

**การออกแบบตัวควบคุมพีไอดีสำหรับระบบเบรกแบบกันล้อล็อกด้วย
วิธีการหาค่าที่เหมาะสมที่สุดโดยกลุ่มอนุภาค**

**A PSO-based Optimum Design of PID Controller for
Anti-lock Braking System**

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บทคัดย่อ

ในปัจจุบันได้มีการนำเอาเทคนิคความฉลาดเชิงการคำนวณ (Computational intelligence techniques) เช่น ขั้นตอนวิธีเชิงพันธุกรรม การค้นหาค่าตอบแบบอาณานิคมมด และการหาค่าเหมาะสมที่สุดแบบกลุ่มอนุภาคมาประยุกต์ใช้ในการควบคุมขบวนการในอุตสาหกรรมขั้นสูง งานวิจัยนี้จึงมีจุดประสงค์หลักในการนำเสนอการนำเทคนิคในลำดับที่สามซึ่งมีความง่ายต่อการนำไปประยุกต์ใช้ รวมทั้งมีเสถียรภาพและมีคุณสมบัติที่ดีในการหาค่าตอบ ตลอดจนการคำนวณที่มีประสิทธิภาพ โดยจะนำเอาข้อดีของวิธีนี้มาใช้ในการปรับแต่งค่าพารามิเตอร์ของตัวควบคุมแบบพีไอดี ซึ่งประกอบไปด้วยค่าคงที่ในการควบคุมแบบสัดส่วน แบบปริพันธ์ และแบบอนุพันธ์ ซึ่งออกแบบบนพื้นฐานของผลตอบสนองการควบคุมแบบวงปิดที่ต้องการ เพื่อนำมาใช้ควบคุมการลื่นไถลของล้อรถยนต์ในระบบเบรกแบบกันล้อล็อก โดยจำลองการควบคุมกับรถโมเดลขนาด ¼ ด้วยโปรแกรมสำเร็จรูป เพื่อทำการทดสอบสมรรถนะของตัวควบคุมที่ออกแบบโดยใช้เทคนิคการหาค่าเหมาะสมที่สุดแบบกลุ่มอนุภาค เมื่อทำการเปรียบเทียบกับตัวควบคุมแบบพีไอดีที่ออกแบบโดยใช้การปรับแต่งค่าพารามิเตอร์ด้วยเทคนิคของ Ziegler-Nichols และตัวควบคุมแบบ Bang-Bang พบว่า ตัวควบคุมที่นำเสนอสามารถลดแรงดันที่เป็นเบรกตลอดจนลดระยะทางในการเบรกได้อย่างชัดเจน รวมทั้งสามารถควบคุมให้ตลอดระยะเวลาที่เบรกมีสัมประสิทธิ์แรงเสียดทานระหว่างล้อรถยนต์และพื้นถนนมีค่าสูงสุด ซึ่งเป็นการยืนยันว่าระบบที่เลือกใช้นี้สามารถนำมาใช้ในการควบคุมระบบเบรกแบบกันล้อล็อกได้อย่างมีประสิทธิภาพ

คำสำคัญ: ระบบเบรกแบบกันล้อล็อก, การปรับแต่งตัวควบคุมแบบพีไอดี, เทคนิคการหาค่าเหมาะสมที่สุดแบบกลุ่มอนุภาค

Abstract

The use of so-called computational intelligent techniques: Genetic Algorithms (GA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) in advanced industrial process controls is nowadays well established. The main objective of this research is to propose the use of Particle Swarm Optimization technique, which is easy to use, highly stable convergence and as well as highly computational efficiency, for tuning of PID controller which regulates the wheel slip in Antilock Braking System (ABS). The PSO searches for the control gains k_p (proportional gain), k_i (integral gain) and k_d (derivative or differential gain) which based on the desired closed-loop control response. The control algorithm is then applied to a ¼ car ABS model. The simulations are performed by using a commercial software package of purpose to test the braking performance from the customized controllers. By comparing Ziegler-Nichols Technique and the Bang Bang-controller, the effects of shock resistance from a brake pedal pulsations and the stopping distance are minimized. Furthermore, the friction coefficient between wheels and road surface can be maintained at maximum value. This is to confirm that the PSO-based optimum designed PID controller can be effectively performed for Antilock Braking System.

