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A Comprehensive review on Cruise Control for Intelligent Vehicles

S. Paul Sathiyan, S. Suresh Kumar, A. Immanuel Selvakumar

Abstract— ***Automatic vehicle speed control is presently one of the most popular research topics throughout the automotive industry and particularly in the Intelligent Transportation Systems field (ITS). Cruise Control (CC) system employs the concept of running at set speed under no obstacle / vehicle in front (velocity Control). CC for the metropolitan areas can significantly enhance the benefits in terms of comfort, safety, traffic flow, noise and emissions with some improved technology. CC fails to work when a vehicle / obstacle is detected in the front of the host vehicle. To overcome this drawback, Adaptive Cruise Control (ACC) system was developed. ACC can also wok in velocity control mode along with distance control mode. In distance control mode ACC can automatically adjust the velocity of the vehicle in order to maintain a proper distance between leading vehicle and the host vehicle. This paper discuss about the various evolutions that has been evolved in the field of cruise control, its recent developments and research trend in the automation of the vehicles in longitudinal/lateral control. The control algorithms like fuzzy logic, sliding mode, genetic algorithm, sensor fusion techniques etc., are used to implement the various level of evolution of cruise control. The techniques with their merits and short comings have been reviewed, keeping safety first and then fuel economy and comfort. The paper concludes with suggestions for future improvement.***

Index Terms— ***Cruises Control, Distance Control, Intelligent Vehicle, Lateral Control, Longitudinal Control, Velocity Control***.

I. INTRODUCTION

In recent years, many studies on Intelligent Vehicle (IV) have been devoted to solve problems such as driver burden reduction [13], accidents prevention [12], traffic flow smoothing [20] [23] [30] and fuel consumption [10]. Research related to the vehicle safety is particularly drawing more and more attention [38], which aims to compensate for human limitations in sensing the environment and reacting to the unexpected events. In fact, headway control is very important [24], [25] to the safe driving of IV. According to Willie d. Jones [46] for every minute, on average; at least one person dies in a crash. Cruise Control (CC) system has been developed to relive the driver for driving in a long distance highway. CC which operates in velocity control mode, at congested traffic, becomes less useful [12]. Adaptive cruise control (ACC) system is developed to cope up with this situation. ACC reduces the stress of driving in dense traffic by acting as a longitudinal control pilot. The conventional CC has only one mode of control, i.e., velocity control [2].

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Mr. S. Paul Sathiyan, Department of Electrical and Electronics Engineering, Karunya University, Coimbatore, India.

Dr. S. Suresh Kumar, Department of Electronics and Communication Engineering, Dr. NGP Institute of Technology, Coimbatore, India.

Dr. A. Immanuel Selvakumar, Department of Electrical and Electronics Engineering, Karunya University, Coimbatore, India,

On the other hand, ACC provides with two modes of control, velocity control and distance control. ACC can work like the conventional CC for maintaining the vehicle's preset velocity. However, ACC can automatically adjust velocity in order to maintain a proper distance between leading vehicle and the host vehicle equipped with ACC [7]. This is achieved by using various sensors [41] [44] to measure the relative distance between the host vehicle and a vehicle in front [4].

A. Classification of ACC

Today's modern system has evolved from the basic Cruise Control (CC) system. Each succeeding evolution has increase in functionality over the previous evolution. Based on the application the ACC system can be broadly classified into.

i. Longitudinal ACC
  1) Distance Keeping
  2) Stop & Go
  3) String
ii. Lateral ACC
  1) Lane Detection / Keeping / Changing
  2) Collision Avoidance
iii. Cooperative ACC

