Vehicular Distance Regulation System

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***Abstract*—Avoiding collision is a crucial issue in most transportation system. Accidents can be minimized by using intelligent vehicle cooperation based on reliable communication system. This leads to Cooperative Adaptive Cruise Control (CACC) system that was developed by adding vehicle-vehicle wireless communication to the Adaptive Cruise Control (ACC) system. The result is that the vehicle can follow more closely, accurately, and safely, with braking and accelerating done cooperatively and synchronously. This paper presents the design, development and optimization of a CACC system. The idea behind CACC is not only to have a vehicle's cruise control system maintain a proper following distance behind another vehicle by slowing down once it gets too close, (ACC), but also to allow cars to "cooperate" by communicating with each other while in the adaptive cruise control mode. Ant Colony Optimization (ACO) algorithm is used to optimize the parameters in the design of a controller. This optimization leads for the development of more accurate system.**

***Index Terms* — Adaptive Cruise Control, Cooperative ACC, Ant Colony Optimization, Intelligent Vehicle.**

I. INTRODUCTION

The main societal and technical problems stemming from mobility are congestion, carbon dioxide emission, and safety. Intelligent vehicles based on on-board perception devices have improved road safety. ACC systems which are developed as comfort systems are the first generation drive assistance system that can influence the traffic flow characteristics .But for smaller headways time (<1s) ACC is known to be string unstable. To prevent string instability, the ACC system commonly based on RADAR and LIDAR should be extended with wireless communication link. The resulting system is called Cooperative Adaptive Cruise Control (CACC) System.[30]

The next step in the development of advanced driver assistance system is the cooperation of wireless communication with the intelligent vehicles. This provides more extensive and reliable information about the vehicles in the surrounding area. By in cooperating V2V communication the ego vehicle gets information not only from its preceding vehicle but also from the leading one. Due to this preview information oscillations due to speed change can be reduced. As a result relatively large inter-vehicular distances can be employed.

When the design of CACC system is considered, string stability plays a key role. The aim is to design a system that can minimize the disturbances propagated from the leading vehicle to rest of the vehicles in the platoon. The car following gap regulation can be obtained by two different approaches. First one is based on constant spacing and the other one is based on constant time gap.[30]

With the ongoing advancement of artificial intelligence and wireless technology, the emphasis has turned to Telematics technology integrated with Advanced Driver Assistance Systems (ADAS). The interest in ADAS applications has been expanding since the early nineties as a tool for making traffic more efficient and safer. ADAS technology functions by reducing the dependence on the human aspect in the driving task. This paper describes a new control system design and implementation based on Ant Colony Optimization technique. Tuning a PID controller means setting the proportional, integral and derivative constant to get the best possible control for the tracking process. The proposed Ant Colony Optimization (ACO) algorithm is used to optimize the parameters in the design of a (PID) controller. Experimental results demonstrate the efficiency and the performance of the proposed ACO based PID controller.[30]

II. RELATED WORKS

Prior experimental results using vehicle–vehicle cooperation to improve vehicle-following performance were achieved by the California Partners for Advanced Transit and Highways (PATH) in 1997 [7] that involves eight fully automated cars was carried out using wireless communication among vehicles, mainly for longitudinal control, and magnetic markers in the infrastructure, mainly for lateral control. Based on the idea of a leading vehicle guiding several followers, the Safe Road Trains for the Environment (SARTRE) European Union project has developed virtual trains of vehicles in which a leading vehicle with a professional driver takes responsibility for each platoon [9]. The European project called CHAUFFEUR [10] developed the concept of the professional driver in the first vehicle. Specifically related to CACC implementations in production cars, two important projects were recently conducted in the Netherlands. The Connect & Drive project, funded by the Dutch Ministry of Economic Affairs, carried out a CACC demo using six passenger vehicles [11] adopting a constant time gap spacing policy. For the Grand Cooperative Driving Challenge competition in 2011, nine heterogeneous vehicles from different European research institutions tried to perform a two-lane CACC platoon [12]. This competition revealed some of the most important problems to be solved before bringing this technology into production, including communication systems reliability. From the control point of view, most of the implementations were based on proportional proportional derivative feedback/feed forward controllers [13] or model predictive control techniques [16].

When it comes to designing a CACC system, string stability plays a key role [18]. The goal is designing a system able to reduce disturbances propagated from the leading vehicle to the rest of the vehicles in the platoon. There are two different approaches to car-following gap regulation, i.e., one based on constant spacing or one based on constant time gap. A comparative study between them, where CACC stability was discussed, was presented in [19]. Several papers have dealt with string stability analysis and simulations [20], based on simplified theoretical models of ACC vehicle-following behavior, and have shown encouraging results. However, real production ACC systems have significant response delays that have not been represented in the prior theoretical analyses but which destabilize vehicle-following responses. Consequently, those theoretical analyses have produced unrealistically optimistic estimates of the traffic stability impacts of ACC.

