UNIVERSITI PUTRA MALAYSIA

PARTICLE SWARM OPTIMIZATION TECHNIQUE OF CURRENT TRACKING CONTROLLER FOR ELECTRIC POWER-ASSISTED STEERING SYSTEM

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By

ADEL AMIRI BAHMANSHIRI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree Master of Science

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DEDICATION

I dedicate this thesis first and foremost to mom, dad for their financial support and love throughout those two years spent in Malaysia. I also dedicate this thesis to my sister for the laughs, encouragement, admiration, and all the love and strength you always give me.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

PARTICLE SWARM OPTIMIZATION TECHNIQUE OF CURRENT TRACKING CONTROLLER FOR ELECTRIC POWER ASSISTED STEERING SYSTEM

By

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June 2015

Chairman : Mohd Khair Bin Hassan,PhD,Ir
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Electric Power Assisted Steering (EPAS) system is a new power steering technology for vehicles especially for Electric Vehicles (EV). It has been applied to displace conventional Hydraulic Power Assisted Steering (HPAS) system due to space efficiency, environmental compatibility and engine performance. An EPAS system is a driver-assisting feedback system designed to boost the driver input torque to a desired output torque causing the steering action to be undertaken at much lower steering efforts.

Various control algorithms are derived in order to achieve the specified system characters. To achieve better driving feeling in the EPAS system for EV, there are two problems need to be addressed: sufficient assist torque should be transferred to drivers; motor current tracking should be perform by controller.

In this thesis, a controller structure design is proposed for EPAS system that addresses motor current tracking performance, offering sufficient gain for different driver torques and different vehicle speeds. This thesis introduces a control strategy to design the controller that control motor current in different speeds and different driver torques. The motor controller is PID controller that optimized by Particle Swarm Optimization (PSO) technique that is used to improve current tracking performance.

The simulation for the whole EPAS system is implemented by Matlab/Simulink. In this case, three test procedure are done to show the performance of current tracking controller in different situations, also the current tracking performance with Particle Swarm Optimization (PSO)-PID controller compared to previous research that used Ant Colony Optimization (ACO)-PID controller [1] to show the percentage of error between reference motor current and actual motor current of proposed PSO optimization algorithm with 0.023% is much less than previous worked (ACO optimization algorithm) with 4.76%.So the proposed control strategy can improve motor current tracking performance in electric powers assisted steering (EPAS) systems.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TEKNIK PENGOPTIMUMAN ZARAH BERKUMPULAN BAGI PENGAWAL PENGESANAN ARUS UNTUK SISTEM STERING TERBANTU KUASA ELEKTRIK

Oleh

ADEL AMIRI BAHMANSHIRI

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Pengerusi : Mohd Khair Bin Hassan,PhD,Ir
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Electric Power Steering dibantu (EPA) sistem adalah baru teknologi stereng kuasa untuk kenderaan terutama bagi Kenderaan Elektrik (EV). Ia telah digunakan untuk menggantikan kuasa hidraulik konvensional Pemandu dibantu (HPAS) sistem kerana kecekapan ruang, keserasian alam sekitar dan prestasi enjin. Sistem EPA adalah satu sistem maklum balas pemandu-membantu dibentuk untuk meningkatkan tork input pemandu untuk tork output yang dikehendaki menyebabkan tindakan stereng yang akan dijalankan pada usaha stereng lebih rendah.

Pelbagai algoritma kawalan diperolehi untuk mencapai watak-watak sistem yang ditetapkan. Untuk mencapai perasaan pemanduan yang lebih baik dalam sistem EPA untuk EV, terdapat dua masalah yang perlu ditangani: mencukupi membantu tork perlu dipindahkan ke pemandu; motor pengesanan semasa perlu dilaksanakan oleh pengawal.

