controller.

To implement this project, rabbit core module 3200 and its prototype board, rabbit core module 2100 and its prototype board, Ethernet switches, L298 dual full bridge driver, DC motor, speed sensor, rectifier and analogue to digital converter is implemented. For software development, Dynamic C is implemented to writing, compiling, debugging, linking and loading the programme to rabbit core module. Finally, hardware and software is integrated for functional test to ensure that the prototype is work as expected.

## ABSTRAK

Tajuk projek ini adalah kawalan motor arus terus melalui rangkaian kawasan setempat (LAN) berasaskan sistem TCP/IP terbenam. Objektif projek ini adalah mereka dan membangunkan pengawal proportional integral (PI) kelajuan motor arus terus dengan menggunakan mikropemproses rabbit dan model modul terasnya RCM 3200 dan RCM 2100. Protokol Pengguna Datagram (UDP) digunakan dalam projek ini untuk menghubungkan antara pengawal tuan dan pengawal hamba melalui jaringan. Pengguna yang berada pada lokasi tertentu boleh mengawal arah putaran dan kelajuan motor arus terus di tempat lain dengan mengawal system pengawal pengguna. System pengawal pengguna adalah disambung kepada pengawal tuan dimana algoritma PI diaplikasikan untuk memberi kawalan suap negative melalui jaringan. Algoritma PI akan membandingkan kelajuan rujukan dari system kawalan pengguna and kelajuan suap balik dari pengawal hamba dan mengira putaran duti pengubahsuaian lebar denyut (PWM) yang diperlu untuk dibekal kepada pemandu motor arus terus. Nilai yang dikira akan dihantar ke pengawal hamba dengan menggunakan UDP. Selepas pengawal hamba mendapat nilai tersebut, ia akan menjanakan signal PWM yang sesuai kepada pemandu motor arus terus untuk memandu motor arus terus pada kelajuan ditetapkan. Selain itu, pengawal hamba akan membaca kelajuan suap balik dari sensor kelajuan dan menghantar bacaan tersebut kepada pengawal tuan untuk pemprosesan selanjutnya. Matlamat projek ini adalah mereka cipta sebuah prototaip berskala makmal bekerja yang boleh mengawal motor arus terus secara jarak jauh melalui rangkaian kawasan tempatan dengan menggunakan pengawal TCP/IP terbenam.

Untuk melaksanakan projek ini, modul teras rabbit 3200 dan papan prototaipnya, modul teras rabbit 2100 dan papan prototaipnya, suis Ethernet, L298, motor arus terus, sensor kelajuan, rectifier and ADC akan digunakan. Untuk pembangunan perisian, Dynamic C akan digunakan untuk menulis, mengkompil, menghubungkan dan memasukkan program pada modul teras rabbit. Akhirnya,



perkakasan dan perisian akan diintegrasikan untuk ujian kefungsian untuk memastikan prototaip yang dihasilkan bekerja seperti yang diharapkan.

## CONTENTS

| <b>CHAPTER</b> | <b>TOPIC</b>                 | <b>PAGE</b>  |
|----------------|------------------------------|--------------|
|                | <b>DECLARATION</b>           | <b>ii</b>    |
|                | <b>DEDICATION</b>            | <b>iii</b>   |
|                | <b>ACKNOWLEDGEMENT</b>       | <b>iv</b>    |
|                | <b>ABSTRACT</b>              | <b>v</b>     |
|                | <b>ABSTRAK</b>               | <b>vi</b>    |
|                | <b>CONTENTS</b>              | <b>viii</b>  |
|                | <b>LIST OF FIGURES</b>       | <b>xii</b>   |
|                | <b>LIST OF TABLES</b>        | <b>xvi</b>   |
|                | <b>LIST OF ABBREVIATIONS</b> | <b>xvii</b>  |
|                | <b>LIST OF APPENDICES</b>    | <b>xviii</b> |
| <b>1</b>       | <b>INTRODUCTION</b>          | <b>1</b>     |
|                | 1.1 Objectives               | 1            |
|                | 1.2 Scope                    | 1            |
|                | 1.3 Problem Statement        | 2            |