In distance control mode, the leading vehicle is detected by the sensors fixed and in the vehicle. Techniques like fuzzy logic by Han-Shue *et al* [31], sliding mode control by Antonella Ferrara *et al* [8], PD Controller [2] etc., have been incorporated with CC to make it intelligent. Results from José E. Naranjo *et al* [3] shows that the velocity control mode has a minimum operating speed limit (30-40 km/h) below which the ACC fails. "Stop and go" has the possibility to slow down the vehicle to a complete standstill. It offers longitudinal support to the driver in an environment characterized by a congested traffic flow on highways and well structured (sub) urban roads at speeds lower than 30-40 km/h [7]. Seungwuk Moon [13] classifies the ACC which operates from standstill to the maximum speed as 'Full-range ACC'. Another extended type of ACC is Predictive Cruise Control (PCC). This system issues location specific warnings, such as speed level while approaching a dangerous curve (e.g. making use of the on-board navigation system). Severe traffic congestion is making improved highway efficiency via Automated Highway Systems (AHS) increasingly attractive. Xiangheng Liu et al [33] the capacity (vehicle/lane/hour) can be increased as much as four times by forming vehicle platoons and operating vehicles under automatic control at spacing closer than is safe for human drivers. Chi-Ying Liang et al [47] defines string stable if, under no other excitations, the range errors decrease as they propagate along the vehicle stream. Still, today's ACC systems are limited as they do not provide a mean to share information between surrounding vehicles.

A common characteristic of most Automatic Driver Assistant System (ADAS), whether they automate (part of) the driver's tasks or 'just' give an instructive message, is the inclusion of on-board sensors to scan the direct vicinity of the vehicle. The range covered by such sensors however is limited by nature, which restricts the anticipative capabilities of the system. Vehicle-to-vehicle communication combined with advanced positioning technology solves this problem [34]. The use of inter-vehicle communication could help fulfill the goals of Intelligent Transport Society (ITS) by providing a system for vehicles to share with others sensor data representing their environment. With a communication system, ACCs become Cooperative Adaptive Cruise Control systems (CACCs), which have communication and cooperation between vehicles as primary concern [27]. The cooperative driving, which is an advanced form of the automated highway systems, is defined as flexible platoon of automated vehicles with a short inter-vehicle distance over a couple of lanes, which enables each vehicle to perform safe and efficient lane changing, merging, and passing [36].

Lateral control system deals with the lateral movement of the vehicle with respect to the direction of run. Lane Keeping Assist (LKA) and Lane Change Assist (LCA) need to be considered as well. These assistance systems help the drivers to be aware of vehicles in the blind spot, or warn them in case of an unintended lane departure [21]. LKS is a driver convenience system maintaining its driving lane [22]. Collision Warning/Avoidance (CW/CA) system warns the driver of an imminent collision and performs the necessary emergency-braking to avoid vehicle-to-vehicle collision. Various names such as preceding vehicle, leading vehicle etc., have been used to refer the vehicle in the front and the vehicle which is following is referred as subject vehicle, host vehicle, ego vehicle etc.,

The problems in an ACC system can be classified into modules like:

1) Sensorial system
2) System performance optimization
3) Driver acceptability

Fuel consumption minimization

II. SENSORS USED IN ACC

Sensors are used to acquire the information from the environment and give them as an input to the controller for actuating the appropriate response. [30] Such sensor systems include both passive systems, which detect the infrared rays emitted by subjects and convert the infrared image to a visible image for display, and active systems, which emit infrared rays from the vehicle and then convert the reflected light to a visible image for display. These systems go no further than the stage of recognition assistance, but systems that use infrared images to detect pedestrians and display them to drivers [6], which support not only recognition but also decision making. These sensors must incorporate intelligent recognition technologies considering various complexes external factors they might encounter in the real world: pedestrians darting out into the road, other vehicles cutting-in in front of the vehicle, poor visibility due to adverse weather conditions, etc [42]. Two technologies that are already being applied to vehicles on the market as environment recognition sensors are ultrasonic sensors mounted on the bumper to detect the distance to an obstacle and rear-view cameras mounted on the back of vehicles that show the driver on a navigation screen what is behind the vehicle. Meanwhile, a number of sensors for longer range detection at higher speeds are nearly ready for the market including radars for ACC systems and lane recognition cameras for implementing LKS [28]. There are blind spots on both the front sides of the vehicle, particularly when driving in urban areas [48]. These blind spots can cause serious accidents. Thus, Driver Assistant Systems (DAS) must also have side looking sensors. The types of sensors used in ACC are

A) Laser Technique
B) Ultrasonic Sensors
C) Charge-Coupled Device (CCD) Cameras
D) Millimeter Wave Radar
E) GPS / DGPS etc.,

A. Laser Technique

In the case of the laser technique, laser projectors and receivers are needed. Although using laser technology has the advantage of speed, object reflectivity plays an important role. If the object reflectivity is bad, the system will work poorly or not at all. The ultrasonic technique has the additional advantage of a pantoscopic range, but with the same problem caused by object reflectivity. Object reflectivity is the common failing of noncontact systems [40].

