Mixed Inititiation for Cooperative Adaptive Cruise Control

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***Abstract*— Cooperative adaptive cruise control (CACC) is a nascent technology that purports to improve many facets of long haul traffic and road usage. Drivers may deploy CACC when traffic is steady and predicable. At other times, traditional driving is preferred. This paper reports on a simulation of CACC and explores the best times to deploy it. Platooning is among chief applications of CACC.**

Keywords—CACC, platoon, leader selection

I. Introduction

Traditional cruise control (CC) is a control mechanism to maintain a single vehicle speed at a preset value. Adaptive cruise control (ACC) is a control mechanism used to maintain intervehicle distance at a constant value. In modern vehicles, ACC is often package with a suite of other mechanisms including pre-collision, lane keep, and other safety features as driver assist features. ACC is performed anonymously and implicitly. The vehicle engaging ACC does not require consent or active participation from other vehicles. Cooperative adaptive cruise control (CACC) extends ACC to a variety of intervehicle speed and/or distance matching for an agreed upon time or condition. CACC requires communication and consent among vehicles involved. The cooperation is an explicit agreement among vehicles to maintain a harmonious, group travel driving pattern. CACC requires decisions to opt in and to opt out. Once opts in, vehicles actively communicate continually to exchange sensory information that is useful for keeping preset distances extending a two car ACC to a larger vehicle group. Alternatively, they actively share sensory information to maintain a preset group speed. CACC is a useful tool for platooning where a group of vehicles travel in close proximity for a substantial distance. Certain types of platooning offer fuel saving from physics of drafting where the following vehicle benefits from reduced drag coefficient from its ahead vehicle from the ahead vehicle. Platoons are also fuel and emission efficient since vehicles avoid frequent acceleration and deceleration. Platoons provide added safety and privacy from their collective driving patterns. CACC reduces total travel duration. Just as ACC subsumes CC, CACC subsumes ACC. Nevertheless, compatible combinations of deploying CC, ACC, and CACC are possible. Currently, exclusively in automotive research laboratories, CACC is a technology being explored for generally connecting vehicles on common roads for greater awareness and cooperative driving. Eventually, CACC will be an added vehicular feature to be added manufactured vehicles. In contrast, platooning is a methodology that may use CACC to keep vehicles together on the road. Platooning is best applicable when long distances are travelled by a group of vehicles that belong to a transportation or delivery agency. Furthermore, platooning might be accomplished without reliance on CACC.

When traffic flow is unimpeded, engaging cruise control offers many benefits including lowering the burden of fully attentive driving. Determining the frequency and duration of automated driving versus traditional driving is at the core of mixed initiation. An autonomous system can be trained to detect unimpeded flow and predict continued steady traffic; therefore, it can automatically initiate cruise control. Such autopilot system must be interrupted when driving events require deceleration and transition to less automated driving mode.

When general traffic speeds are near the speed limit and there are small deviations from the average surrounding traffic speeds, engaging ACC yields a more laid back, relaxed driving style along with other ACC efficiencies. Automatic ACC initiation is also possible when a car ahead is detected to be on CC or ACC to be interrupted when the car ahead is no longer on CC or ACC modes. Upon yet greater steady traffic patterns, CACC can be engaged for added benefits beyond ACC such as those of platooning. CACC initiation can be automated when: (a) the head vehicle is detected to be on ACC, (b) both the head car ahead and the follower vehicle are on CC, or (c) the vehicle has joined a platoon [1][2][3][4].

There are technological advancements in data collection, management, vehicle communication, and data storage of vehicular platoons [2][3][4][5]. Section 2 outlines CACC and ACC modes with presented with algorithms. Section 3 describes an implemented testbed we have developed for exploring ACC and CACC modes as well as our initial results. Concluding remarks are found in section 4.

II. CACC Algorithm

Fundamental components for using radar controlled ACC and CACC is outlined in Figure 1. ACC is only applicable if there is an ahead vehicle and it subsumes CC. If there is no ahead vehicle, CC is the default mode. CACC requires at least one vehicle ahead and one vehicle behind and subsumes ACC. Without being between two vehicles, the driving mode is reverted to ACC. ACC is considered as level 1 autonomous vehicle, which has been explored in academia and commercialized by the automotive industry. At level 1, the driver is responsible for steering, acceleration, and deceleration with the assistance of the system, yet the driver needs to be cautious with the surroundings even though the ACC can assist in preventing collisions. ACC system consists of various type of sensors and a data processing unit [1]. ACC system may use camera and radar sensors [6]. The radar will gather specific distances from other vehicles [6]. Front facing radar is used for collision detection when the distance is shorter than a certain amount or a certain range of the current speed. CACC system is an expansion of ACC, in which communication is set up between members to share driving information. The earliest research on CACC was by the PATH program [7]. CACC is ACC with a wireless connection between other vehicles or infrastructures. Mostly the research about CACC would only focus on the dynamics of the longitudinal direction in order to improve the performance of the string stability of the platoon. In our research, we also discuss the longitudinal dynamics only except for lane shifting occasions.

