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Using improved chaotic ant swarm to tune PID controller on cooperative adaptive cruise control

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ABSTRACT

In the study of introducing PID controller into Cooperative Adaptive Cruise Control (CACC) system, there still exist some problems, such as driving comfort and fuel consumption problems. Also, not making rational use of intelligent algorithm to tune PID controller cannot be overlooked. Hence, this paper presents a way to tune PID controller using improved chaotic ant swarm (CAS) to achieve the goal of improving driving comfort, fuel consumption and reducing the minimum safe distance. CACC controller, composed of PID controller and safety distance model, is erected with joint simulation of PRESCAN and MATLAB/Simulink. This paper presents experiments carried out on vehicle queues at low and high cruising speeds under various kinds of working conditions, including platoon driving, cut-in, cut-out vehicle queue and so on. Additionally, the experiments were conducted, respectively, before and after setting the PID controller. Results based on the data analysis of velocity, acceleration, the scale of throttle and brake power, wheel vertical displacement and longitudinal spacing between the vehicles demonstrate that this paper improved driving comfort at the same time decreased the minimum safety distance and fuel economy.

1. Introduction

Traffic congestion is now a serious problem in most metropolises, resulting in fuel consumption, environmental pollution and especially low traffic efficiency. Besides, due to the driver's bad driving behavior, traffic accidents often happens [1–3]. CACC, based on wireless network and automatic control technology, achieves traffic information sharing and platoon driving at the premise of ensuring safe driving. Its primary purpose is to reduce string instabilities, improve the driving comfort and decrease fuel consumption. Under these conditions, PID controller has the characteristics of simple structure, reliable operation and convenient adjustment [4], introducing the PID controller into the CACC control system is of great practical significance. During the process, setting and realization of parameters are of vital importance for the design and application of PID controller. PID controller tuning is a typical multi-objective optimization problem, so applying genetic algorithm and ant colony algorithm to it becomes a popular and effective method.

A vast amount of literature of CACC is available. Milanés et al. [5] implemented a new CACC system on four production Infiniti M56s vehicles, and tested their CACC system in real traffic situations. Zohdy et al. [6] developed a heuristic optimization algorithm for automated vehicles (equipped with CACC system) at uncontrolled intersections using a game theory framework. Kloiber et al. [7] presented a concept to reduce the energy consumption and extend the range for EVs in case of traveling over longer distances, based on ITS communication. Güvenç et al. [8] presented the cooperative adaptive cruise control implementation of Team Mekar at the Grand Cooperative Driving Challenge. Schakel et al. [9] used the Intelligent Driver Model and CACC algorithms to assess the effects of CACC on traffic flow stability. Guo et al. [10] investigated sampled-data CACC of vehicles with sensor failures. Wolterink et al. [11] introduced a new geocasting concept to target vehicles based on where they will be in the direct future, instead of their current position. These literatures give us valuable experience on research.

However, there still exist some problems in CACC research. For instance, although the study on the platoon driving and safe distance has made relatively abundant achievements, the study on the driving comfort and fuel consumption is not enough. Furthermore, problems in the study on the PID controller tuning using intelligent

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Table 1
PID design method and its corresponding parameters and index.

PID controller tuning algorithm	CACO	ACO
K_v	0.7821	1.767
K_s	1.6937	1.202
K_a	2.8894	2.743

optimization algorithm such as slow convergence speed and local optimum limit the application and development of CACC to some extent.

Considering the ability of globally optimal searching, it is used as the tuning algorithm of PID controller to realize the optimization of CACC controller. Meanwhile, this study introduced the pheromone strength factor P_t to improve the algorithm convergence speed. Finally, the purpose of improving the driving comfort and decreasing fuel consumption is achieved. In order to prove the tuning PID controller using improved CAS, which can promote the performance of the CACC controller, this paper performed experiments on vehicle queues at low and high cruising speeds under various kinds of working conditions, including platoon driving, cut-in and cut-out vehicle queue and so on. Experiments were conducted respectively before and after setting the PID controller. Based on analysis of velocity, acceleration, the scale of throttle and brake power, wheel vertical displacement and longitudinal spacing, the method of tuning PID controller using improved CAS, which can improve driving comfort, decreases fuel consumption and safety distance of the vehicle equipped with CACC system.