In previous PATH research, a CACC involving two vehicles was tested with very favorable results [6]. Building on that previous work, this paper describes a new control system design and implementation that is integrated in four production vehicles. A constant time-gap car-following strategy was implemented similar to the commercial ACC, but with the availability of significantly shorter time-gap settings. This is achievable because V2V communications permit tighter control of vehicle spacing and guarantee string stability, so that inter vehicle time gap settings significantly shorter than the production ACC time gap settings are comfortable and acceptable to drivers [24].

II. System Architecture

The vehicle under consideration, i.e, the ego vehicle consist of a lidar based ACC, blind spot detection system and a lane departure warning system. In order to obtain CACC a 5.9 GHz communication system with Global Positioning System (GPS) is incorporated in the safety unit. The data from both the Wireless Safety Unit (WSU) and the Controller Area Network (CAN) is received for the proper controlling of the vehicle.

A. Control Architecture

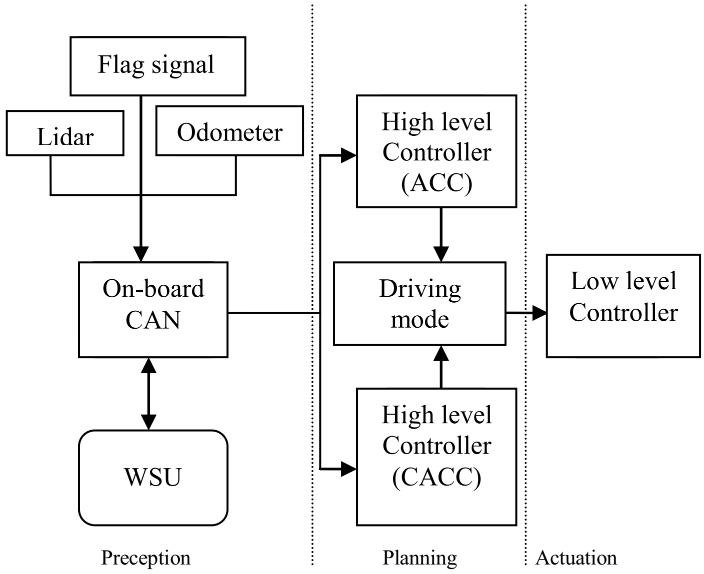

Fig.1. Block Diagram of Control Architecture

Target speed command is send to the actuators by the controller. The control variables for both ACC and CACC are the same. But in CACC the control action is to be carried out through low-level controller. The control architecture is shown in fig.1. The control architecture consists of three stages:

i) Preception phase: It receives the information for all the sensors installed in the vehicle. The CAN receives information from two sources one is the WSU system and the other is the on-board sensors. The data communicated by other vehicles include the speed, acceleration, current time gap and so on are receiver through the WSU system. The relative distance between the ego and preceeding vehicles is measured by lidar data. Odometer gives the current speed and acceleration of the ego vehicle. The information about the driver, driver interface interaction such as activation and deactivation of the system is obtained through flag signal.

j) Planning phase: This consist of high-level controller. The newly developed CACC system and commercial ACC system is available. The CAN bus information is read by the control code to perform the switching action. The different transmission mode available includes eco-driving made, sport mode, snow mode or standard mode. The high level controller choose the CACC output if the selected mode is sport mode. In all other case the ACC output is carried to the low-level controller. Either by pressing the brake pedal or by using the interface button, the driver can deactivate the CACC controller.

k) Actuation phase: Commands received from the planning stage are executed. The speed commands are converted into throttle or brake action by the low-level controller.

B. Vehicle Model

Vehicle performance is evaluated using the vehicle model. Speed commands to the vehicle are generated using the open loop controller. The braking response has an overshoot due to high engine braking force. The vehicle model is represented by a second order equation

$$F(s) = ke^{-T_d S} / s^2 + 2\theta\omega_n s + \omega_n^2 \quad (1)$$

Where k is the gain, θ is the damping factor, ω_n is the natural frequency and T_d is the delay time. Both the dynamics of the vehicle and the low level controller to manage the throttle and brake action is incorporated in the model.

TABLE 1
MODEL PARAMETERS

	k	θ	Wn	Td
Accelerating	0.156	0.661	0.369	0.146
Braking	1.136	0.5	1.067	0.287

III. CONTROL DESIGN

The CACC controller is used to maintain the desired time gap. It includes gap settings, options to increase or decrease the speed. The shortest gap set is 0.6s. Other gap setting available for CACC controller is 0.9s and 1.1s. The CACC controller design limitation include: Low-level controller modification is not possible and also the low-level controller limits the speed to its maximum value.

