DESIGN AND DEVELOPMENT OF INTELLIGENT ELECTRIC POWER ASSIST STEERING (EPAS) SYSTEM FOR ELECTRIC VEHICLE

BY

RABIATULADAWIAH ABU HANIFAH

A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Mechatronics Engineering)

Kulliyyah of Engineering
International Islamic University Malaysia

APRIL 2015

ABSTRACT

Energy management in Electric Vehicle (EV) technology is very important as the energy source of all its system operations are solely relying on the battery. It is evident since, most auto-makers are still focused on maximizing travel distance and battery energy storage in improving the performance of the vehicle in EV. Efforts are being made to reduce the energy consumed as much as possible in EV system. As one of the auxiliary elements of the system, of Electric Power Assist Steering (EPAS) system can be controlled or manipulated in such a way that minimum energy from the battery source is being drawn during operation. This unique feature of EPAS system enables the EPAS system to be tuned with the optimal performance setting so that less power is needed for its optimum operation. The research's aim is to apply the Computational Intelligence (CI) technique; Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) to improve the controller's performance. The investigation involves an analysis of the convergence behavior of PSO and ACO toward the optimal solution and a comprehensive assessment on the current supplied to the assist motor of the EPAS system and power consumption evaluation. The test rig of the EPAS system is also designed and successfully developed in this research to be used for the testing of the proposed controller. Both simulation and experimental tests are conducted to validate the proposed controller performance. The test show about 75.22 % of power reduction with PID-PSO tuned controller and 76.87 % less power consumed when PID-ACO tuned controller is implemented in the EPAS system.

خلاصة البحث

تنظيم الطاقة في تقنية السيارات الكهربائية (EV) مهم للغاية حيث ان مصدر الطاقةلجميع نظام العمليات يعتمد فقط على البطارية. يدل ذلك على استمرار تركيز معظم صانعي السيارات على تحسين أداء السيارة EV باستخدام أقل طاقة مُخزنه لأطول مسافة ممكنة. وتُبذل الجهود للحد من الطاقة المستهلكة قدر الإمكان لنظام EV. وباعتبار مساعد التحكم بالطاقة الكهربائية (EPAS) احد العناصر المساعدة للنظام، يمكن التحكم أو معالجته بطريقة ما للحد من استهلاك الطاقة المخزنة خلال الأستخدام.هذه الميزة الفريدة لنظام EPASتمكنه من القيام بعملية التشغيل الامثل وذلك باستخدام طاقة أقل. تهدف الباحثة إلى تطبيق تقنية الذكاء المحوسب (CI)، استمثال عناصر السرب (PSO) و استمثال مستعمرة النمل (ACO) من أجل تحسين أداء النظام.ويشمل البحث على تحليل أداء نشاط اللقاء التقارب بين PSO و ACO من أجل الحل الأمثل و تقييم شامل على التيار الموفر لمساعد المحرك لنظام EPAS وتقييم استهلاك الطاقة.وقام هذا البحث بإنشاء وتصميم منصةاختبار لنظام EPAS بنجاح لاستخدامه على النظام المقترح. ونفذت اختبارات محاكاةو تجارب للتحقق من أداء النظام. وأظهرت نتائج الاختبار الحد من استهلاك الطاقة بحوالي 75.22٪ باستخدام ضابط التحكم PID-PSO ، واستهلاك طاقة اقل ب 76.87٪ مع ضابط التحكم PID-PSOعند استخدامه مع نظام EPAS.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechatronics Engineering).

…………………………………….
Siti Fauziah Toha @ Tohara
Supervisor

……………………………………
Salmiah Ahmad
Co-Supervisor

I certify that I have read this study and that in my opinion, it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a thesis for degree of Master of Science (Mechatronics Engineering).

……………………………………
Hazlina Md Yusof
Internal Examiner

…………………………………….
Intan Zaurah Mat Darus
External Examiner

This dissertation was submitted to the Department of Mechatronics Engineering and it is acceptable as a fulfilment of the requirement for the Master of Science (Mechatronics Engineering).

………………………………......
Tanveer Saleh
Head, Department of
Mechatronics Engineering

This dissertation was submitted to the Kulliyyah of Engineering and it is acceptable as a fulfilment of the requirement for the degree of Master of Science (Mechatronics Engineering).

