Adaptive Cruise Control System for Vehicle Using Model Predictive Control Algorithm

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Abstract - *Adaptive cruise control (ACC) system is sub technology advanced driver assistant systems (ADAS) which is playing and critical role for Safety of vehicles and avoid the accidents. There are some other technologies like cruise control (CC), Blind spot detection, collision avoidance etc. which consider the ACC as base technology for them. Above all this Methods are improved their performance for autonomous driving. The Model Predictive Controller (MPC) is advance version of feedforward controller which have capability to predict for future. MPC also follow the constrains like speed limit, acceleration dynamics also MPC has preview capability. In this paper, a MPC based ACC system for vehicle is designed and Its results are observed in MATLAB. The ACC system is latest system for vehicles.*

Key Words: ADAS, Adaptive Cruise Control, Model Predictive control, multi-input multi-output.

1. INTRODUCTION

The cruise control is speed control for vehicles that automatically control speed of car or vehicles. ACC is modified, latest and advanced version of cruise control system that also adjust the speed of vehicles with considering the safe distances between them [1]. ACC system have increasing graph for automobile in last few years. The ADAS and ACC are both used as base technologies for autonomous driving technology [2]. This ACC will work with help of different sensors which help it to avoid accidents and sensors also help to detects such incidents previously so that driving actions are taken. So, it will a pre alert to driver to concentrate on driving in such situations i.e., lane change warning [3]. Latest ACC are using MPC method which is most popular now days. There are various studies and research are in this literature [1]-[10]. In past Cruise control PID controller was used but because of some drawbacks like optimization multi-input multi-output together are not possible on PID. MPC Can handle multi-input multi-output systems which have interactions between their input and outputs [4]. MPC can handle the input and output constraints that helps in improve the performance of overall ACC. The ACC can track the speed or set velocity and maintain safe distance from leading vehicle by adjusting speed of initial car.[4] The ACC system have three total subsystems Car acceleration dynamics with MPC, Collision Detection system and last is Lane change function for vehicles [5]. There are different features which will help about environment in vision range also rain density etc. The ACC will take the raw data from sensors then MPC will optimize that data and will take only required data. This data can be calculated with help of Radar sensors which are widely used in ACC Systems [1], [4].

The MPC computes optimal control actions while satisfying safe distance, speed, and acceleration constraints [6]. MPC uses algorithm for step prediction N for both acceleration and deceleration and then take the required control action or inputs. In ACC case like jerk is also considered for best comfort is considered by system [7]. In this study past cruise control system has some problems that will be considered in ACC system which is totally control an architecture for autonomous driving. ACC is designed in MATLAB with MPC and considered the cases like emergency break, free driving mode and second mode of driving. In section 2 the block diagram of ACC system with current technology is presented also mathematical equation for acceleration dynamics. In section 3 proposed system is given. In Section 4, the simulation and experimental results are given. In last section 5, conclusion is given.

2. METHOLOGY- THE SUBSYSTEM IN ACC

2.1 Block diagram For ACC.

The simple ACC system have 4 main parts as shown in below Fig.1 i.e., MPC controller, collision detection, car plant with standard acceleration dynamics and sensors. This block diagram will help to implement the ACC.