B. Ultrasonic Sensor

Agarwal *et al* [43] describe an accurate and fast DAS that detects obstacles and warns the driver in advance of possible collisions in such a congested traffic environment. It is important for any DAS to be least dependent on the external environmental conditions. The system is suitable for a short-range collision warning system or a parking assistance system for application in a congested traffic environment, where vehicle speeds are relatively low. A survey of the existing system has been done in [43]. It is experimentally verified that the sensors performance is not significantly affected by the external environmental conditions.

Alessio *et al* [42] describes an ultrasonic sensor that is able to measure the distance from the ground of selected points of a motor vehicle. A constrained optimization technique is employed to obtain reflected pulses that are easily detectable by means of a threshold comparator. Such a technique, which takes the frequency response of the ultrasonic transducers into account, allows a sub-wavelength detection to be obtained. Experimental tests, performed with a 40 kHz piezoelectric-transducer based sensor, showed a standard uncertainty of 1 mm at rest or at low speeds; the sensor still works at speeds of up to 33 m/s (120km/hr), although at higher uncertainty and is able to self-adapt to different conditions in order to give the best results [42]. Although ultrasonic sensors have reasonable lateral resolution, multiple sensors are needed to get a full-field view. The problem observed in using multiple sensors is that the sensors randomly influence each other, particularly when a rapid firing strategy is adopted. The general solution to this problem is to associate a unique identification (signature) with each transmitted signal, so that each sensor detects its own echo and discards the echoes due to other sensors [43].

C. Charged Coupled Device Camera

Q.-T. Luong *et al* [14] proposed a vision based longitudinal and lateral vehicle control. The novel feature of this approach is the use of binocular vision. Moreover, the camera information is also used to update the camera geometry with respect to the road, therefore allowing us to cope with the problem of vibrations and road inclination. Image Captured is affected by rain, fog, lighting condition etc., which may require additional filters [43]. Mixing up the input from two different cameras without any time lag might be a problem (overlapping the Image for information extraction)

Ho Gi Jung [22] the overall structure of lane detection is the same as the conventional method using monocular vision: Edge Distribution Function (EDF) based initialization, sub-ROI (Region of Interest) for left/right and distance-based layers, steerable filter-based feature extraction, and model fitting in each sub-ROI.

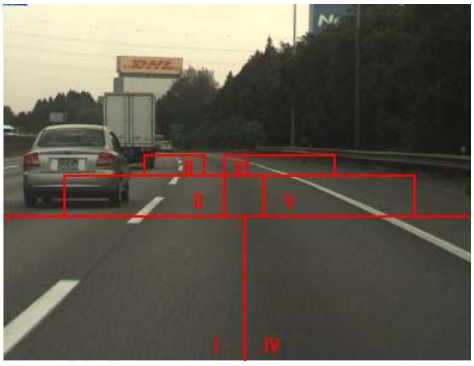

Fig. 1 Three Layers Region of Interest

The proposed method adds only the system for confining lane detection ROI to free space that is established by range data. Experimental results indicate that such a simple adaptive. ROI can overcome occlusion of lane markings and disturbance of neighboring vehicles. The measurement of the lane markers enables us to perform an on-line updating of the external geometric parameters of the stereo rig with respect to the road. Therefore deal with change in slope of the road, as well as variations in inclination of the car caused by bumps or accelerations and decelerations.

Fig. 2.Traffic signs on road surface

Although the proposed method overcomes various problems experienced by the conventional method, it cannot overcome a situation when there are many traffic signs on a road surface. Fig. 2 shows a situation when the proposed method fails to detect lane markings because of traffic signs on the road surface. Further research is required to overcome the disturbance of traffic signs on road surface.