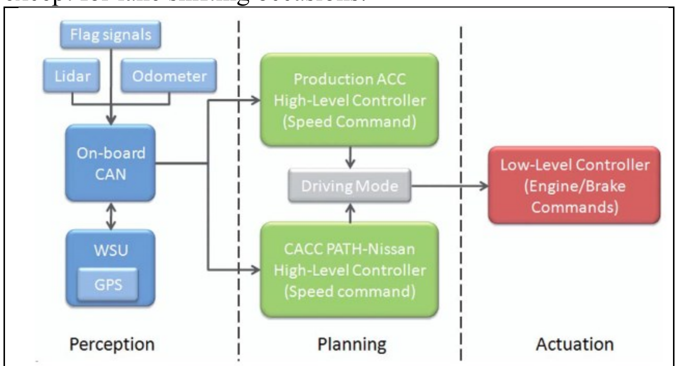

Figure 1. CACC System Structure

III. CACC TESTBED

Using Unity 3D we implemented a testbed for exploring the spectrum of sharing autonomy for speed and distance based vehicle following with three vehicles driving on a segment of a highway. Steering for lane maintenance is assumed automatic. The lead vehicle is programmed to drive at a relatively high and near the highway speed limit. The user is given adjustment tools to change the lead vehicle speed. The user can set the follower vehicles in ACC or CACC modes. Figure 2 shows a snapshot of the user interaction panel. The simulation consists of the three vehicles, the roadway surroundings, and the user interface. In the center of the environment, there are three vehicles depicted. Cr 1 is the lead vehicle. Car 2 is the middle vehicle following car 1. Car 3 is the trailing vehicle. When in the CACC mode, these three cars are form a platoon on the road and travel as a unit. Car1 is the lead vehicle, which is capable of maintaining a constant speed and direction set in the CC driving mode. The scrollbar to the left, labeled SPEED is used to adjust vehicle speed. By sliding the scrollbar, the tester will accelerate and decelerate the target vehicle. The scrollbar next to SPEED is BRAKE. This scrollbar is equivalent to the brake pedal on target vehicles, available to the user. The tester can simulate sudden braking that may arise from road obstacles or driver error, and research the car brake activity on succeeding cars to evaluate collision prevention, comfortable and etc. Car2 is the connection between the head and tail of the platoon. Car3 possess further mechanisms with capabilities to switch driving modes based on observing driving conditions of ahead vehicles. In summary, car1 is the lead vehicle, car2 is the intermediate vehicle and largely operates in ACC mode. Car3 as the last car in the platoon following Car2. We allow the third car be able to drive in either manual, CC, ACC, or CACC modes. For a given velocity, the distance covered by the car is determined by the expected distance covered at that velocity minus the distance during which brake was applied, given in equation 1.

$D_A = D_T - D_B$ (1)

D_A is the actual distance traveled, D_T is the distance that the car is expected supposed to travel for a certain velocity and D_B is the distance that the brake was applied.

Numerous experiments were conducted about the need to engage ACC and CACC. A prototypical two minutes of speed profiles was captured for analysis. Figure 3 shows when our control vehicle (i.e., car3) is driven manually. The peaks and valleys in Figure 3 highlight that there are energy wastage and the driving experience is not as steady as in ACC. The Figure 3 points labeled A-D are speed levels at which the manual driver user changed speeds. Car 1 drove in CC mode setting the leads vehicle pace. Car3 speeds are user choices and no rationale are available. Meanwhile, car1 followed CC mode and we observe steady speeds. Car 2 was in ACC mode and followed car 1 at near constant speeds producing similarly smooth speeds to car 1. At the end, car 3 is nearly caught up to car2 as it was adjusting its speed to follow car 2.