Dalam tesis ini, reka bentuk struktur pengawal adalah dicadangkan untuk sistem EPA yang menangani motor prestasi pengesanan semasa, yang menawarkan keuntungan yang mencukupi untuk tork pemandu yang berbeza dan kelajuan kenderaan yang berbeza. Tesis ini telah memperkenalkan strategi kawalan untuk mereka bentuk pengawal yang mengawal arus motor pada kelajuan yang berbeza dan tork pemandu yang berbeza. Pengawal motor pengawal PID yang dioptimumkan dengan Particle Swarm Optimization (PSO) teknik yang digunakan untuk meningkatkan prestasi pengesanan semasa.

Simulasi untuk sistem EPA keseluruhan dilaksanakan oleh Matlab / Simulink. Dalam kes ini, tiga prosedur ujian yang dilakukan untuk menunjukkan prestasi pengawal semasa pengesanan dalam situasi yang berlainan, juga prestasi pengesanan semasa dengan Particle Swarm Optimization (PSO) pengawal -PID berbanding kajian sebelum ini yang digunakan Ant Colony Optimization (ACO) -PID pengawal [1] untuk menunjukkan peratusan ralat antara arus motor rujukan dan semasa motor sebenar dicadangkan PSO pengoptimuman algoritma dengan 0.023% adalah lebih kurang daripada sebelum bekerja (ACO pengoptimuman algoritma) dengan 4.76% .So strategi kawalan yang dicadangkan boleh meningkatkan motor semasa prestasi pengesanan dalam kuasa elektrik dibantu mengemudi (EPA) sistem.

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I certify that a Thesis Examination Committee has met on 11 June 2015 to conduct the final examination of Adel Amiri Bahmanshiri on his thesis entitled "Particle Swarm Optimization Technique of Current Tracking Controller for Electric Power-Assisted Steering System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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CHAPTER 1

INTRODUCTION

1.1 Background

Electric vehicle (EV) technology start to kick back in 20th century after being suppressed by the internal combustion engine (ICE) vehicle because of the increasing awareness of environment for its global warming issue and fuel energy depletion issue[2]. The ever increasing fuel prices around the world spike the need of alternative energy to run the vehicle. Electric powered vehicle uses battery as a power supply to run its system and thus completely eliminating the need of fuel for its operation. With the battery as the core in supplying energy for EV, the battery energy management become very significant and vital issue. In electric vehicle, battery is needed as energy supplier to its electric propulsion subsystem, energy source subsystem and auxiliary subsystem[1].

Battery capacity, braking system, motor efficiency, regenerative braking, converters, thermal management and steering system are areas that show much attention in the automotive researches[3].The steering system is one of many key subsystems for car function[4].Electric Power Assisted Steering (EPAS) system presents the continuing future of power-assisted steering technology for passenger vehicles and has already beginning to appear in high-volume, lead-vehicle applications, more flexible than traditional Hydraulic Power Assisted Steering (HPAS) system, the fact of EPAS is to supply steering assistance to the driver using an electrically controlled electric motor. EPAS is a classic example of a smart actuator operating under feedback control. It can provide necessary assist torque in different car speed and different driver torque[5].

Power steering systems contains three type as below[6]:

i. Hydraulic Power Assisted Steering system (HPAS)
ii. Electro Hydraulic Assisted Steering System(EHPS)
iii. Electric Power Assisted Steering System (EPAS)

Recently, there is a huge apparent raising interest within in the automotive market in EPAS systems as viable substitute of traditional Hydraulic Power Assisted Steering (HPAS) which has been predominantly installed in the majority of vehicles in the last decades. Particularly, new small and medium size cars are generally getting designed with EPAS systems. The five main points validate this change:

1. **Easy Tunability**: Compared to the mechanical fixed-structure hydraulic systems, EPAS systems are types of mechatronic systems which utilize software programmable functions which make them quickly adjustable to broader stages of operation enhancing their performance [3].
2. **Fuel economy**: Electric power assisted steering systems are on demand systems that run just when the steering wheel is turned, hence providing better fuel efficiency in comparison to hydraulic systems that need a pump, driven by the engine, to be constantly working to enhance the hydraulic circuit pressure. Moreover, EPAS systems eliminate many components such as the

pump and its pulley-belt system attached to the engine as well as hydraulic-circuit components such as hoses and the fluid tank, therefore EPAS systems are substantially lighter in weight than their hydraulic counterparts. It has been reported in [5] that among power assisted steering system available for passenger cars, EPAS systems provide the best fuel consumption[7-9].

