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Hybrid pid and pso-based control for electric power assist steering system for electric vehicle

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Abstract: Electric power assist steering (EPAS) system provides an important significance in enhancing the driving performance of a vehicle with its energy-conserving features. This paper presents a hybrid PID (Proportional-Integral-Derivative) and particle swarm optimization (PSO) based control scheme to minimize energy consumption for EPAS. This single objective optimization scheme is realized using the PSO technique in searching for best gain parameters of the PID controller. The fast tuning feature of this optimum PID controller produced high-quality solutions. Simulation results show the performance and effectiveness of the hybrid PSO-PID based controller as opposed to the conventional PID controller.

Keywords: Electric Power Assist Steering (EPAS); C-type EPAS; PID; Particle Swarm Optimization (PSO); electric vehicle.

1. Introduction
In electric vehicle technology, battery served as a power supply to drive the vehicle. Hence, it has been a major concern in EV technology in terms of battery energy capacity to support the long-range operation [1]. As the result of this limitation give an opportunity to electric assist power steering (EPAS) system by replacing mechanical steering system. Mechanical steering system or hydraulic power assist steering (HPAS) draws a constant energy supply from battery to maintain the pressure in hydraulic pump [2]. Whereas the EPAS system improves the energy efficiency due to its on-demand system feature which is only operating when the steering wheel is turned [3].

It offers an additional advantages than hydraulic power steering 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 [4]. The EPAS system becomes an alternative to the automotive manufacturer in providing the convenience of steering assist without adding value to the engine cost and fuel consumption. 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 [5].

The electric motor is attached to the steering rack or column via gear mechanism and sensors are located on the input shaft in EPAS system. It uses electromechanical actuation where the sensors determine the driver’s torque, steering angle and speed and direction of the steering wheel. The sensors together with the vehicle velocity are fed into the ECU. The resulting demand from the ECU process is used to excite the circuitry of the motor and finally giving an output to the rack [6].

In the research on EPAS system, the primary goals are to reduce the steering torque exerted by the driver and also to improve the steering performance. In line with these goals, many control strategies have been applied and implemented in the EPAS system such as a reference model, fuzzy logic, PID, H_{2} and H_{\infty} [7-11].

2.0 PID Controller

Proportional-Integral-Derivative (PID) control technique continues to provide the simplest and effective solutions in industrial control system application since its introduction in 1936. The PID controller has been widely used in the industry because of its simple structure and robust performance as well as low cost and cheap maintenance. [12, 13]. Three individual values of proportional, integral and derivative parameters involved in the PID controller calculation. The proportional value determines the reaction of the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing the weighted sum of these three actions is used to adjust the process via the final control element [14].

The PID controller tuning aim to determine its proportional, integral and derivative parameters that fit into the system to assure the closed loop system performance specification and robust performance of control loop over a wide range of operation are met [14]. In practice, it is difficult to ensure the system meets all the desirable qualities simply because the behavior of the parameters. For example, in achieving a better transient response of the system, its response under disturbance condition will be slow.

In the industrial plants, it has been difficult to tune the PID controller gains properly because of the uncertainties encountered in control system both in the environment and within the system [15]. Resulting from this, the conventional PID controller cannot provide solutions to all control problems because of the complexity, inadequate dynamic definition and time-variant with delays and non-linearity [13]. To improve the conventional PID, many optimization methods have been developed such as auto tuning and intelligent PID controller.

3.0 Particle Swarm Optimization (PSO)

Particle Swarm Optimization is a population based evolutionary algorithm which originally developed by J. Kennedy and R. C. Eberhart on 1995 [16]. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [12]. 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.

This method is developed from research on swarm such as bird flocking and fish schooling. It has features of easy implemented technique, stable characteristic convergence and good computational efficiency[17]. Instead of using evolutionary operators such as mutation and crossover to manipulate the particle, a flock of particles is put into the d-dimensional search space for a d-variable optimization problem. Each particle flies within the search space with velocities and positions which is dynamically adjusted according to its
own flying experience and its neighbors’ flying experience [12, 14]. A fitness function is used in determining the optimal solution. At each iteration, the fitness of each particle is evaluated. Each particle keeps track of its own best position and its best fitness in the problem space it has achieved so far. This is called particle best or pbest. The algorithm used for updating the particle velocity and position at each iteration is in equation (1) and (2) below:

\[ v_{id_{\text{new}}} = (w \times v_{id}) + C_1 \left( \text{rand}(p_{id} - x_{id}) \right) + C_2 \left( \text{rand}(p_{gd} - x_{id}) \right) \]  
\[ x_{id_{\text{new}}} = x_{id} + v_{id_{\text{new}}} \]  

PSO also tracked another best value associated with the location of the best fitness particle which is called as global best or gbest. These two best values influence how the solution change or particle movement in the search space. PSO is faster in finding solutions than evolutionary computation methods because it produces random initial population and generates new population based on current cost [18].