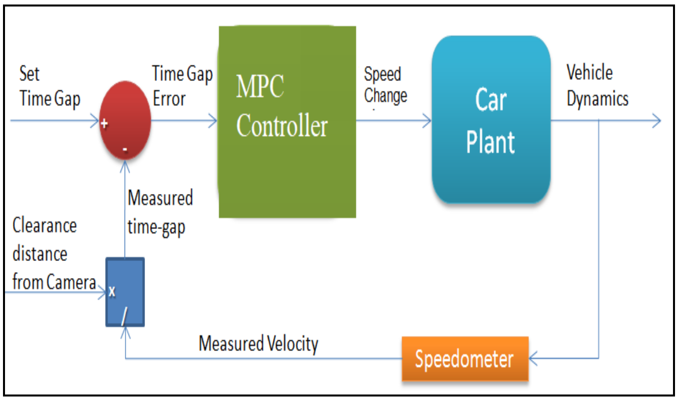

Fig -1: Block Diagram of Adaptive cruise control system

2.2 Mathematical modeling of acceleration dynamics

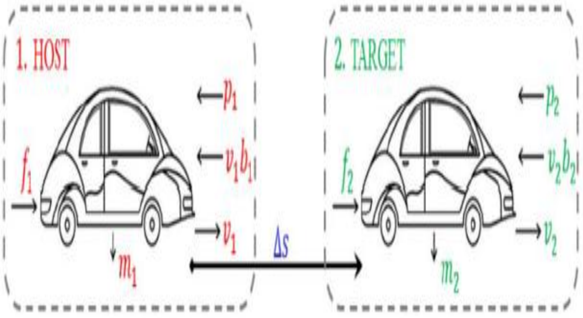

Fig -2: Model for leading car initial car

Here from Fig.2 is model for leading car and initial car consider this model of car understanding here we considered only weight m of car and friction with road and environment like air oppose given by b. The distance between the two cars is Δs. According to mass damper system the car has equation like [11].

$$m\frac{dv(t)}{dt} + bv(t) = u(t) - p(t)$$

Taking Laplace transform on both sides of above equation the transfer function in Laplace domain will be

$$V(s) = \frac{1}{ms + b}\big(U(s) - P(s)\big)$$

$$= \frac{K}{Ts + 1}(U(s) \ - P(s)$$

$$S(s) = \frac{V(s)}{U(s)} = \frac{K}{ms + b} = \frac{K}{Ts + 1}$$

Now This above transfer function is for both leading and initial car. Here we add integrator in acceleration dynamics. to get change in reference speed. So finally standard acceleration dynamics is given as follows:

$$G(s) = \frac{1}{(0.5s^2 + s\ )}$$

Here we can simulate above acceleration dynamics and we can see that the simple acceleration dynamics with MATLAB results in fig.3.

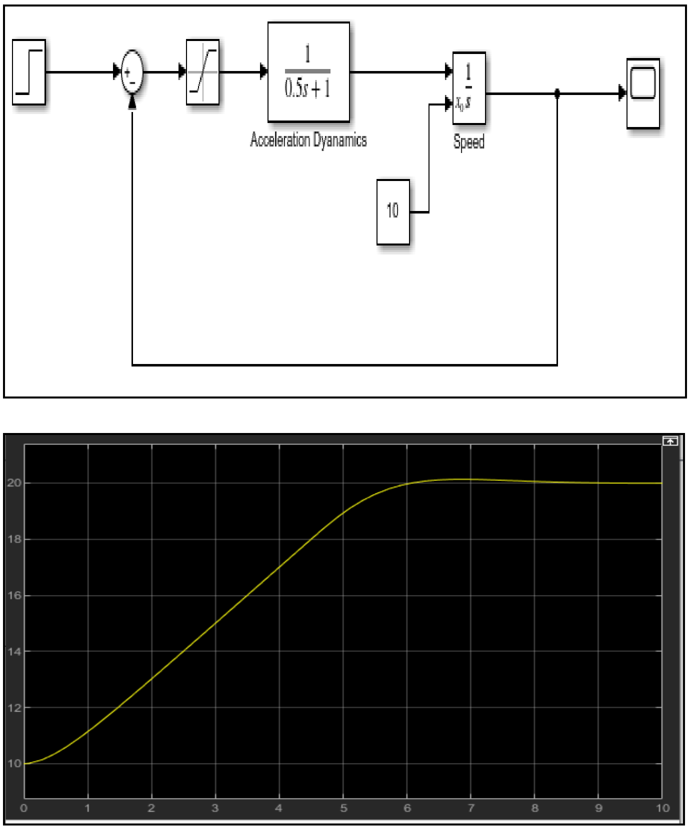

Fig -3: Acceleration Dynamics and vehicle following reference speed

Here from Fig. 3, we can get that with help of integrator we can externalize the speed value of "10 km/hr" for vehicle as reference speed and the saturation block is used to accelerate and decelerate the vehicle without reaching speed limit to negative. Here the speed is gradually increasing which will follow reference speed and overshoot is also not too much at starting In Literature we can find various types of controllers are used in control algorithm [6]. As we discussed the model predictive control algorithm have preview capability which will help calculate preferred acceleration, deceleration and safe distance constraints [11]. Here the two control loops are present in ACC as shown in below figure 4 where outer loop is consisting of MPC controller unit and Inner loop consider the acceleration and deceleration data. The performance Index also consider the relative safe speed, relative safe distance and emergency break conditions [6][11]. The ACC will control the speed for initial car according to the reference speed and relative distance and will follow the track desired speed also it is possible for vehicle to change the lane and cross the leading vehicle to reach at desired location within time.