Keywords: Antilock Braking System, ABS, Tuning of PID, Particle Swarm Optimization, PSO

1. Introduction

An Antilock Braking System (ABS) has been introduced and developed since 1930s-1970s [1][2]. In 1945, the first implementation of ABS is found on a Boeing B-47 to prevent spin outs and tires from blowing and later in the 1950s, ABS were commonly used in airplanes braking system [3]. Antilock Braking System is used in purposes of providing the largest possible braking torque while keeping the vehicle maneuvered and preventing excessive wheel slippage. The major advantages of ABS are both reducing of stopping distance and enhancement of steering ability of vehicle in the same time. The performance of Antilock Braking System relies upon the proper identification of road surface types. There is currently no existence of affordable sensors which

can accurately provide the road surface conditions and make this information available for the ABS controller[4]. Moreover, the difficulties in designing of an ABS controller, as proposed by researchers in literature [5][6][7], are composed of the nonlinearity in the vehicle and braking dynamics, variation of model parameters over a wide range due to difference of road surface and vehicle conditions, operation of controller at unstable equilibrium point in an optimal performance and uncertainty of sensor signals creates problem[5]. Due to these Difficulties, Fuzzy logic control (FLC) is considered as a suitable controller to overcome these problems and also frequently applied in case of lagging of analytical modeling information. Furthermore, FLC is often shown its nature highly robustness

[8] and ability in handling of the uncertainties and nonlinearities in complex system likes ABS. FLC has been proposed to hold up the problem of ABS for the unknown environmental parameters[9]. Further review on an Antilock Braking Systems (ABS) control techniques is reported by Ayman A. Aly et al.[5]. Although FLC is an effective method for ABS control, its major drawback is the large amount of the fuzzy rule bases which make the analysis more complex. These fuzzy rules should be previously tuned by time-consuming trial-and-error procedures[10]. The conventional PID controller, which is characterized by small amount of computation, good real time and easy to implement etc., is considered as an alternative option using for ABS control. Tuning of proper PID control parameters can be achieved by many proposed methods such as Ziegler-Nichols or Chien-Hrones-Reswick method[11]. These conventional approaches are still having problems in tuning process that should be done by experienced engineer.

In the recent year, the soft computing, i.e. computational intelligence such as Genetic Algorithms (GA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO), has been extensively studied and developed [12], which leads to the application in advance control of industrial processes.

This research proposes the use of Particle Swarm Optimization (PSO) in conjunction with MATLAB/Simulink for an automatically optimized parameters tuning of PID controller. The ABS model will be simulated in the MATLAB/Simulink environment to test and verify

the braking performance of using PSO-based PID controller.

The comparisons between Bang-Bang controller, PSO-based PID controller and the traditional parameter tuning methods are performed to confirm the advantages of the proposed PSO-PID tuning scheme for using in Antilock Braking System.

2. Vehicle Dynamic and Particle Swarm Optimization

2.1 Simple $\frac{1}{4}$ ABS Car Model : In this research, the quarter-car ABS model in Fig.1 is considered as dynamic system to be controlled by closed loop controller. The mathematical model of vehicle dynamics can be divided in to 2 parts which can be described by the following equations, respectively