Wei-Yen Wan *et al* [40], proportionality of similar triangles to measure the distance between a CCD camera and taillights of a vehicle in front. At night, the taillights form two bright spots in the CCD image, therefore producing two measurable signals. A circuit for counting the number of external clock pulses between the two bright spots is employed to calculate the interval between them in the video image. Due to the proportionality of similar triangles, there is a linear relationship between the actual distance and the interval of the two taillights. Thus, the actual distance from the CCD camera to the vehicle can be calculated from a simple formula. The system suffers in identifying the closest vehicle, when the tail lights of more than one vehicle are visible to the host vehicle at the same time.

CCD cameras are significantly affected by bad weather conditions (e.g., snow, rain, dirt, and dust) [43]. Ultrasonic sensors are less affected by adverse weather conditions and are more economical compared with all other sensors

D. Millimeter wave radar

S .Tokoro *et al* [41] describes the electronically scanned millimeter-wave radar sensor developed for use in the system. Radars with phase array technology are used for high performance in object recognition. Other features of the radar include a high-efficiency planar antenna, high-power and low-loss Monolithic Microwave ICs (MMICs) and Millimeter-Wave circuit and a high-speed Digital-Beam Forming (DBF) algorithm. Matthias Steinhauer *et al* [50] describe a new radar sensor architecture comprising an array of transceiver modules. In conjunction with a monolithic integration of each transceiver, the concept offers the possibility for a cost-effective realization of digital- beam forming radar sensors at millimeter-wave frequencies. A modulation sequence is investigated based on simultaneously transmitted frequency-modulated continuous-wave signals, which are separated by frequency multiplexing. Richard Grover [50] has presented a method for the fusion of mm-Wave Radar and Night-vision data. The characteristic information is combined to yield an environmental representation containing both sensor signatures for each object, significantly simplifying and improving the performance of detection, classification and tracking algorithms.

E. GPS / EGPS

José E. Naranjo *et al* [16] present an ACC based on fuzzy logic, which assists the speed and distance vehicle control, offering driving strategies and actuation over the throttle of a car. The driving information is supplied by the car tachometer and a RTK differential GPS, and the actuation over the car is made through an electronic interface that simulates the electrical signal of the accelerator pedal directly to the onboard computer. R. Hallouzi *et al* [29] discusses about the field experiments conducted to evaluate a co-operative longitudinal controller for a cluster of vehicles with inter-vehicle communication (IVC). The information is obtained by a DGPS-based Extended Kalman Filter (EKF). There must be a relatively clear "line of sight" between the GPS antenna and four or more satellites.

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Objects, such as buildings, overpasses, and other obstructions, that shield the antenna from a satellite can potentially weaken a satellite's signal such that it becomes too difficult to ensure reliable positioning. These difficulties are particularly prevalent in urban areas. The GPS signal may bounce off nearby objects causing another problem called multipath interference [49].

III. LATERAL CONTROL

Kwang So Chang *et al* [1] has given the theoretical approach of Fuzzy logic in ACC. It approaches with feedback linearization method and Lyapunov stability theory to derive the parameter tuning law in the fuzzy-inference engine. This approach gave a guarantee of string (only for a max of two vehicles in a string) stability of the vehicle following dynamics and the prevention of the slinky-effect. For the two modes of operation of ACC [2] and [4] uses PD controller with error compensation algorithm, for velocity control mode and Fuzzy logic techniques for Distance Control mode.

Li Bin *et al* [17] proposed a new quadratic optimal theory controller for intelligent vehicle (IV) headway distance. The constant headway time strategy is adopted in this paper. There were some oscillations recorded by the author. Comparative charts of the variables between the host and the preceding vehicle might have strengthened the claim.

Nassaree Benalie *et al* [2] suggest a new adaptive cruise control system to maintain a proper inter-vehicle gap based on the speed of leading vehicle and time headway (THW). Uses a PD control the inner loop is the velocity control loop, while the outer loop is the position control loop.