3. DESIGN- THE PROPOSED ACC SYSTEM

The two rules are followed when ACC is considered:

So, from fig.2 If $Drel \geq Dsafe$ here this will activate the speed control mode. The controller must track the set velocity, Set. If $Drel < Dsafe$.,, here the distance maintain mode is active. The controller must maintain safe distance, Safe [12].

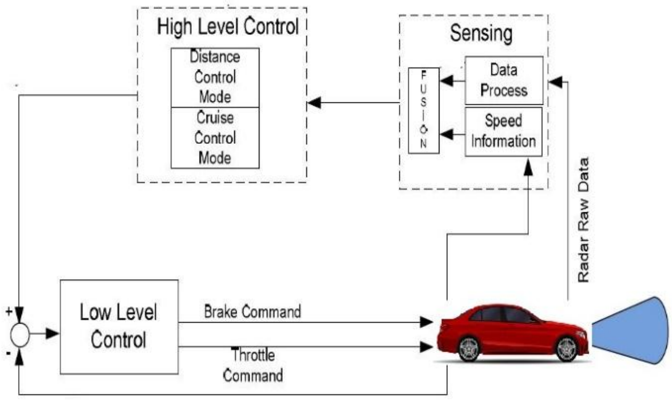

Fig -4: Proposed ACC system

The above architecture has multi decision control so that is used for autonomous vehicle control system. Here in fig. 4 the high-level control unit used to adjust the speed, desired velocity or to keep the minimum distance between two cars. The low-level control unit handle the controlling action on throttle or break which will maintain safe speed[17][18].

3.1 Three modes of ACC operation.

From above Fig 5. The ACC have three modes of driving ACC free driving mode considered as driving mode 1, this mode will only operate when relative distance between the two cars is greater than 50m otherwise the driving mode 2, i.e., vehicle following mode will operated because relative distance is less than or equal to 40m. In vehicle following mode the initial car will follow the leading car while maintain safe relative distance between them. And last ACC driving mode is Emergency break mode i.e., driving mode 3 which will be applicable only if relative distance is less than or equal to 10m between two cars.

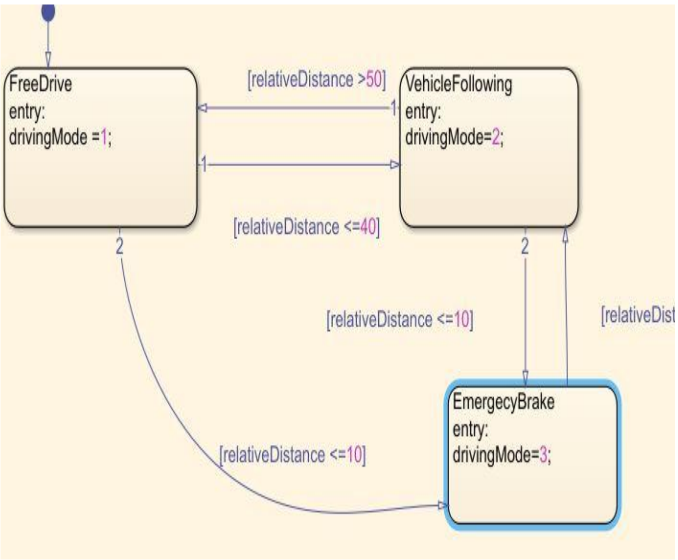

Fig -5: Three modes of ACC.

3.2 Collision Detection system.

The collision detection system will stop the ACC if there is sudden jerk or suddenly relative distance fall below 5m. The collision detection system consists of constant block in MATLAB have 2m as input which will be considered the half-length for vehicle. When the half-length will less than or equal to zero then simulation suddenly get stopped and ACC will exit the loop as shown in figure 6 below [13],

