PID Control of Vehicle Active Suspension Based on Particle Swarm Optimization

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Abstract. In order to select the PID controller parameters, particle swarm optimization (PSO) is used to optimize the PID controller parameters. To evaluate the ride comfort of the vehicle, the objective function is established which integrates the vertical acceleration, suspension dynamic travel and tire dynamic load, and the controller parameters are optimized by particle swarm optimization. Simulate it in the software MATLAB. The result shows that the function of PID controller after particle swarm optimization is better than that before optimization.

1. Introduction

The automobile suspension is one of the important components of the automobile. In order to improve its function, people have discussed from time to time, and presented the automatic suspension, which can control the suspension movement, improving the ride comfort of the vehicle. There are many ways to control automatic suspension. Among them, the PID control is the most commonly used way. It has been studied for nearly one hundred years, and has put forward a variety of parameter solutions and improving methods. In determining PID controller parameters, there are formulas to calculate traditional methods such as echo curve methods. These methods have certain advantages, but they can only be applied to objects that meet the conditions of the experience formula, and only apply most methods.

With the development and the use of intelligent technology, intelligent approaches such as neural network approach, genetic algorithm and rule-based adjustment approach have been emerged. They are flexible and can be used sensitively to build controllers. They can extend the scope of use and reduce restrictions, but they still have quite a few drawbacks. For example, the optimization speed of genetic algorithm is slow and difficult to improve. Particle swarm optimization (PSO) is a swarm intelligence optimization algorithm presented in recent years, with the advantages of complex structure, fast convergence speed, less setting parameters and easy completion\cite{1}. It can effectively handle complex optimization results. In this paper, the PID parameters are optimized by this algorithm,
and the optimal PID parameters are searched when some vehicle parameters are set. After modeling and simulation, the data obtained before and after optimization are compared to verify the effectiveness of optimization.

2. PID control

PID controller usually consists of three control links: proportional, integral and differential. Proportional links provide the system with open-loop gain, reducing the steady-state error of the system, and improving the control accuracy of the system[2]. Integral link is used to improve the anti-interference ability and eliminate the dynamic error of the system. The function of differential linkage is to avoid deviation change and to control according to deviation velocity. The PID control system of suspension consists of controller and suspension. PID controller is a linear controller whose output is a bias between the given signal and the practical input signal.

Researches found that if K is increased, it has less adjusting time[3]. However, if the scheme K is too large, it may attack over. Local integral plays the role of dynamic error, and the larger the coefficient K is, the weaker the integral role will be. The late correction signal is introduced in differential link, which slows down the response speed of the system. The above three coefficients are difficult to adjust and it is difficult to get the best value through repeated experiments.

3. PID parameter optimization based on particle swarm optimization

3.1. PID parameter optimization based on particle swarm optimization

Particle swarm optimization is used to optimize the parameters of LQG controller. Particle swarm optimization (PSO) algorithm and the simulation model is the connection between the particles and the fitness value of particles, which is the performance of the control system[4]. Optimization process: PSO particle swarm was generated according to certain rules, which could be the initial particle swarm particle swarm or update ones, and the generated particles and LQG the parameters of the schemes of the particle swarm, which are respectively expressed by q1, q2 and q3, have equal relation to the controller. Then establish the simulation model in MATLAB SIMULINK, getting the corresponding performance indexes corresponding to the parameter setting. Then pass it to PSO to set the particle's fitness value, determining whether it meets the termination conditions.

Suppose that there are m particles in the n-dimensional object search space to form a community. The ith particle is expressed as an n-dimensional vector:

\[
X_i = (X_{i1}, X_{i2}, \cdots, X_{in}),
\]

\[
i = 1, 2, 3, \cdots, n
\]

That is, the position of the ith particle in the n-dimensional search space is Xi. The fitness value of Xi can be calculated by turning Xi into an objective function and the quality of Xi can be measured according to the fitness value. The "flying" speed of the ith particle is also an n-dimensional vector:

\[
V_i = (V_{i1}, V_{i2}, \cdots, V_{in}),
\]

At the same time, the velocity determines the displacement of particles in the unit iteration time of the search space. Then, the best location for the i-particle swarm is Pi:

\[
P_i = (P_{i1}, P_{i2}, \cdots, P_{in}),
\]

and the best position of the whole particle swarm is Pg:

\[
P_g = (P_{g1}, P_{g2}, \cdots, P_{gn}).
\]
In each iteration, the particle updates its speed $V_{id}$ and position $S_{id}$ through the individual extremum $P_{id}$ and the group extremum $P_{sb}$, then

$$V_{id}(n+1) = W V_{id}(n) + \eta_1 r_1 (P_{id}(n) - S_{id}(n)) + \eta_2 r_2 (P_{sb}(n) - S_{id}(n))$$  \hspace{1cm} (5)$$

$$S_{id}(n+1) = S_{id}(n) + V_{id}(n+1)$$ \hspace{1cm} (6)

Where: $W$ is inertia weight; $\eta_1$, $\eta_2$ are acceleration constants; $r_1$ and $r_2$ are random numbers between 0 and 1; $N$ is the number of iterations.