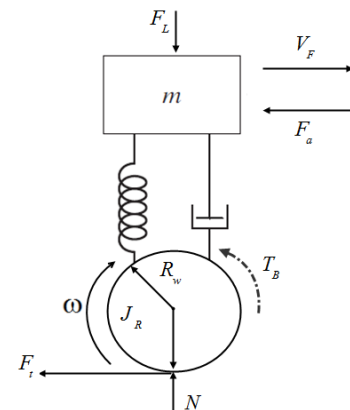


Fig.1 Free Body Diagram of $\frac{1}{4}$ ABS car model

- Vehicle dynamics

$$m\dot{v}_F = -F_t - F_a \quad (1)$$

$$m\dot{v}_F = -\mu(\lambda, v_F)F_L - (1/2)c_L\rho v_F^2 \quad (2)$$

- Wheel dynamics

$$J_R\dot{\omega} = \mu(\lambda, v_F)F_L R_w - T_B \quad (3)$$

where, $F_t = \mu(\lambda, v_F)F_N$: traction Force, F_L : vertical Load, $F_a = (1/2)C_L \rho v_F^2$: aerodynamic force acting on the vehicle, T_B : braking torque, v_F : vehicle velocity, m : quarter vehicle mass, J_R : wheel moment of inertia, ω : wheel angular speed, R_w : rolling radius of wheel, μ : friction coefficient, ρ : mass density of Air, C_L : drag coefficient and $\lambda = (v_F - \omega R_w)/v_F$: wheel slip

2.2 Particle Swarm Optimization (PSO)

Algorithm : PSO is computational technique based on heuristic evolutionary searching method. The algorithm is basically developed after being inspired by social behavior of bird flocking or fish schooling. [13]. It was first introduced in 1995 [14]. Later a modified PSO, where a new parameter called inertia weight: w is added, was then proposed in 1998 in order to improve the performance of the original PSO algorithm [15]. The particles are updated according to equations (4) and (5)

$$v_{i,m}^{(t+1)} = w \cdot v_{i,m}^{(t)} + c_1 \cdot \text{rand}(\dots) [Pbest_{i,m} - x_{i,m}^{(t)}] + c_2 \cdot \text{rand}(\dots) [gbest_m - x_{i,m}^{(t)}] \quad (4)$$

$$x_{i,m}^{(t+1)} = x_{i,m}^{(t)} + v_{i,m}^{(t+1)}; i=1,2,\dots,N \quad m=1,2,\dots,d \quad (5)$$

where: N : number of particles in the group, d : dimension, t pointer of iterations (generations), $v_{i,m}^{(t)}$: velocity of particle i at iteration t ; $[V_d^{Min} \leq v_{i,m}^{(t)} \leq V_d^{Max}]$, w : inertia weight factor, c_1, c_2 acceleration constant, $\text{rand}(\dots)$: random number between 0 and 1, $x_{i,d}^{(t)}$: current position of particle i at iterations t , $Pbest_{i,m}$: best previous position of the i -th particle, $gbest_m$: best particle among all the particles in the population.

3. PID Controller and PSO-based Tuning

Scheme

PID Controller parameters are composed of 3 independent terms namely: proportional, integral and derivative term. Each terms has constant gain noted as k_p , k_i , and k_d . An Appropriate tuning of these control parameters will improve the dynamic response and control performance of a considered system, reduce of maximum percent overshoot, eliminate steady state error and increase stability of the system. The transfer function of a PID controller is described in Equation (6) as following:

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_d s^2 + k_p s + k_i}{s} \quad (6)$$

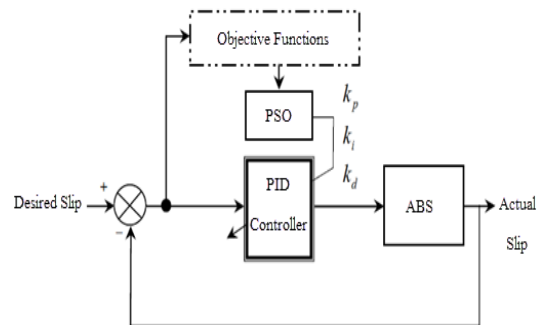


Fig. 2 PSO-based PID controller tuning scheme

The traditional parameters tuning method, i.e. Ziegler-Nichols and etc., can be usually done by a manual. This approach is not only time consuming but also not guarantee the best performance. The PSO-based PID controller tuning scheme showed in Figure 2 will be used to utilize these control parameters in conjunction with Simulink model of 1/4 Car ABS. The dynamic equations of ABS are described in equation (1),(2) and (3). An error used as input to PID controller is the difference between