|          |   |           |
|----------|---|-----------|
| <b>2</b> | <b>LITERATURE REVIEW</b>                              | <b>3</b>  |
| 2.1      | Transmission Control Protocol / Internet Protocol     | 3         |
| 2.1.1    | Medium Access / Logical Link Control                  | 3         |
| 2.1.2    | The Packet Switched Foundations of TCP/IP             | 4         |
| 2.1.3    | Functional Layers of TCP/IP                           | 5         |
| 2.1.4    | Internet Protocol / Internet Control Message Protocol | 6         |
| 2.1.5    | User Datagram Protocol                                | 7         |
| 2.1.6    | Transmission Control Protocol                         | 7         |
| 2.1.7    | TCP/IP Applications                                   | 8         |
| 2.2      | Local Area Network                                    | 9         |
| 2.2.1    | Components of Local Area Network                      | 9         |
| 2.2.2    | Network Topology                                      | 9         |
| 2.3      | Networked Control System                              | 12        |
| 2.4      | Need for Real-Time Operating Environments             | 15        |
| 2.5      | Microcontroller                                       | 17        |
| 2.6      | DC Motor Speed Control                                | 18        |
| 2.7      | PI Controller   | 19        |
| 2.8      | Application   | 21        |
| 2.8.1    | Telerobotics System                                   | 21        |
| 2.8.2    | Tele-micro-surgery System                             | 22        |
| <b>3</b> | <b>METHODOLOGY</b>                                    | <b>24</b> |

|         |                                      |    |
|---------|--------------------------------------|----|
| 3.1     | Project Implementation Flow Chart    | 24 |
| 3.2     | Project Planning                     | 26 |
| 3.3     | Project Description                  | 27 |
| 3.4     | Equipment                            | 31 |
| 3.4.1   | Digital Oscilloscope                 | 31 |
| 3.4.2   | DC Voltage Power Supply              | 33 |
| 3.4.3   | AC/DC Adapter                        | 35 |
| 3.5     | Hardware                             | 36 |
| 3.5.1   | Master Controller (RCM 3200)         | 36 |
| 3.5.1.1 | RCM 3200 Prototype Board             | 38 |
| 3.5.1.2 | Rabbit 3000 Microprocessor           | 39 |
| 3.5.1.3 | Parallel I/O                         | 42 |
| 3.5.1.4 | Parallel Port A                      | 42 |
| 3.5.1.5 | Parallel Port F                      | 43 |
| 3.5.1.6 | Summary of RCM 3200<br>Configuration | 44 |
| 3.5.2   | Slave Controller (RCM 2100)          | 45 |
| 3.5.2.1 | RCM 2100 Prototype Board             | 46 |
| 3.5.2.2 | Rabbit 2000 Microprocessor           | 48 |
| 3.5.2.3 | Parallel I/O                         | 50 |
| 3.5.2.4 | Parallel Port A                      | 50 |
| 3.5.2.5 | Parallel Port B                      | 51 |
| 3.5.2.6 | Parallel Port D                      | 51 |

|          |  |           |
|----------|--|-----------|
| 3.5.2.7  | Summary of RCM 2100 Configuration                    | 53        |
| 3.5.3    | Ethernet Switches                                    | 54        |
| 3.5.4    | LAN Cable  | 55        |
| 3.5.5    | H-Bridge Driver                                      | 56        |
| 3.5.6    | DC Motor with Speed Sensor                           | 59        |
| 3.5.7    | Feedback Circuit                                     | 62        |
| 3.5.8    | User Control System                                  | 64        |
| 3.6      | Software Development                                 | 67        |
| 3.6.1    | Dynamic C  | 67        |
| 3.6.2    | Initialization of Parallel I/O Ports Using Dynamic C | 67        |
| 3.6.3    | Program Flow Chart                                   | 70        |
| 3.6.4    | Memory Mapping for Rabbit Microprocessor             | 72        |
| 3.7      | Experimental Procedure                               | 75        |
| 3.7.1    | Hardware Setup                                       | 75        |
| 3.7.1.1  | Master Controller                                    | 75        |
| 3.7.1.2  | Slave Controller                                     | 77        |
| 3.7.1.3  | Hardware Integration                                 | 80        |
| 3.7.2    | Programme Master and Slave Controller                | 84        |
| <b>4</b> | <b>RESULT</b>  | <b>88</b> |
| 4.1      | Speed Profile with Different Kp and Ki Parameter     | 88        |