……………………………………
Md Noor Bin Salleh
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Rabiatuladawiah Abu Hanifah

Signature …………………………… Date ……………………….

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

DESIGN AND DEVELOPMENT OF INTELLIGENT ELECTRIC POWER ASSIST STEERING (EPAS) SYSTEM FOR ELECTRIC VEHICLE

zzzzNo part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below.

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

Affirmed by Rabiatuladawiah Binti Abu Hanifah.

……………………………… …………………
Signature Date

Dedicated to

My beloved parents : Abu Hanifah Bin Mat Dom

&

Nortifah Binti Mohd Ali.

My sisters and brothers.

"May Allah bless and reward them"

ACKNOWLEDGEMENTS

Alhamdulillah, praise be to Allah and may peace and blessings be upon Prophet Muhammad (peace and blessings be upon him), and all of his companions. First and foremost, praise be to Allah with the greatest help and mercy from Him, for bestowing upon me such patience and strength to complete this dissertation writing.

I express heartfelt gratitude to my project supervisor Dr. Siti Fauziah Toha@Tohara. I owe more than I can articulate to her. I sincerely thank her for her invaluable support, encouragement and guidance during my years at Kulliyyah of Engineering IIUM. I genuinely appreciate the many hours she has spent working with me on this thesis as well as the research work. Her understanding, tender-heartedness and endless patience in guiding me have left a deep impression upon me.

My gratitude also goes to my project co-supervisor Dr. Salmiah Ahmad. I feel indebted to her for her insightful guidance, support, intuitive comments and limitless patience given to me from the start until the completion of this research. Her friendly approach and immense support to me have help me develop my research skills to complete this project.

I would also like to thank all my lectures who have taught me throughout my master's degree especially Dr. Nahrul Khair bin Alang Md Rashid for his course in research methodology and Dr. Sheroz Khan from ECE department for his course in seminar. My gratitude also goes to the technical assistance from Mechatronics department; Br. Shahlan Dalil, Br. Nasrul Faizin and Br. Abd. Aziz Ibrahim; and all technical assistance from Manufacturing department especially Br. Mohd. Faisal Mohd. Room for their advice on my project and support in providing all the laboratory equipment.

I will be forever grateful to my fellow research friends who have been so gracious with their knowledge and idea; Aimi Shazwani, NurFarahana, Sado Fatai, Tareq Altamas, and all my lab mate in Biomechatronis lab. Thank you all for providing inspiration and helpful suggestions as well as many hours of helping me with my prototype.

Finally, my deep appreciation goes to my beloved father and mother Abu Hanifah Mat Dom and Nortifah Mohd Ali, for their unlimited patience and unfailing support, love, care and continuous prayers for my successful completion of this research. Thank you Mak and Ayah for believing in me. Thank you also to my sisters, brothers and my younger cousins for their support and cheering.

Special thanks to the Department of Mechatronics Engineering which has provided the support and equipment needed to complete my thesis. I would also like to thank the Ministry of Higher Education (MOHE) and International Islamic University Malaysia (IIUM) for the financial support throughout my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

The era of Electric vehicle (EV) begins in 1830, nevertheless the era of the electric car did not sustain for long. The limited battery capacity and the need to recharge the battery were the reasons for car with internal combustion engine replacing the electric car. However, due to the continuous rising consciousness of global warming, climate changing and oil crisis have shifted the interest of automotive industry towards electric vehicle (Emadi & Williamson, 2006; Faria, Moura, Delgado, & de Almeida, 2012). Around the world, road transportation sector is to be accountable for the largest contributors to the emission of greenhouse gasses (GHG) (Berggren & Magnusson, 2012; Mahlia, Saidur, Memon, Zulkifli, & Masjuki, 2010). This is because most of the vehicle are operated using Internal Combustion Engine (ICE) which exhausting gasses such as carbon dioxide, hydrocarbons, carbon monoxide and nitrogen oxides.