The plot shown in Figure 1-1 indicates that EPAS systems have the lowest fuel consumption in comparison to Hydraulic Power Assisted Steering (HPAS) system with savings in excess of 3.0% in average and up to 3.5% in city driving [5].

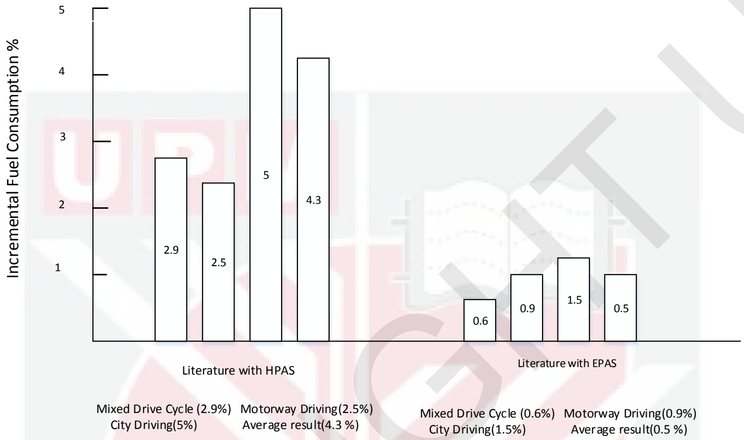

Figure 0-1 Typical EPAS Fuel Consumption Saving[5]

3. **Modularity**: EPAS systems are inherently modular given that they are consist of smaller sized components which are simply packed into separate subsystems. This modularity presents a number of EPAS types based on the located area of the assist-motor system, as well as direct accessibility to the system's components leading to much easier tunability of the system parameters [10].
4. **Low Production Cost**: EPAS systems are comprised of parts which are more affordable to manufacture than traditional parts of hydraulic circuits, removal of a belt-driven engine item, and many high-pressure hydraulic hoses between the hydraulic pump, installed on the engine[11, 12].
5. **Environmental friendliness**: EPAS systems eliminate the requirement for hydraulic oil refills hence removing oil removal problems as well as oil loss problems[9, 13].

Furthermore, from feedback-systems perspective, EPAS systems are largely modeled using linear dynamics which lend itself to linear feedback control structures, whereas hydraulic steering systems inevitably have nonlinear pressure-flow dynamics requiring more complicated to implement nonlinear feedback strategies in most times. However, a drawback in EPAS systems compared to hydraulic steering systems is the limited torque capacity deliverable by the electric assist motors. Because of this, EPAS systems are mostly suitable for compact cars.

An EPAS system is an electro mechanical system composed of four main subsystems which are interconnected via mechanical springs and/or joints. These subsystems are shown in Figure 1-2.

1. **Steering subsystem**: comprised of the steering column, steering wheel and torsion bar (torque sensor).
2. **Assist motor**: comprised of an electric motor and gear box assembly. Currently Motor applied in EPAS is divided into two main categories[14]:
    i. Brushed DC motor.
    ii. Permanent magnet brushless motor.
3. **Rack and pinion**: comprised of a rack driven by a pinion attached to steering subsystem via a universal joint.
4. **Road tires**: comprised of the road tires attached to the rack and pinion assembly via tie-rods.

The ECU decides most appropriative assistant torque and steering direction, then sends control signals to motor. These signals produce the motor working by power drive module and protection module. The motor torque can drive the gear to generate the corresponding assistant torque. The EPAS can adjust this torque arbitrarily by precise algorithm and make the gear acquire assistant torque what the driver needs [8].