|          |  |           |
|----------|--|-----------|
| 4.1.1    | Results Capture from Oscilloscope              | 88        |
| 4.1.2    | Analysis of Capture Results                    | 92        |
| 4.2      | Speed Profile with Different Reference Voltage | 93        |
| 4.2.1    | Result Capture from Oscilloscope               | 93        |
| 4.2.2    | Analysis of Capture Result                     | 95        |
| <b>5</b> | <b>CONCLUSION, SUGGESTION AND FUTURE WORK</b>  | <b>96</b> |
| 5.1      | Conclusion                                     | 96        |
| 5.2      | Suggestion and Future Work                     | 97        |
|          | <b>REFERENCE</b>                               | <b>98</b> |
|          | <b>APPENDICES</b>                              | <b>99</b> |

## LIST OF FIGURES

| NO   | TITLE  | PAGE |
|------|--|------|
| 2.1  | Structural Layer of TCP/IP   | 6    |
| 2.2  | Unconstrained Topology   | 10   |
| 2.3  | Star Topology  | 11   |
| 2.4  | Ring Topology  | 12   |
| 2.5  | Bus Topology   | 12   |
| 2.6  | Block Diagram of Feedback Control over Network   | 14   |
| 2.7  | Distributed Control System with Multiple Clients   | 14   |
| 2.8  | Time-delay components of the network latency in a periodic client-server communication process | 16   |
| 2.9  | Block Diagram of Automatic Speed Control System  | 19   |
| 2.10 | Block Diagram with PI Controller   | 20   |
| 2.11 | Architecture of the Internet-Based Cooperative Telerobotics System                             | 21   |
| 2.12 | Overview of the Tele-micro-surgery system  | 22   |
| 3.1  | Flow Chart of Project Implementation   | 25   |
| 3.2  | Block Diagram of Overall Project   | 27   |
| 3.3  | Photo of Overall Project   | 28   |

|      |   |    |
|------|---|----|
| 3.4  | Circuit Diagram of Overall Project                  | 29 |
| 3.5  | State Diagram of Overall Project                    | 30 |
| 3.6  | Digital Oscilloscope                                | 31 |
| 3.7  | Oscilloscope Probe                                  | 32 |
| 3.8  | Block Diagram of Oscilloscope Connection            | 33 |
| 3.9  | DC Voltage Power Supply                             | 33 |
| 3.10 | Block Diagram of DC Voltage Power Supply Connection | 34 |
| 3.11 | AC/DC Adapter                                       | 35 |
| 3.12 | Block Diagram of Adapter Connection                 | 35 |
| 3.13 | Rabbit Core Module 3200 Top View                    | 36 |
| 3.14 | Rabbit Core Module 3200 Bottom View                 | 37 |
| 3.15 | Rabbit Core Module 3200 Subsystems                  | 38 |
| 3.16 | RCM 3200 Prototype Board                            | 38 |
| 3.17 | Rabbit 3000 Microprocessor                          | 39 |
| 3.18 | Block Diagram of Rabbit 3000 Microprocessor         | 41 |
| 3.19 | Rabbit Core Module 2100                             | 45 |
| 3.20 | Rabbit Core Module 2100 Subsystems                  | 46 |
| 3.21 | RCM 2100 Prototype Board                            | 46 |
| 3.22 | Rabbit 2000 Microprocessor                          | 48 |
| 3.23 | Block Diagram of Rabbit 2000 Microprocessor         | 49 |
| 3.24 | Ethernet Switches                                   | 54 |
| 3.25 | Block Diagram of Ethernet Switches Connection       | 55 |