desired slip and actual slip. ITAE (integral of time-weighted absolute error criterion) is selected as Performance indicators which being use as fitness function. It is defined as :

$$ITAE = \int_0^{\infty} t|e(t)|dt \quad (7)$$

Once, the PSO parameters are initialized. The dimension of PSO is equal to number of PID control parameters. The lower and upper bound of k_p , k_i , and k_d are $[0,200]$, $[0,20]$ and $[0,20]$, respectively. The tuning process, in MATLAB simulation, is performed with respect to PSO-based PID controller tuning scheme as shown in Fig.2. The simulation parameters indicated in Table 1 are implemented. The ZGN-PID control parameters are manually calculated by means of Ziegler-Nichols Method. The Bang-Bang controller is also introduced. The comparisons of 3 different tuning methods are performed and illustrated in the next section.

Table 1: Simulation parameters

Symbol	Quantity	Value
m	mass of $\frac{1}{4}$ car model	375 kg
g	gravitational acceleration	9.81 m/s^2
R_w	rolling radius of wheel	0.326 m
J_R	wheel moment of inertia	1.7 kg-m ²
v_F	vehicle velocity	30 m/s
Pb_{max}	maximum braking pressure	1500 N/m ²
λ_d	desired wheel slip	0.134
c_L	air drag coefficient	0.30

4. Simulation Results

The optimized PID-gains obtained from PSO are noted as: $k_p = 121.75$, $k_i = 8.50$, and $k_d = 12.75$. The ZGN-PID parameters are $k_p = 150$, $k_i = 2.50$ and $k_d = 2.00$ yields the results:

4.1 Wheel Slip – Stopping Distance and Time

The simulation results shown in Fig.3-10 are based on simulation parameter in Table 1. Three types of controller are introduced to control the desired wheel slip in order to get the possible better performance than braking without ABS. In Fig.1 indicated that wheel slip reaches maximum point, i.e., in case of braking without ABS which results to wheel locking condition. The PSO-based PID controller (PSO-PID) can regulate the wheel slip to maintain at target value of 0.134 without any oscillation while Bang-Bang controller and PID controller with Parameter obtained from Ziegler-Nichols tuning method (ZGN-PID) failed to suppress this fluctuation. The comparison of stopping distance can be seen from Fig.4, It's clearly shown that the shortest distance can be achieved from PSO-PID controller. The results from ZGN-PID and Bang-Bang Controller are acceptable and better than No ABS which has the longest way before the Vehicle Speed is decreased to zero.