The fitness function measures the advantages and disadvantages of a particle swarm and is inversely proportional to the position of the particle. Since the fitness function should obtain its minimum value and the objective function has the same variation rule as the fitness function, the objective function is chosen as the fitness function of particle swarm optimization. In the objective function, the unit and magnitude of vertical vibration acceleration, suspension dynamic stroke and tire dynamic displacement are different, then the corresponding passive suspension performance index is obtained.

The fitness function $Z$:

$$Z = J_1(X)/P_1 + J_2(X)/P_2 + J_3(X)/P_3$$ \hspace{1cm} (7)$$

$$X = (q_1, q_2, q_3)$$ \hspace{1cm} (8)$$

$$J_i(X) < P_i; J_1(X)/P_1, J_2(X)/P_2, J_3(X)/P_3$$ \hspace{1cm} (9)$$

$$i = 0,1,2,3, s.t. \quad 0.1 < x < 6 \times 10^6$$ \hspace{1cm} (10)$$

Where: $J_1$ is the mean square root acceleration of optimized suspension parameters of active suspensions; $P_1$ is the mean square root acceleration of optimized suspension parameters of passive suspensions; $J_2$ is the mean square root of moving stroke of active suspensions; $P_2$ is the mean square root of moving stroke of passive suspensions; $J_3$ and $P_3$ are separately the root mean square value of tire dynamic displacement of active and passive suspensions.

3.2. The constraint condition determination and algorithm flow of optimization variables

3.2.1. Objective function.
The optimization variable of PSO is selected as the coefficient of PID controller's proportion, integral and differential. The objective function is a function of three objectives: the vertical vibration acceleration of the vehicle's center of mass, the dynamic suspension travel and the dynamic deformation of the tire. Since the units and sizes of these three targets are different, the optimization objective function can be obtained by dividing them by the corresponding active suspension performance index.

3.2.2. Fitness function selection.
The fitness function is the function of measuring particles. The larger $k$ value is, the better the particle is. Therefore, the maximum value of the fitness function $k$ should be obtained. The objective function is to seek the minimum value, so the objective function is chosen as the fitness function of particle swarm optimization.

4. Simulation analysis

4.1. Automatic suspension simulation
Establish the simulation model of two degree of freedom 1/4 vehicle automatic suspension in MATLAB SIMULINK and its parameters are shown in Table 1.

| parameter | $m_s$ | $m_u$ | $k_s$ | $k_u$ | $c_s$ |
|-----------|-------|-------|-------|-------|-------|
| /kg       | /kg   | /N·m  | /N·m  | /Ns/m |
where \( m_s \) is body weight; \( \mu \) is tire weight; \( k_s \) is spring stiffness; \( k_u \) is tire stiffness; \( c_s \) is damping coefficient.

Chose the roads of grade B and C, whose \( G_q(n_0) \) are \( 64\times10^{-6} \) and \( 265\times10^{-6} \); lower stopband edge frequency \( f_0=0.1 \); vehicle velocity \( v=20 \, \text{m/s} \); frequency index \( w=2 \).

### 4.2 The road simulation

The active suspension model is simulated by using the above optimization algorithm. After stabilization, the objective function value is 2.7252. The convergence curve of the objective function is shown in Figure 1.

![Figure 1 Objective function curve](image)

### 4.3 Simulation consequence analysis

The summary of simulation results is shown in Table 2.

| Items                  | Road conditions | Optimized PID | Normal PID |
|------------------------|-----------------|---------------|------------|
| Body acceleration/ \( (m \cdot s^{-2}) \) | Maximum         | 1.536         | 1.626      |
|                        | Minimum         | -1.427        | -2.342     |
| Suspension dynamic travel/m | Maximum         | 0.0112        | -0.0145    |
|                        | Minimum         | -0.1214       | -0.0137    |
| Dynamic load of wheel/N | Maximum         | 435           | 563        |
|                        | Minimum         | -643          | -664       |

Assuming that the initial particle velocity is random, after optimization, the objective function value is 2.7184, corresponding to the PID controller parameters. Compared with the active suspension before and after the optimization, the vertical acceleration of the vehicle body, the dynamic travel distance of the suspension and the dynamic load of the tire are obtained. The PID controller optimized by particle swarm optimization has better control effect than the controller before optimization in all aspects. Among them, the vertical vibration acceleration of quarter body mass center is reduced by 6.23%, suspension dynamic travel is reduced by 1.19%, and wheel dynamic load is reduced by 4.95%.

### 5. Conclusions

Suspension is one of the most important parts of vehicle, which can transfer the force and torque between the wheel and the body and strengthen the vibration and impact caused by uneven road surface. Conventional active suspension installations have no external power supply. The stiffness and damping of the suspension can only accommodate certain loads, vehicle speeds and certain road conditions. Therefore, the ride comfort and other objectives of the vehicle under different road surface and load conditions are not as good as the parameter adjustable suspension. Automatic suspension is equipped with the main actuator, which can produce the best control force according to the output.
parameters, so that the suspension has a good shock absorption function, improving the ride comfort and ground function of the vehicle.

Selecting a reasonable control algorithm can give full play to the function of automatic suspension. The results show that the optimized PID controller can effectively improve the vibration of body acceleration, tire dynamic load and suspension dynamic stroke. Due to the limitation and some uniformity of PID control, it cannot consider all performance indexes. However, particle swarm optimization PID controller can effectively reduce its limitations. While effectively controlling its main purpose, other shortcomings are also improved.

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