|      |   |    |
|------|---|----|
| 3.26 | RJ-45   | 55 |
| 3.27 | H-Bridge Driver   | 56 |
| 3.28 | Circuit Diagram of H-Bridge Driver                              | 57 |
| 3.29 | H-bridge Configuration  | 58 |
| 3.30 | Forward Motoring Control Signal                                 | 58 |
| 3.31 | Reverse Motoring Control Signal                                 | 59 |
| 3.32 | DC Motor with Speed Sensor                                      | 59 |
| 3.33 | Graph Amplitude Voltage of Speed Sensor versus Armature Voltage | 60 |
| 3.34 | Graph Frequency of Speed Sensor versus Armature Voltage         | 60 |
| 3.35 | Permanent Magnet Equivalent Circuit                             | 61 |
| 3.36 | Feedback System   | 62 |
| 3.37 | Circuit Diagram of Feedback System                              | 62 |
| 3.38 | Block Diagram of Feedback System                                | 62 |
| 3.39 | ADC Controlled Signal   | 63 |
| 3.40 | ADC Controlled Signal   | 64 |
| 3.41 | User Control System   | 64 |
| 3.42 | Circuit Diagram of User Control System                          | 65 |
| 3.43 | Graph Reference Voltage versus Resistance                       | 66 |
| 3.44 | Graph Speed versus Reference Voltage                            | 66 |
| 3.45 | Flow Chart of Port D Initialization                             | 69 |
| 3.46 | Flow Chart of Slave Controller Program Structure                | 70 |
| 3.47 | Flow Chart of Master Controller Program Structure               | 71 |

|      |   |    |
|------|---|----|
| 3.48 | Addressing Memory Component                             | 72 |
| 3.49 | Memory Map of RCM 3200                                  | 73 |
| 3.50 | Memory Map of RCM 2100                                  | 74 |
| 3.51 | Install the RCM 3200 Module on the Prototyping Board    | 75 |
| 3.52 | Connect Programming Cable to RCM 3200                   | 76 |
| 3.53 | Power Supply Connections                                | 77 |
| 3.54 | Installing the RCM 2100 Module on the Prototyping Board | 78 |
| 3.55 | RCM 2100 Installed and Seated on the Prototyping Board  | 78 |
| 3.56 | Attaching Programming Cable to the RCM 2100             | 79 |
| 3.57 | Power Supply Connections to Prototyping Board           | 80 |
| 3.58 | Circuit Diagram of Overall Project                      | 81 |
| 3.59 | Overall Project with Measurement Tool                   | 82 |
| 3.60 | Block Diagram of Hardware Integration                   | 83 |
| 3.61 | Step to Open New Project in Dynamic C                   | 84 |
| 3.62 | Step to Compile to Flash in Dynamic C                   | 85 |
| 3.63 | Step to Compile to Flash, Run in RAM in Dynamic C       | 86 |
| 3.64 | Step to Run the Program in Dynamic C                    | 86 |
| 3.65 | Step to varied Kp and Ki Parameter in Dynamic C         | 87 |
| 4.1  | Speed Profile of $K_p = 1$ , $K_i = 0.05$               | 88 |
| 4.2  | Speed Profile of $K_p = 2$ , $K_i = 0.05$               | 89 |
| 4.3  | Speed Profile of $K_p = 3$ , $K_i = 0.05$               | 89 |
| 4.4  | Speed Profile of $K_p = 8$ , $K_i = 0.05$               | 89 |

|      |  |    |
|------|--|----|
| 4.5  | Speed Profile of $K_p = 2$ , $K_i = 0.08$              | 90 |
| 4.6  | Speed Profile of $K_p = 2$ , $K_i = 0.1$               | 90 |
| 4.7  | Speed Profile of $K_p = 2$ , $K_i = 0.2$               | 90 |
| 4.8  | Speed Profile of $K_p = 1.5$ , $K_i = 0.02$            | 91 |
| 4.9  | Speed Profile of $K_p = 1.5$ , $K_i = 0.1$             | 91 |
| 4.10 | Speed Profile of $K_p = 1.5$ , $K_i = 1$               | 91 |
| 4.11 | Speed Profile of $V_{ref} = 2.5V$                      | 93 |
| 4.12 | Speed Profile of Load Disturbance for $V_{ref} = 2.5V$ | 93 |
| 4.13 | Speed Profile of $V_{ref} = 2.0V$                      | 94 |
| 4.14 | Speed Profile of Load Disturbance for $V_{ref} = 2.0V$ | 94 |
| 4.15 | Speed Profile of $V_{ref} = 1.5V$                      | 94 |