The ever increasing oil prices also served as the catalyst to the resurgent interest in electric vehicle technology (Emadi & Williamson, 2006; Wu, Yeh, & Huang, 2013). In electric vehicles, rechargeable battery served as power supply and electric motor as the driver for the wheel. Its power is exclusively derived from the battery and up to 75% of its energy is consumed only to run the car (Tie & Tan, 2013). With the battery as the core in supplying energy for EV, the battery energy management become very significant and vital issue. It has been a major concern in EV technology in terms of battery energy capacity to support the long-range operation. Therefore, it is crucial to minimize energy consumption in EV to improve the performance of EV. Many automakers are still focusing on maximizing the distance travelled by the vehicle while forsaking the potential of electrical accessory loads in influencing the performance of electric vehicle (Tie & Tan, 2013). By improving the efficiency and performance of the EV accessory such as electric power steering will contribute to the reduction of power consumption in EV. Electric Power Assist Steering (EPAS) is one of the auxiliary components that make up the EV system.

Indeed, the electric power assist steering (EPAS) system improves the energy efficiency due to its on-demand system feature where its only operating when the steering wheel is turned (Xue-Ping, Xin, Jie, & Jin-Lai, 2009). Currently, EPAS systems are used in a full range of vehicles. In a smaller and lower mid-size car the column type EPAS is used. Whereas the pinion configuration of EPAS is used in mid-size car while the rack type EPAS is used for large car. Column-type EPAS provide assist torque by mounting the assist motor at the column, in a pinion-type the assist motor is mounted on the pinion of the rack and pinion assembly and as for rack-type EPAS the assist motor is mounted on the rack.

EPAS also offers an additional advantages than hydraulic power assist steering (HPAS) as it can reduce the steering torque, provide various steering feel and improve return-to-center performance of a steering wheel when it is steered (Chih-Jung, Shih-Rung, Ming-Chih, Tsung-Hsien, & Tsung-Hua, 2007). Only approximately one-twentieth of energy is consumed by the EPAS system compared to the conventional HPAS system and this feature make EPAS a very suitable candidate in EV steering system (Hao-bin, Jing-bo, Hai-mei, & Long, 2008). Unlike HPAS, EPAS eliminates the need of hydraulic pump and its hydraulic components by utilizing the electric motor to provide the required assist torque to the driver. With much simple and less rigid assembly configuration, couple together with the presence of electronically controlled-motor give advantages to the EPAS system in terms of its control flexibility.

EPAS system therefore, attract the interest of auto-makers and researchers to tailor the EPAS system control according to their own desired purpose and function. Many research have been conducted in EPAS including integrating other system as a means to control and improve the vehicle steering performance. However, research on EPAS control method not only limited to the infusion between EPAS with another system or assist motor current or torque control. There are many different approaches in enhancing the EPAS system especially in controller part have been explored and studied however limited number of study involving the integration of evolutionary algorithm are available.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Reducing energy consumption in electric vehicle is crucial since the energy source of all its system operation relies on the battery. Efforts have been made to reduce the energy consumed as much as possible in an EV system. As one of the auxiliary elements of the system, EPAS system can be controlled or manipulated in such a way that minimum energy from the battery source is being draws during its operation. The controller in the EPAS system need to be tuned with the optimal performance setting so that less current is needed for its optimum operation. With the dynamic changes of vehicle speed and external disturbance resulted from road condition, the controller need to be able to deliver a sufficient and best possible assist torque to the driver with minimum power consumed. For that reason, significant improvement should be made to the controller of EPAS system to ensure optimum performance with lowest possible current draws from the battery.

1.3 RESEARCH OBJECTIVES

The objectives of this research which attempt to measure the assist current supplied to the assist motor and the amount of power consumed by EPAS system are:

1) To develop an EPAS test rig for controller validation.
2) To implement the Swarm Intelligence algorithms in PID controller tuning using:
   2.1 Particle Swarm Optimization (PSO) algorithm
   2.2 Ant Colony Optimization (ACO) algorithm
3) To test and validate the tuned PID controllers on EPAS system test rig in comparison to conventional PID.

1.4 RESEARCH METHODOLOGY

In order to achieve the objectives of the research, the following procedures were implemented. The flowchart of complete procedures taken is provided in Figure 1.1.