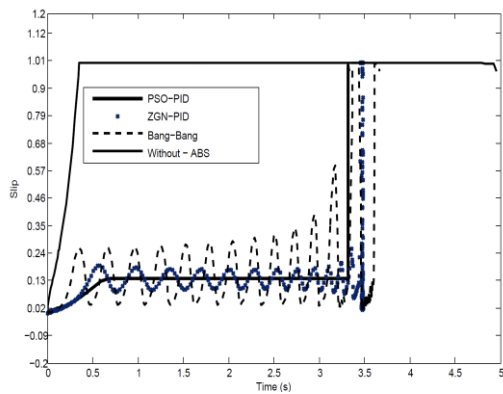


Fig.3: Comparison of wheel slip

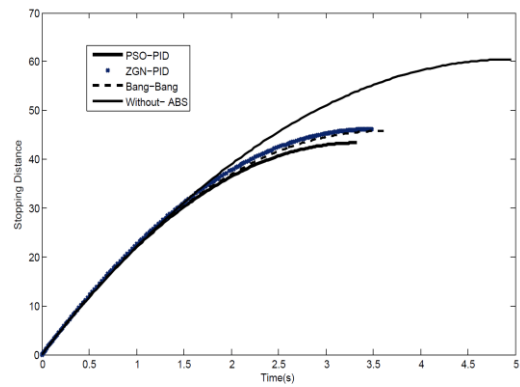


Fig.4: Comparison of stopping distance

4.2 Vehicle Speed vs. Wheel Speed and Time

The vehicle and wheel speed curve as showed in Fig. 5-8 reported the superior performance of PSO-PID as Antilock Braking controller when compared with ZGN-PID and

Bang-Bang Controller, as well as without ABS scenario. The wheel speed was decreased steady, without any rise and fall in speed, in the same manner with vehicle speed so the stable steering can be achieved.