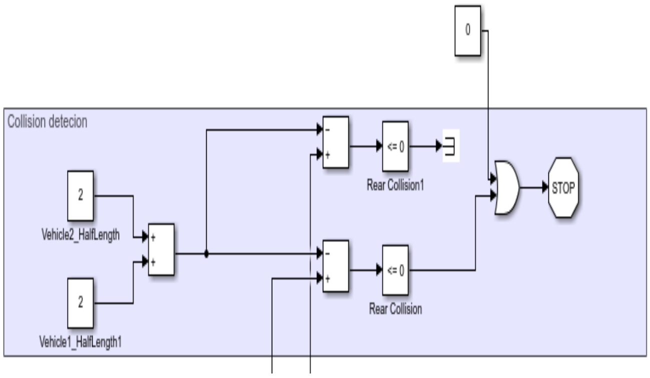

Fig -6: collision detection

3.3 Lane Change Function and 2D car preview.

The lane change function will have lane change program which carry logic to change the lane for initial car to cross the leading car to reach destination within specified time. And to visualize this in 2D we must specify some dimensions of vehicle in program, function plotVehicle(V1_Pose, V2_Pose, V3_Pose)

```
%% Clear previous Vehicle
cla;
%% Vehicle 1 - Pose
```

```
x1 = V1_Pose(1);
y1 = V1_Pose(2);
yaw1 = V1_Pose(3);
centerP = [x1;y1];
V1_HalfLength = 2; % Length = 4m
V1_HalfWidth = 1; % Width = 2m
% Creating a rectangle
p1 = [V1_HalfLength; V1_HalfWidth];
p2 = [V1_HalfLength; -V1_HalfWidth];
p3 = [-V1_HalfLength; -V1_HalfWidth];
p4 = [-V1_HalfLength; V1_HalfWidth];
% Rotation Matrix
Rmatrix = [cos(yaw1) -sin(yaw1); sin(yaw1) cos(yaw1)];
    % Rotated Points
    p1r = centerP + Rmatrix*p1;
    p2r = centerP + Rmatrix*p2;
    p3r = centerP + Rmatrix*p3;
    p4r = centerP + Rmatrix*p4;
    % Connecting points
    Hitbox_V1 = [p1r p2r p3r p4r p1r];
    cornersV1_x = transpose(Hitbox_V1(1,:));
    cornersV1_y = transpose(Hitbox_V1(2,:));
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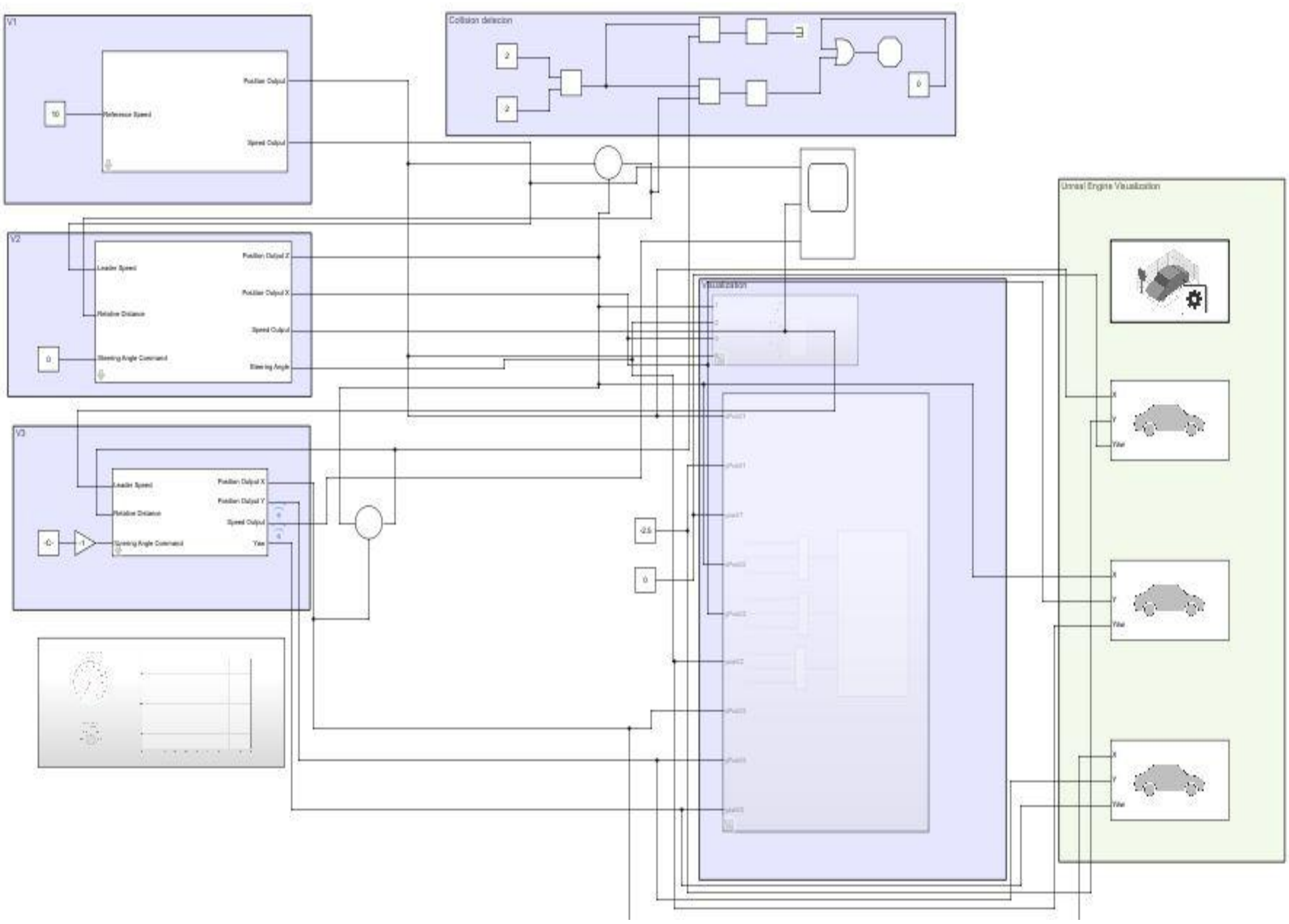

Fig -7: Overall ACC system for vehicle.

4. SIMULATION AND RESULTS

Here the Overall adaptive cruise control system has designed and with above information and data we can achieve cruise control for vehicles. as shown in Fig. 7 where right-hand side is showing automated driving toolbox and vehicle 3D configuration and left-hand side is for vehicle acceleration dynamics.