1. The study begins with exploring the background of electric vehicle and electric power assisted steering (EPAS) system and analyses the limitations and potential of the system through an extensive literature review.
2. Development of mathematical model of EPAS system and Simulink model for simulation study.
3. Implementation of swarm intelligence techniques in the controller. The techniques include PSO algorithm and ACO algorithm. The intelligent controllers' performance in Simulink environment are evaluated and analysed.
4. Development of EPAS system test-rig for experimental validation.

5. Evaluation of controllers' performance in optimizing the power consumption.

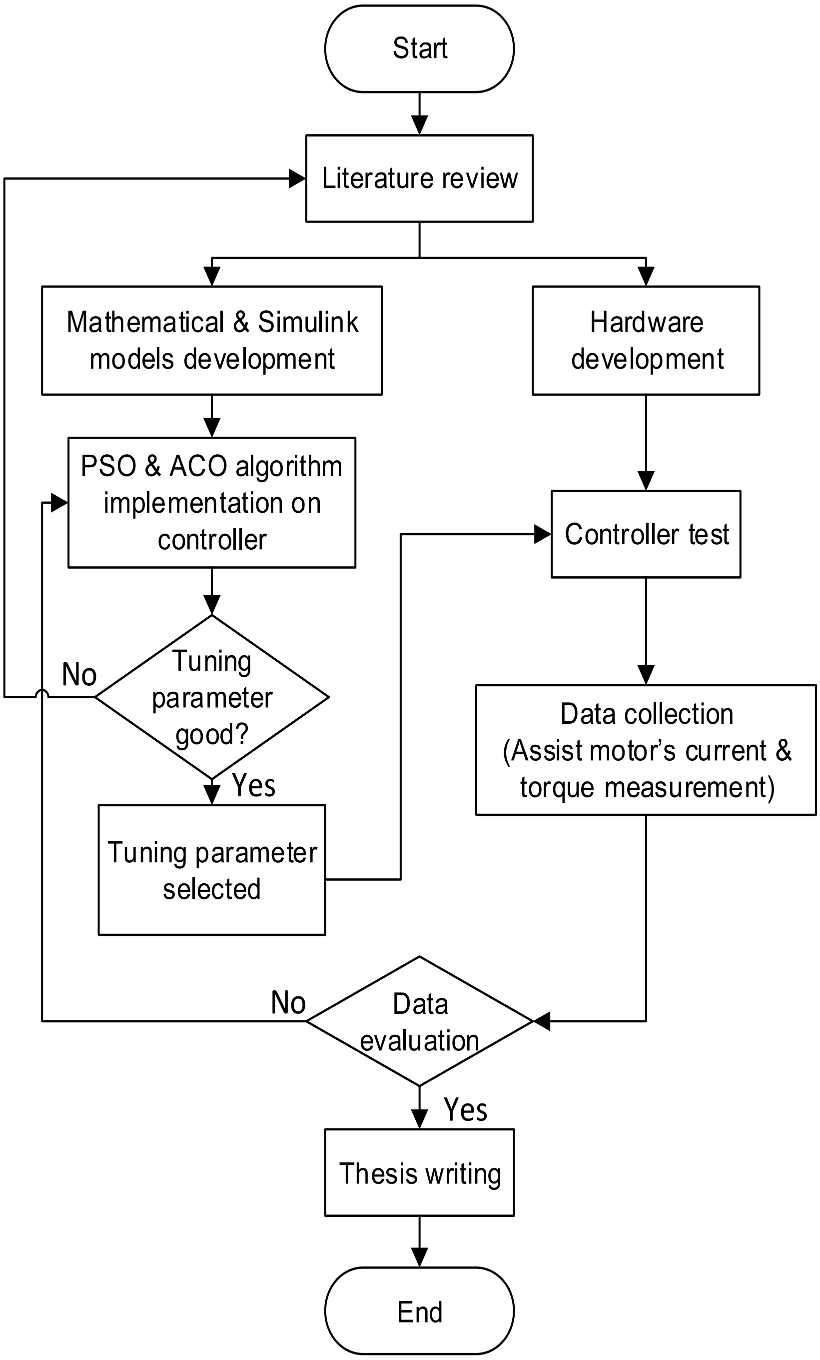

Figure 1.1 Flowchart of the research.