Jassbi *et al* [6] has developed a hybrid method for determining the fuzzy rules and membership functions simultaneously by using Genetic Algorithm which determines the rule base and an Extended Kalman filter approach for tuning the parameters of the membership functions. The author has reduced the settling time from 20sec with fuzzy logic controller to 14s with rule and membership optimization using GA and EKF. The optimized FLC requires only a few fuzzy sets. The experimental validation has not been performed. Moon *et al*. [13], the driving situations are divided into: comfort-mode (Mode-1), large-deceleration mode (Mode-2), and severe-braking situation (Mode-3)

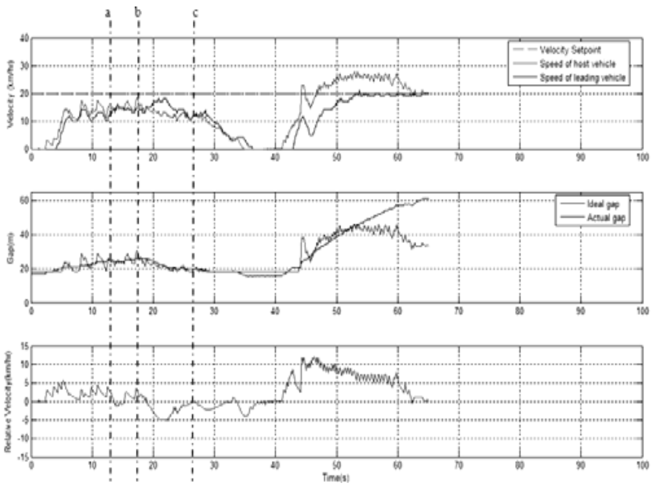

Fig. 3. Velocity Set Point = 20 km/hr & THW = 6 sec

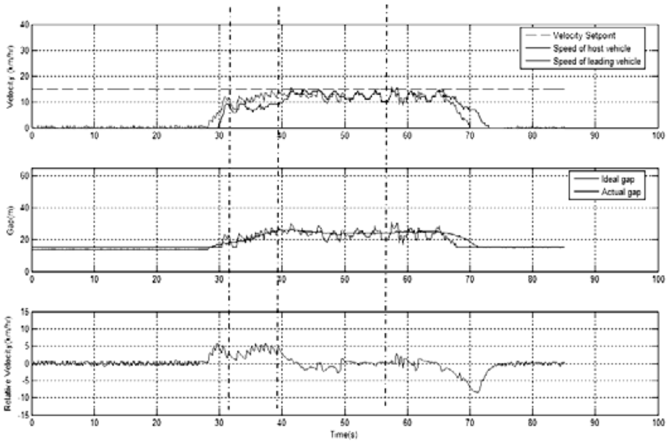

Fig. 4. Velocity Set point = 15 km/hr & THW = 7 sec

The graphs (Fig.3 and Fig. 4) [2] shown that the system developed more deviations as the speed is increased from 15 to 20 km/hr

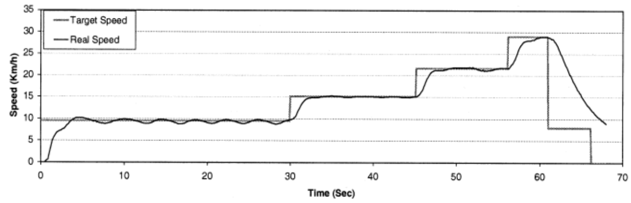

Fig. 5. Fuzzy cruise control performance at 9.6, 15, 21.6, and 29 km/h in the same round.

Fuzzy logic based control proposed by José E. Naranjo *et al* [16], has been efficiently working with for a set speed values of speed values of 15,20,25 km/hr respectively. The controller developed oscillations at 10km/hr (Fig. 5), which leads to more fuel consumption and jerks

C. Chien *et al* [15] it is assumed that the human driver mimics a linear optimal controller in performing vehicle following. The optimal controller is based on a quadratic cost function that penalizes the weighted sum of the square of the intervehicle spacing and the square of the relative velocity. Since these weights differ from driver to driver and are therefore unknown. This optimal control approach can only be used to come up with the structure of the controller that the human driver mimics. Another drawback of this approach is that it omits the driver's reaction time, the neuromuscular dynamics and nonlinearities of the vehicle dynamics. For these reasons Burnham first modified the optimal controller structure by introducing the effects of the reaction time and vehicle nonlinearities and then estimated the unknown parameters and controller gains using real traffic data.