The organization of this paper is described as follows. Section 2 introduces the way to tune PID controller using improved CAS in this study, and the method of how to match the safety distance model. Section 3 presents the experimental design and discusses the findings of this paper. Section 4 draws conclusions and proposes directions for further research.

2. PID controller tuning based on improved CAS

2.1. Improved CAS

Because of the globally optimal searching ability of CAS, it is suitable for the PID controller parameters tuning of this study. Besides, this study introduced the pheromone strength factor P_t to improve the algorithm convergence speed.

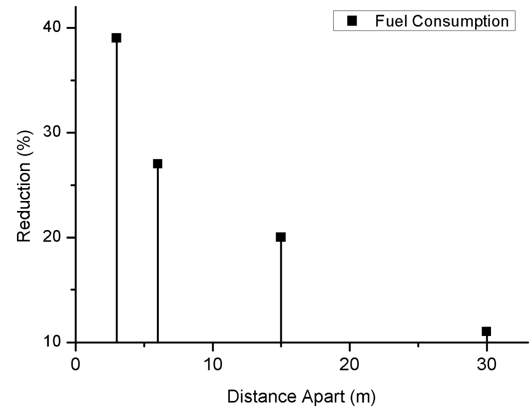

Fig. 2. Measurement results of fuel consumption at 89 km/h [21].

In order to tune PID controller with improved CAS, this study makes $K = [K_v, K_s, K_a]$ to establish the ant colonies individual vector K, and s, v, a respectively represent the safe distance, velocity and acceleration. In the meantime, this study uses 10 ants to form the ant colonies, the maximum search space d is 30. On the basis of normal formula of improved CAS and PID controller of this paper, formula (1) is generated. In order to make K move to the best position of objective function, this paper makes $\alpha_i(n)$ as continuously changing organizational variants. In formula (1), n is the moment of the present step for the individual ant, and $n-1$ is the moment of the previous step for the individual ant. In this paper, the tissue factor of the algorithm is r_i, the ant crawling velocity. It influences the convergence rate and optimization effect of tuning PID controller based on CAS. In the CAS of this paper, the pheromone evaporation rate is σ, and its value is 0.95. In order to make 10 ants have different crawling speed, this paper makes $r_i = 0.2 + 0.1S_t$, and S_t is a random number of uniformly distributed among 0 – 1 .Besides, f is used to represent the iterations of the algorithm, and its value is 20. The search range of tuning PID controller using CAS is decided by ψ_d, and with the search range ω_d, there is such a relationship $\omega_d \approx 7.5/\psi_d$. The current state of the d-dimensional variable of ant i is $K_{id}(n)$, and $d = 1, 2, \ldots 30$. The η is a constant which varies from 0 to 2/3. The searching area of ant i is determined by V_i, and its value is 0.5. The other parameters of formula (1) are a and P_{id}, the former

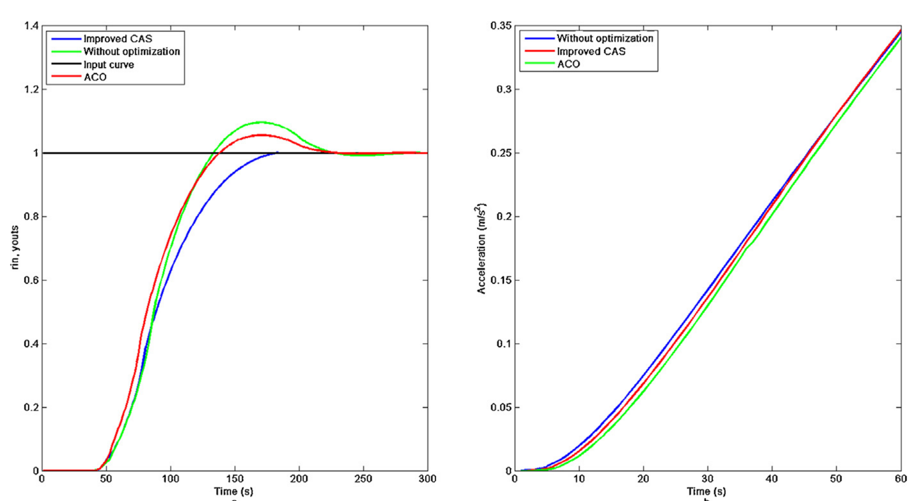

Fig. 1. PID controller step response curve and acceleration curve.