1.5 SCOPE OF RESEARCH

Several different control method are available in assist motor which include voltage control or current control. In this research, current control method is selected to be applied and studied. The assist current supplied to the assist motor of the EPAS system is monitored and analysed for assist motor performance evaluation. The research will be conducted in both software simulation and also in experimental setup. In software simulation, mathematical model of the EPAS system is employed to represent it in Matlab and Simulink platform. The research will be focusing on the application of Swarm intelligence technique particularly Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) algorithms to tune the PID controller. While in experimental setup, the test rig is designed in the scale of the go-kart system. The scaled down go-cart size is chosen in this study in order to reduce the complexity of the design from the real life system. The tuned controllers are applied for the analysis of power consumption of the assist motor based on assist current control. The performance of the PSO-tuned and ACO-tuned controllers are the main scope of this research.

1.6 CONTRIBUTIONS OF THE RESEARCH

The contributions of the research can be underlined as the following:

1. Test rig of the EPAS system is designed and developed in this study. The purpose of the test rig development is to test the designed controller under study in the real life application. Hardly seen in the previous research conducted on EPAS system which build a test rig to test their developed theories. In this research, a column type EPAS system configuration is selected and the steering is build similar to the Go-cart steering mechanism. Critical component in EPAS system such as torque sensor is used in the test

rig for precise information gathering from the steering wheel input and provide the controller with sufficient valuable data to make the system mimic the actual assist steering mechanism.

2. Particle Swarm Optimization (PSO) is used as a tuning mechanism in the PID controller of the system. PSO was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems. Using this algorithm, the solution obtained is a high-quality solution which is generated within the shorter calculation time and can achieve stable convergence characteristic. The PSO algorithm is applied in the system controller in searching for best gain parameters of the PID controller.

3. Ant Colony Optimization (ACO) is applied as another tuning mechanism for the PID controller in the system. It is a general purpose optimization technique developed by Dorigo and colleague (Dorigo, 1992; Dorigo, Maniezzo, & Colorni, 1991, 1996) . The ACO algorithm have been used in many applications of combinatorial optimization problems (COPs) such as in the optimization problem of traveling salesman (Merkle, Middendorf, & Schmeck, 2002) and assignment problems (Annaluru, Das, & Pahwa, 2004). In this study, a Continuous-ACO algorithm is applied in tuning the PID as this is the continuous optimization problem.

1.7 THESIS ORGANIZATION

This thesis is organized into six chapters. Elaboration on each chapters is described as follow:

1. CHAPTER ONE: An overview of this research concern is explained briefly in terms of the history of EV technology, the reason for shifted automotive technology towards EV and the issue on EV regarding energy utilization and consumption. The issue is then elaborated further in the problem statement and is emphasized on the significant to tackle this issue. In the research methodology, the steps taken to conduct the research is explained in details. Scope of the research is also included to brief on the area will be covered in this study. This chapter also consist of the contribution of this study and publications that have been made so far with the research conducted.
2. CHAPTER TWO: This chapter focus on the literature survey done in the field of EV, power assist steering system and EPAS system in general. The survey is then narrow down in depth on the current state of research involving EPAS system which explore on which area have been in the interest of the researchers and how it is done.
3. CHAPTER THREE: This is the chapter which discuss on the modelling of the system. The mathematical model of EPAS system is elaborated and presented in this chapter along with the development of the system Simulink model. In this chapter, the PID tuning mechanism using swarm intelligence technique is explained. Two different swarm intelligence technique is applied in this study which are Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO).

4. CHAPTER FOUR: As this research required both software simulation and also experimental, a chapter of hardware design and development is dedicated. In experimental setup, the design of EPAS mechanical system and modification are discussed. The design of the data acquisition of this system is also explained in this chapter.
5. CHAPTER FIVE: This chapter investigates the performance of PSO and ACO algorithms in tuning the PID controller. Simulink model simulation is developed and tested using both algorithm to find the optimal parameters of PID controller. The resulting optimal parameters is then applied in the PID controller and called as PID-PSO tuned controller and also PID-ACO tuned controller. The aim to investigate the potential of these controllers in reducing the power consumption is done both in Simulink environment and also experimental setup. In the experimental setup, the PID-PSO tuned and PID-ACO tuned controllers are implemented in the test rig controller.
6. CHAPTER SIX: This chapter summarises the thesis with the concluding remarks. Further research work is also outlined in this chapter.