4.0 System Modeling

There are four types of EPAS system which are column-type (C-type), pinion type (P-type), rack type (R-type) and dual pinion type. This paper uses C-type EPAS which consist of a torque sensor, an electric motor, a reduction gear, a column and a rack-pinion mechanism. Figure 1 shows the schematic diagram of EPAS system.

![Figure 1. Schematic diagram of the EPAS system](image)

The mathematical model of the EPAS system can be described as equations shown below,

\[ J_s \ddot{\theta}_s + B_s \dot{\theta}_s + K_s \theta_s = T_s + K_s \left( \frac{\dot{x}_s}{r_s} \right) \]  
\[ J_m \ddot{\theta}_m + B_m \dot{\theta}_m + K_m \theta_m = T_m + G K_m \left( \frac{\dot{x}_s}{r_s} \right) \]  
\[ M_r \ddot{x}_r + B_r \dot{x}_r + K_r x_r = \frac{K_s \theta_s}{r_s} + \frac{G K_m \theta_m}{r_s} - F_d \]
where $J_s$ is the steering column moment of inertia; $B_s$ is the steering column viscous damping; $K_s$ is the steering column stiffness; $J_m$ is the motor moment of inertia; $B_m$ is the motor viscous damping; $K_m$ is the motor stiffness; $G$ is the motor gear ratio; $M_r$ is the mass of the rack; $B_r$ is the rack viscous damping; $K_r$ is the tire spring rate; $F_d$ is the road random force; $x_r$ is the rack position; $r_s$ is the pinion radius; $T_s$ is the steering wheel torque from the driver and $T_m$ is the electromagnetic torque provided by electric motor.

According to the mathematical model, a Simulink diagram is designed. PID controller is used in the system to help minimizing the current and hence reducing its power consumption. The PID is known for its satisfying impact to the system performance, however it needs some tuning optimization to ensure maximum performance. Hence, the hybrid PID and PSO are applied in the system to improve the tuning of the PID controller. The mechanism is illustrated in the Figure 2.

![Figure 2. PID controller with PSO tuning of the EPAS subsystem](image)

### 5.0 Simulation and Result

From the mathematical model obtained, a Simulink diagram is constructed. The system utilizes the PID controller to reduce the power consumption of EPAS system. The hybrid PSO-PID controller is then applied to the system to find the optimal tuning performance of the PID controller. This approach is opposed to the trial and error technique used in conventional PID tuning.

Preliminary test is conducted to validate all parameters of PID controller and justify the potential of reducing the EPAS system power consumption. Figure 3 and Figure 4 show the performance of PID controller with random signal as the input and sinusoidal input signal respectively.
From Figure 3 and Figure 4, it shows that the PID controller provides a good control signal and able to control current accordingly. The test was simulated under a constant speed of 30km/h and at random driver's torque. It shows that the PID controller was able to control the assist current supplied to the motor as per requirement. However, the PID controller is tuned by trial and error which is time consuming and not the perfect optimal tuning.

Thus, to reduce the time consumption in parameters tuning of the PID hybrid PSO-PID is applied. In PSO, a swarm of particles is defined and each particle will be evaluated for its fitness at each iteration within the swarm. Particle with best fitness value is called local best and the best among the local best is called global best. This global best value is the optimum solution for the tuning. Parameters used in PSO algorithm are tabulated in Table 1. Figure 5 illustrates the controller performance for PID and hybrid PSO-PID controllers. Hybrid PID_PSO shows a better performance than PID controller. Simulation on power consumption shows that PSO-PID based controller produced a smooth power compared to PID controller. Figure 6 illustrates the comparison.
Table 1. Parameters of PSO algorithm

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of iterations</td>
<td>50</td>
</tr>
<tr>
<td>Number of variables</td>
<td>3 (Kp,Ki,Kd)</td>
</tr>
<tr>
<td>Swarm</td>
<td>70</td>
</tr>
<tr>
<td>Inertia weight, w</td>
<td>Wmax = 0.9, Wmin = 0.4</td>
</tr>
</tbody>
</table>

Figure 5. Controller performance of PID controller and PSO-PID controller
Figure 6. Power consumption comparison of PID controller and PSO-PID controller

6.0 Conclusion
The simulation done for PID and PSO-PID based shows an improvement in terms of assist current control and also power consumption of the assist motor. The result shows that PSO-PID controller able to control the current almost accurately and produce a smooth motor power. However, further improvement need to be carried out in the case of dynamic vehicle velocity. The PSO-PID based controller shows a potential in optimizing energy efficiency of EPAS system.

References