In Figure 4, car 1 is automatically put in CC driving mode. Car 2 holds steady following car1 using ACC. Our control vehicle (i.e., car 3) changes from manual driving mode at point A to ACC mode at point B, which makes it catch up to car2. At point C, all three cars gain similar speed for the remaining duration. This is as if they are implicitly in CACC mode. Slight gaps in speed curves reflect small delays in speed change transitions. In the real world environmental conditions affect sensors and natural speed gaps emerge similar to the ones we have shown. Adaptive cruise control relies on an ideal situations. Inclement weather will affect performance of ACC. Also, ACC is error prone with sharp turns in the road since sensors lose track of the preceding vehicle. To mitigate, we could either add more sensors or switch to CACC mode that rely on exact vehicle coordinates transmitted to car2. In Figure 5, CACC mode is turned on at point A. Therefore, all three vehicles start and remain close for the duration. The small gap between vehicle speeds is the natural lag present in ACC. The choice of when to engage ACC and CACC is a user choice but can be automated as discussed in [1].

III. Mixed Initiation of CACC

We explored the best times for deploying CACC, which is considered to be a toggle on and off assistance of smart cars. In our model, the decision is made by both the driver and the computer. In the user interface (see Figure 2.), there are two main statues detected by the vehicle: weather and road type.

There are three kinds of weather in the system: sunny, cloudy, and rainy, sorting by visibility for the driver. On sunny weather, the driver has the highest visibility and on rainy weather, the driver can barely see a thing. There are two types of road: urban and rural. In an urban condition, the traffic is assumed to be crowded. On the contrary, the rural road is less crowded. In Table 1 we present the preset recommend by the computer.

	SUNNY	CLOUDY	RAINY
URBAN	ACC	CACC	MANUAL
RURAL	CACC	CACC	MANUAL

Table 1. Preset Recommended Modes.

The table above is the initial selection of modes, the driver's experience and feedback will adjust the items in the table.

	SUNNY	CLOUDY	RAINY
URBAN	ACC	CACC	MANUAL
RURAL	MANUAL	CACC	CACC

Table 2. Recommended Modes after Drivers' Feedback.

Table 2 presents the recommendation system after several runs. This shows a mixed decision made by both the driver and the computer. The driver gives positive or negative feedback through driving experiences then the computer learns from the driver's behavior. Thus, on a higher autonomous level, the computer will turn the recommend mode on automatically to adjust to the driver's demand. The model is:

$$V_{Mode} = V'_{Mode} + V_{feedback}$$

Where V_{Mode} means the weight of certain mode, V'_{Mode} means the earlier value of the mode. The driver's feedback will adjust the priority of a certain mode.

```
Mode < Manual by default
If CACC option is selected
CACC mode is ON,
   Cruise Control is set to ON to maintain speed
   Search for the preceding vehicle.
     Radar is on for basic ACC function and wireless communication is on
   If the available preceding vehicle is detected
      If target speed decreases
        host slows down
      If target speed increases
        hosts speed up;
      If safe distance<=distance<Radar range
           Maintain distance
      If distance < safe distance (enter critical distance)
           Brake, Switch to manual mode
   Else maintain CC speed
```

Figure 1. CACC Algorithm Pseudocode

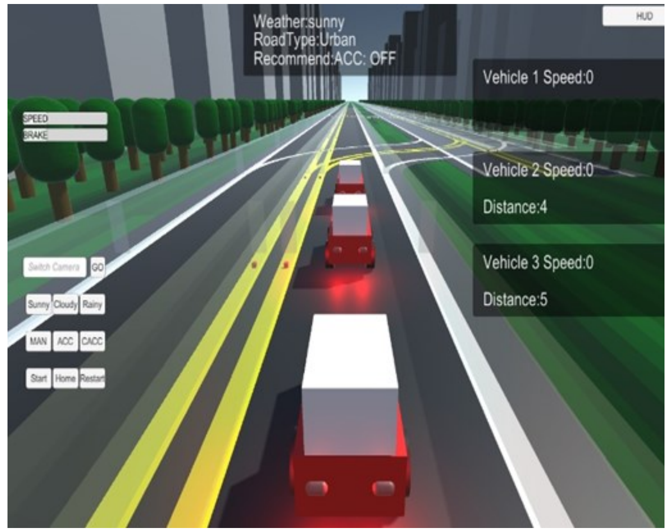

Figure 2. The Simulation User Interface

Table 1 shows that corresponding to Figure 3 whereas table 2 contains data points fo Figure 4.