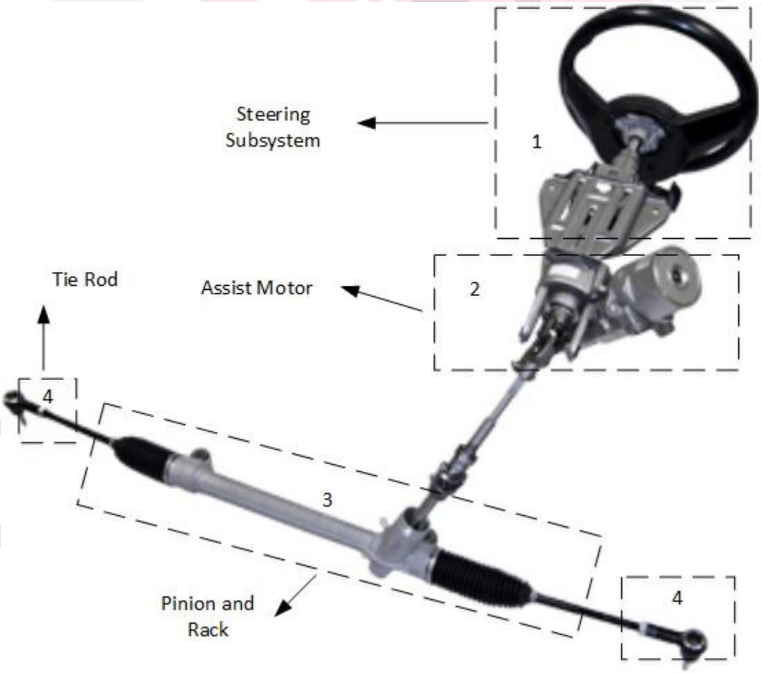

Figure 0-2 EPAS Diagram[15]

The modular nature and compact size of EPAS systems render them readily amenable to a variety of types with regards to the located area of the assist motor in the steering system. The most popular kinds of EPAS systems are:

1. **Column-Electric Power Assisted Steering Type(C-EPAS):** The assist motor unit is installed to the steering column.
2. **Pinion-Electric Power Assisted Steering Type (P-EPAS):** The assist motor unit is installed to the steering gear's pinion shaft.
3. **Rack-Electric Power Assisted Steering Type (R-EPAS):** The assist motor unit is installed directly to the steering rack forming single package.

The advantages of each type and the typical vehicle size for which it is appropriate depends on EPAS manufacturers [16].

In according to raising demand for C-EPAS systems, technology for system adaption and development of efficiency of the entire system will also be required [8].
So the research in this thesis is dedicated to the first type namely column-assist EPAS systems.

1.2 Problem statement

The restriction of battery capacity happens to be a significant issue in electric car (EV). Mechanical system or Hydraulic Assisted Power Steering (HPAS) are no further useful in EV system. That is as a result of continuous power supply from battery is needed to keep the pressure in the hydraulic pump. Additionally needs normal maintenance to the hydraulic mechanism system. Meanwhile, EPAS system is just used energy when the steering wheel controls is turned. In the EPAS system actual current motor cannot follow the desired current that is output from look-up table. So EPAS system needs precise current tracking controller to minimize error between target current and electric motor current.

The first restriction is on the controller dc gain that guarantees the necessary amount of steering torque amplification and appropriate performance of the assist in different speeds and different driver torques.

The second restriction is current tracking performance that guaranties the stability of the assist system, also control of motor current is very essential for electric vehicles and decreasing the power consumption.

The most popular controller to enhance the efficiency of actuators in industry is PID controller, because it is simple to use and also robust. Optimizing value of variables K_p, K_i and K_d of the PID controller can improve the performance characteristics of the systems such as reference tracking performance. The normal method is trial and error but it has disadvantage like wasting the time. Therefore a few researchers have created an attempt to emphasize the significance of energy effectiveness in auxiliary of electric vehicle system. In [1]Ant Colony-PID controllers was used to minimized the error between target current and motor current . In this research ACO algorithm applied to find the best gain for PID parameters, it is observed from result the percentage of error between the reference motor current and output motor current is 4.76%but it is still high and itcould not achieve the best current tracking control performance.

1.3 Research objective

The EPAS control must ensure the generation of the desired assist torque, a stable system with a large amount of assistance. The aim of this study in EPAS is to control the electric motor that supplies an appropriate assist torque to decrease the drivers steering effort in various speeds.