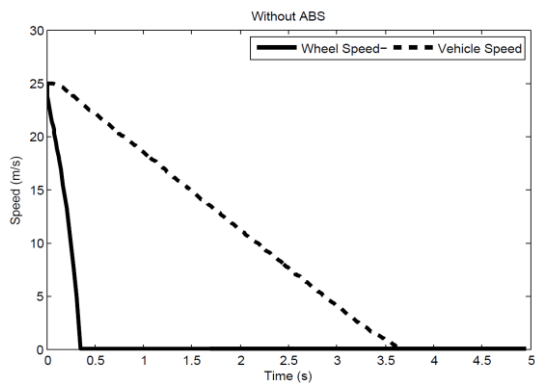


Fig.5: Vehicle-wheel speed without ABS

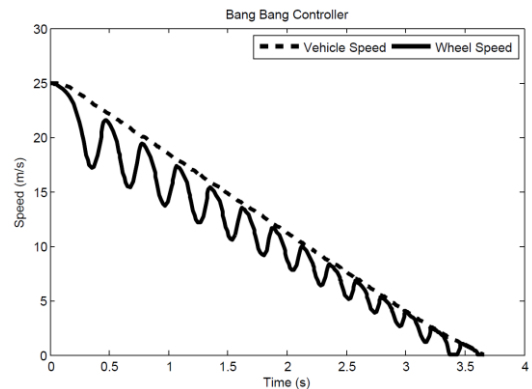


Fig.6: Vehicle-wheel speed with Bang-Bang

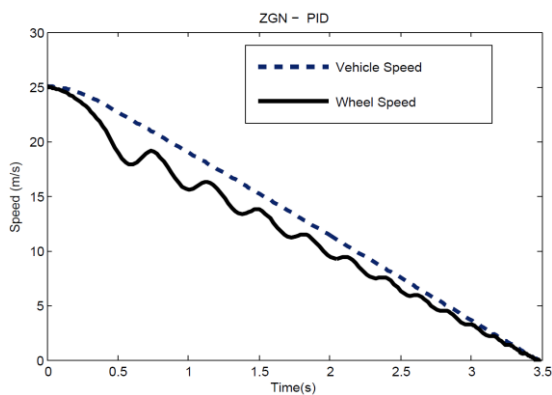


Fig.7: Vehicle-wheel speed with ZGN-PID

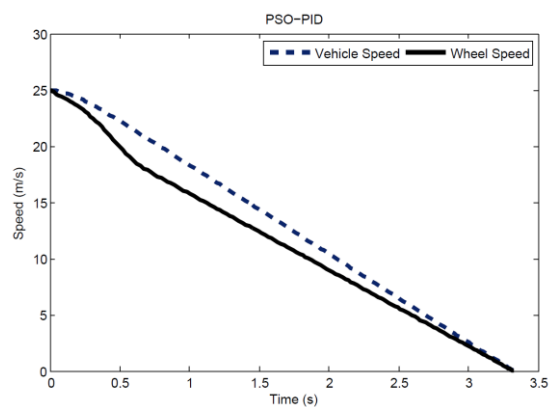


Fig.8: Vehicle-wheel speed with PSO-PID

4.3 Braking Torque - Friction Coefficient and Time

As indicated in Fig.9, the braking torque in the case of using Bang-Bang and ZGN-PID swings around the nominal point about 1000 N.m. caused rising up and down of Wheel Speed. Furthermore, this braking torque fluctuation can induce the shock resistance from a brake pedal pulsations which is uncomfortable for a driver. PSO-PID showed better result by providing steady braking torque and consequently, having no resistance pulsation force on brake pedal.

The comparison of friction coefficient values resulted from controllers during braking

process is shown in Fig.10. It's obviously seen that this controlled value remains constant at $\mu = 0.80$ by using PSO-PID and a few lower than 0.80 by ZGN-PID controller. In contrast to this result, Bang-Bang controller could not regulate this coefficient steadily, but oscillatory. In addition, it's presented that the friction coefficient value suddenly reached peak value about 0.80 and then decreased to maintain constant value of 0.50 as fully locked wheel condition existed. The vehicle still kept moving. Hence the vehicle control was consequently unstable and out of control.

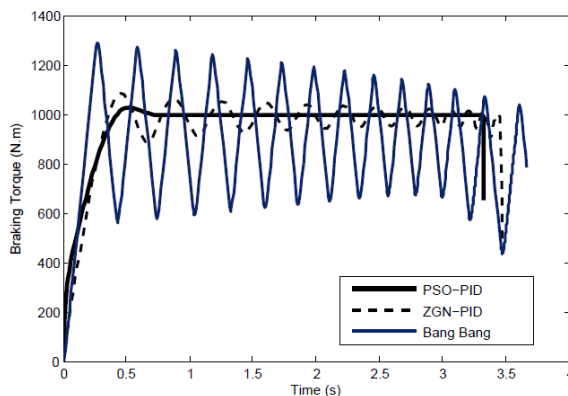


Fig.9: Comparison of braking torque

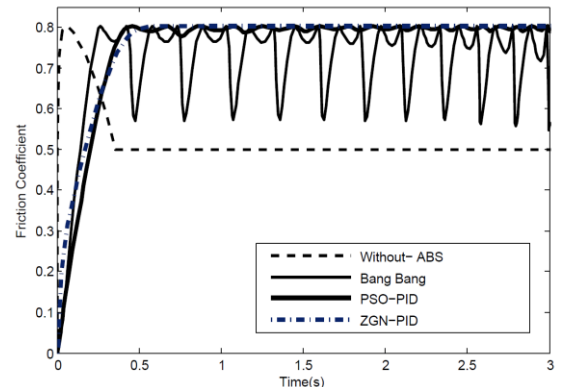


Fig.10: Comparison of friction coefficient

5. Conclusions and Discussion

Antilock Braking System model of a quarter-car is modeled in MATLAB/Simulink. The Particle Swarm Optimization (PSO) is implemented in m-Code, MATLAB environment, as tuning scheme to automatically adjust the optimized control parameters in PID-controller. The comparison of 3 controllers, i.e. Bang-Bang, ZGN-PID and PSO-PID, was carried out in order to measure the braking performance. The

simulation results clearly illustrated that the ground vehicles embedded with ABS control module have improved the braking performances and maintained better directional stability, vehicle maneuverability, that prevent the wheels from being Lock when a vehicle stops in emergency situations. The PSO-based PID controller showed better results, i.e. good vehicle stability, shorter stopping distance, than the conventional ZGN-PID and Bang-Bang controller, respectively. Besides,

PSO-PID also provided not only an improvement of braking performance but also the minimized braking resistance pulsation force on brake pedal. It's clearly seen that PSO is an effective tool for tuning PID parameter. The optimized parameters provided better braking performance than the conventional tuning method and Bang-Bang controller.

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