In simulation we considered that initial car is coming with speed of 30km/hr. which was in free driving mode when initial car realize that leading car is ahead it will slow down and follow the reference speed as we can see in below figure 8

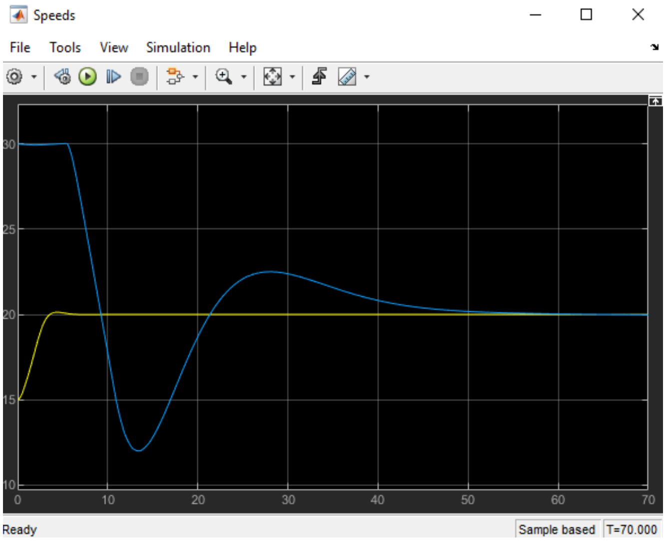

Fig -8: Reference speed tracking result.

To visualize this in 3D we can get the real car visualization in MATLAB auto using automated driving toolbox, simulation 3D scene configuration and simulation 3D vehicle with ground following block as shown in fig. 7. The 3D scene configuration block will give us some other features like it have inbuilt sensors like air density, fog opacity, rain etc. and 3D vehicle block will take input as X axis, Y axis and Yaw angle [13]. We can better visualize this simulation in video to get actual idea of ACC. Here some 3D picture from simulation is attached in below figures9,10,11 with all driving modes.

Fig -9: Free Driving Mode.

Fig -10: Vehicle following mode

Fig -11: Lane change mode

3. CONCLUSIONS

In this paper an adaptive cruise control (ACC) system is designed. We tasted each driving mode independently considering all the circumstances. MPC control play an important role in ACC in high-level control. In adaptive cruise control system when the safe distance is reaches to zero then there is chance of collision so the ACC system will stop. If distance is more between the two vehicles or no vehicle is present on the road then it will be free driving mode and if the distance is less between the two vehicles, then the vehicle is in second mode which will automatically back and forth.

With help of Lane change function car can automatically change its path and will cover the distance in Required time with Safe Speed.

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