Therefore, current research proposes two main objectives:

1. To develop the electric motor current tracking performance a PID controller is used.
2. To optimize the PID controller parameters Particle Swarm Optimization (PSO) algorithm is applied.

1.4 Scope of Study

There are two main type steering system in vehicle, the old one is manual steering system and the new one is power steering system that is more attractive and more useful. High weight on the front area of car, friction and extra can make the experience of driver hard to maneuver the steering wheel so it causes a need of system to assist driver to turn steering wheel easily in different situation. There are three type of power steering in the market:1.Hydraulic Power Assisted Steering (HPAS)system2.Electro-Hydraulic Power Assisted Steering(EHPAS) system and the newest one is Electro Power Assisted Steering System (EPAS).EPAS removes all the hydraulic system, there are a few advantage compared to hydraulic systems such as easy tunability, modularity and fuel economy. In EPAS system three main objectives which are very extensive, but the main focus is generate assist torque to assist the driver while driving. In this area the main issue is electric motor current tracking performance. Figure 1-3 shows the scope flow chart of this thesis.

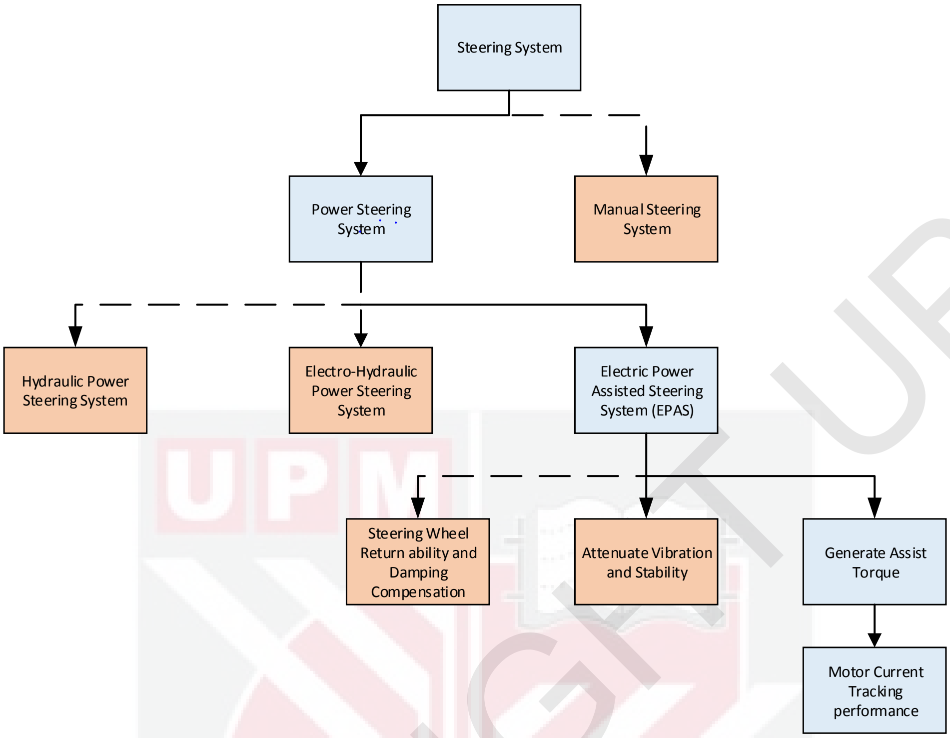

Figure 0-3 Scope Flow Chart

1.5 Thesis outline

In this research, the mathematical model of EPAS system is simulated in Simulink/Matlab and a characteristic curve (Look-Up table) and a PID controller optimized by Particle Swarm Optimization (PSO) algorithm are implemented to achieve well current tracking performance for the EPAS system. This method is compared with previous work that applied Ant Colony Optimization (ACO)-PID controller to show the current tracking improvement. Also three test procedures are applied to validate the controller in real. The results shows the performance and efficiency of control strategy for EPAS system.

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