Design of controller consists of two stages. First one occurs when there is no vehicle in front of the ego vehicle. In this case the vehicle will follow the set speed. This controller is called the gap closing controller. It is also used when a vehicle decided to leave the platoon and the ego vehicle has to cover the gap. This process is called the cut-out maneuvers.

Second one is the gap regulation controller. The car following policy is maintained depending on the time set by the driver. It is also responsible for maintaining the cut-in maneuvers.

A. Gap Regulation Controller

The vehicle switches to gap regulation controller when the ego vehicle is close enough to the preceding vehicle and the gap closing controller action is finished. In case of a ACC system it tries to reduce the gap error by using the information from the lidar. The gap error is given by the equation

$$x_e = x_r - v_f t_g$$

where, x_r is the relative distance, v_f is the speed of the ego vehicle and t_g is the desired time gap. For a CACC system the controller system is designed using standard PD controllers. The main goal while designing a CACC controller is string stability. Fig.2 represents the block diagram of CACC controller.

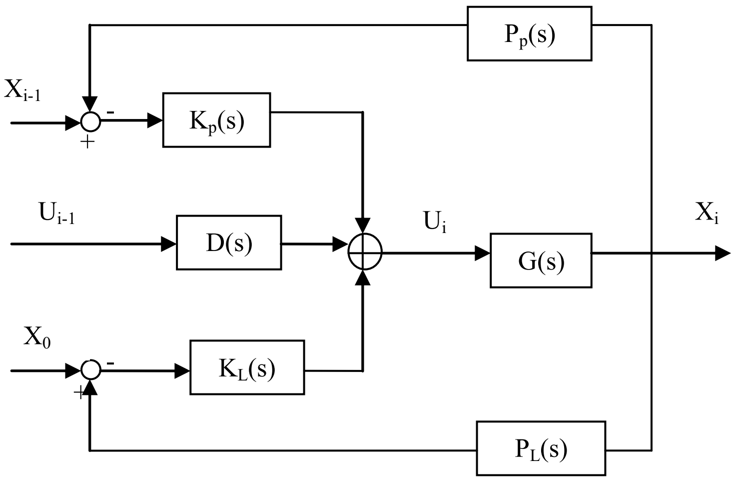

Fig. 2 Block Diagram of CACC controller

G(s) represent the vehicle model, the car following policy is represented by $P_p(s)$ and $P_L(s)$ and the gap regulation controller is represented by $K_p(s)$ and $K_L(s)$. D(s) shows the time delay of the communication system. X_i, X_{i-1}, X_0 represents the position of the ego vehicle, preceding vehicle and the leading vehicle respectively. The controller is designed to keep the current speed and also tries to keep the error as small as possible. The PD structure is defined as:

$$K_P(s) = k_1 s + k_2$$
$$K_L(s) = k_3 s + k_4$$

The car following policies is defined as:

$$P_P(s) = h_P s + 1$$
$$P_L(s) = h_L s + 1$$

where h_p and h_L are the time gap target values. Through experiments the value of k are obtained as shown in table 2.

TABLE 2
CONTROLLER PARAMETER

k1	k2	k3	k4
0.45	0.25	0.15	0.1

B.Gap Closing Controller

Fig.3 shows the gap closing controller operation. Dr_{start} represents the intial inter vehicle distance, relative speed is given by vr_{start}, vr_{end} gives the final relative speed while dr_{end} indicates the distance when controller switches to gap regulation mode.

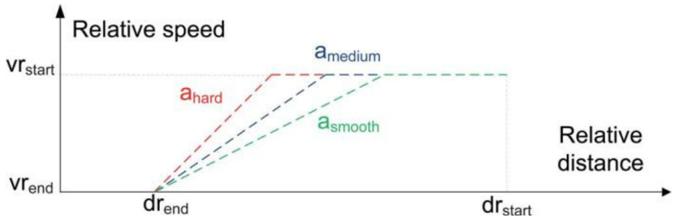

Fig.3 Gap closing controller operation

a_{hard}, a_{smooth}, and a_{medium} indicates the ego vehicle braking maneuvers. The smoother the deceleration, the earlier the vehicle starts.