## LIST OF TABLES

| NO   | TITLE   | PAGE |
|------|---|------|
| 2.1  | Nomenclature of Time-Delay Components                   | 16   |
| 3.1  | Gantt Chart of Project Planning                         | 26   |
| 3.2  | Specification of Oscilloscope                           | 32   |
| 3.3  | Specification of Oscilloscope Probe                     | 33   |
| 3.4  | Specification of DC Power Supply                        | 34   |
| 3.5  | Parallel Port A Registers of RCM 3200                   | 42   |
| 3.6  | Parallel Port A Data Register Bit Functions of RCM 3200 | 42   |
| 3.7  | Parallel Port F Registers of RCM 3200                   | 43   |
| 3.8  | Parallel Port F Register Functions of RCM 3200          | 43   |
| 3.9  | Summary of RCM 3200 Configuration                       | 44   |
| 3.10 | Parallel Port A Register of RCM 2100                    | 50   |
| 3.11 | Parallel Port A Data Register Bit Functions of RCM 2100 | 50   |
| 3.12 | Parallel Port B Registers of RCM 2100                   | 51   |
| 3.13 | Parallel Port B Data Register of RCM 2100               | 51   |
| 3.14 | Parallel Port D Registers of RCM 2100                   | 51   |
| 3.15 | Parallel Port D Registers of RCM 2100                   | 52   |

|      |  |    |
|------|--|----|
| 3.16 | Summary of RCM 2100 Configuration          | 53 |
| 3.17 | Specification of Ethernet Switches         | 54 |
| 3.18 | Pin Out for Ethernet                       | 56 |
| 4.1  | Analysis of Difference Kp and Ki Parameter | 92 |
| 4.2  | Analysis of Difference Reference Voltage   | 95 |

## **LIST OF ABBREVIATIONS**

|        |   |
|--------|---|
| DC     | - Direct Current                                    |
| DSP    | - Digital Signal Processor                          |
| LAN    | - Local Area Network                                |
| PI     | - Proportional Integral                             |
| PLC    | - Programmable Logic Controller                     |
| PWM    | - Pulse Width Modulated                             |
| RAM    | - Random Access Memory                              |
| RCM    | - Rabbit Core Module                                |
| TCP/IP | - Transmission Control Protocol / Internet Protocol |
| UDP    | - User Datagram Protocol                            |

## **LIST OF APPENDICES**

| <b>NO</b> | <b>TITLE</b>                                | <b>PAGE</b> |
|-----------|---|-------------|
| A         | Source Code of Master Controller (RCM 3200) | 99          |
| B         | Source Code of Slave Controller (RCM 2100)  | 104         |
| C         | Datasheet of RCM 3200                       | 108         |
| D         | Datasheet of RCM 2100                       | 111         |
| E         | Datasheet of L298                           | 114         |
| F         | Datasheet of ADC0802                        | 123         |
| G         | Datasheet of SB130                          | 131         |
| H         | Datasheet of 1N4148                         | 133         |

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Objectives**

- To develop an embedded TCP/IP-based DC motor controlled via local area network by using rabbit microprocessor.
- To develop a Proportional-Integral (PI) controller that can remotely controls a DC motor through local area network.

#### **1.2 Scope**

- Develop algorithms that enable communication between Master Controller (RCM 3200) and Slave Controller (RCM 2100) by using User Datagram Protocol (UDP).
- Develop a software function to enable Slave Controller (RCM 2100) to produce PWM signal.
- Build an H-bridge driver for DC motor.
- Design and constructs a feedback circuit from motor speed sensor to Slave Controller (RCM 2100).