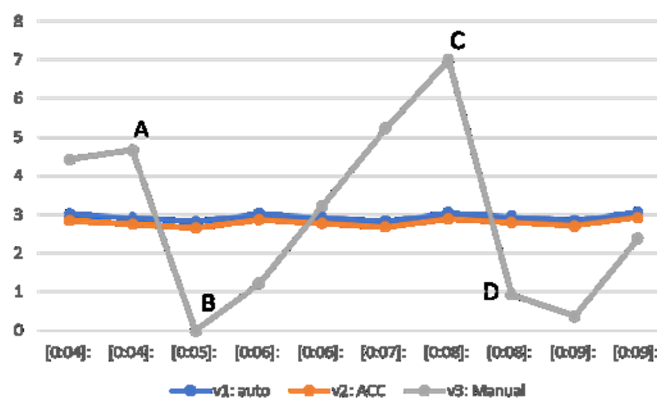

Figure 3. Speed changes during driving mode switch from manual to ACC

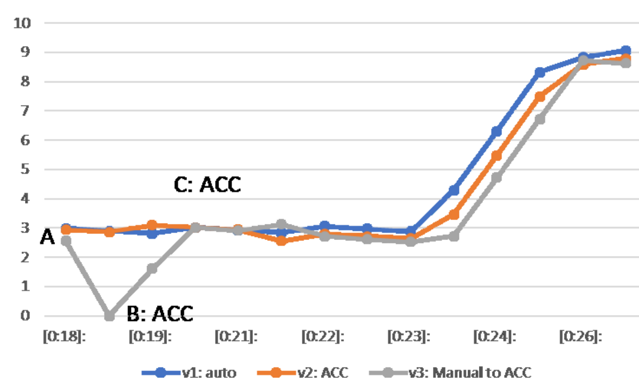

Figure 4. When the control vehicle changes from manual to ACC

Time	Vehicle 1 Speed (unit/s)	Vehicle 2 Speed (unit/s)	Vehicle 3 Speed (unit/s)	Vehicle 3 Driving Mode
[0:18]:	2.98133	2.94870	2.55	Manual
[0:19]:	2.89286	2.86947	2.41	Manual
[0:19]:	2.80473	3.0912	1.614	ACC
[0:20]:	3.01695	3.01353	3.014	ACC
[0:21]:	2.92951	2.93699	2.916	ACC
[0:21]:	2.84242	2.56167	3.1181	ACC

Table 1. Driving Mode of Vehicle 3 with Speed Data for Figure 3.

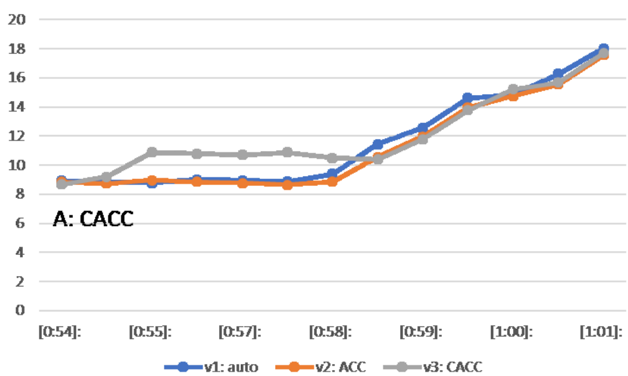

Figure 5. Control vehicle enter CACC mode

Time	Vehicle 1 Speed (unit/s)	Vehicle 2 Speed (unit/s)	Vehicle 3 Speed (unit/s)	Vehicle 3 Driving Mode
[0:53]:	8.98698	11.3564	11.7834	ACC
[0:54]:	8.91810	8.85792	8.68470	ACC
[0:55]:	8.84957	8.75947	9.18586	CACC
[0:55]:	8.78138	8.96103	10.8870	CACC
[0:56]:	9.01353	8.86257	10.7881	CACC
[0:57]:	8.94603	8.76412	10.6893	CACC

Table 2. Driving Mode of Vehicle 3 with Speed Data for Figure 4.

IV. Observations and Conclusions

CACC is a promising driver assist technology. Detecting when to engage CACC can improve safety and lower driver cognitive load. With this work, we have shown the need to determine the range of driver versus automated vehicle determination for CACC engagement. This range is controlled by adjustments in negotiated sense of autonomy between the driver and the vehicle driver assist system.

We have explored deciding when to engage ACC and CACC. Clearly, ACC can be used for close following to mimic platooning behavior. Automating automatic engagement of ACC is very reasonable and perhaps on the horizon. Explicit use of CACC give us more predicable driving patterns and application platooning. Automatic engagement of CACC is also reasonable and depend on capabilities to analyze traffic in real time. This in turn can be accomplished with machine learning approaches yet to be explored. Driver intention recognition as well as cooperative reasoning about driver intentions could also be used in mixed initiative decision making surrounding CACC.

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