B. Ant Colony Optimization

ACO is a probabilistic technique. It is a meta-heuristic optimization. The algorithm for this optimization is shown in fig.4. The ants navigate from nest to food source and each ant will move in random. Pheromone is deposited in the path and the path with more pheromone deposit increase the probability of path being followed. Path selected at random based on amount of trial present on possible path from starting node. The process continues until it reaches the starting node. The Finished tour is the solution

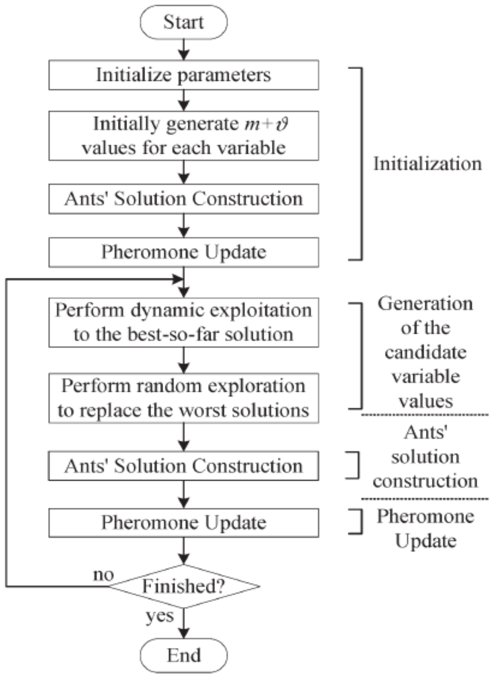

Fig.4 ACO algorithm

One first has to derive a finite set of solution components which are used to assemble solutions to the co problem. Pheromone model is the central component. The candidate solutions are obtained using the model and these solutions are used to modify the pheromone values. These update aims to concentrate the search regions of search space containing high quality solutions.

IV. RESULT AND DISSCUSION

The experiment is carried out using the MATLAB/ Simulink Model. The fig.5 represents the step response of the CACC system. By using ACO optimization the oscillations of commercial CACC system is reduced and a more accurate control is obtained.

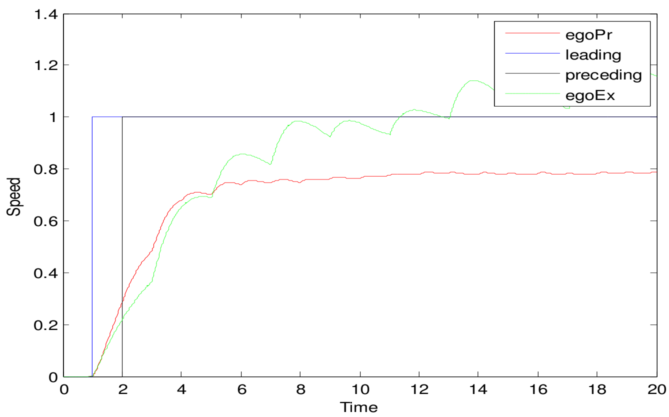

Fig.5 Step Response

Fig.6 represents the relative speed. Here also the ACO optimization has reduced the oscillations of commercial CACC system and produced more accurate result.

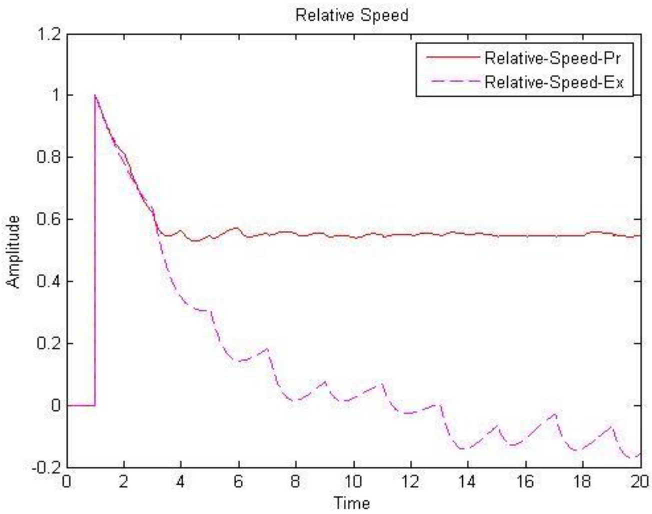

Fig.6 Relative Speed

V. CONCLUSION

In this paper an ACO algorithm is used to improve the working of commercial CACC system. The CACC system has the advantage of wireless communication system to exchange the vehicle information without any line of sight problem. The system has being developed with the help and simulink model and verified its working by giving various inputs like step input, random input and so on. Then the system performance is compared with commercial ACC, CACC and ACO optimized CACC system. ACO optimized CACC clearly showed improved performance in gap regulation and relative speed maintenance. Hence it clearly maintain string stability thereby improve highway capacity and traffic flow stability. This was clearly verified using random signal and checking its response for cut-in and cut-out maneuvers. Future research on this topic is mainly focused on the improvements that a CACC system might have on traffic response.

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