IV. STOP AND GO CONTROL

José E. Naranjo *et al* [3] the system input information is acquired by a real-time kinematic phase Differential Global Positioning System (D-GPS) (i.e., centimetric GPS) and wireless local area network links. The outputs are the variables that control the pressure on the throttle and brake pedals, which are calculated by an onboard computer. In addition, the car control is based on fuzzy logic.

The system has been installed in two mass-produced Citroën Berlingo electric vans, in which all the actuators have been automated to achieve humanlike driving. The results from real experiments show that the unmanned vehicles behave very similarly to human-driven cars and are very adaptive to any kind of situation at a broad range of speeds, thus raising the safety of the driving and allowing cooperation with manually driven cars.

Gerrit *et al* [11] has proposed a Model Predictive Control framework. Firstly metrics to enable objective performance evaluation of an ACC S&GO in a qualitative manner are specified, distinguished between comfort of the resulting longitudinal vehicle behavior and the behavior due to traffic requirements. Secondly, a structured ACC S&G design is proposed, incorporating these performance metrics. In general, ACC systems are divided into a generic vehicle independent part and a vehicle-specific part, i.e. an outer control and an inner control loop respectively. The generic part determines the behavior of the system by prescribing a desired acceleration profile a_h, d for the vehicle. The vehicle-specific part assures tracking of this profile via actuation of the throttle and brake system. This paper focuses on the generic part. A model of two following vehicles, the control objectives and the corresponding constraints are presented after which the design of an explicit Model Predictive Controller (MPC) is discussed. Both comfortable driving behavior and driving behavior due to traffic requirements have to be considered when evaluating the performance of an ACC (S&G) system.

John-Jairo [18] proposes a novel reference model-based control approach for automotive longitudinal control. The proposed reference model was nonlinear and provides dynamic solutions consistent with safety constraints and comfort specifications. This model was based on physical laws of compliant contact and has the particularity that its solutions can be explicitly described by integral curves. This allows characterizing the set of initial condition for which the constraints can be met. In addition, the model is combined with a simple feedback loop used to compensate un-modeled dynamics and external disturbances.

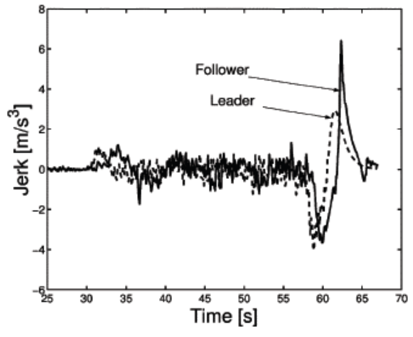

Fig. 6. Jerk from experiment.

An advantage of the proposed structure is that both the reference model and the controller can be designed independently. The inter-distance model-design problem can be studied by making a parallel with the problem of compliant contacts. Simulations show that the model is very sensitive to the inaccuracies of the estimated leader acceleration. In practice, this measurement has a poor SNR. It is observed that the following vehicle experienced large amount of jerks (Fig. 6) when compared to the leader vehicle.

Kyongsu *et al* [19] proposed a distance control algorithm and Throttle/brake control algorithm for acceleration tracking. Vehicle desired acceleration for vehicle-to-vehicle distance control has been designed using Linear Quadratic optimal control theory. Linear optimal control theory has been used to design the desired acceleration in the case of the distance control mode. Simulation has been performed assuming that the other vehicles are traveling at a constant speed. Particularly in cutting in of the vehicle the linearity (which is assumed) will be disturbed.

Yang Bin *et al* [37] suggests a Model Matching Control (MMC) controller based on Sliding Mode Control (SMC) method is proposed for longitudinal acceleration tracking control of vehicular stop-and-go cruise control system acceleration response on low-speed condition, a nominal trans-junction model of the vehicle longitudinal dynamic system is obtained with the LMS system identification technique. Using this nominal trans-junction model, the MMC controller, including a SMC feedback compensator, is designed It can combine the advantage of the two control methods, control robustness and rapid response.

Zille Eizad *et al*. [39] have modeled the engine and transmission system as a first order differential equation. The input of the system is engine (throttle) input and the output is the driving (engine) torque. It must, however, be noted that the control algorithm is tested on electrical vehicles and, therefore the experimentation does not verify the vehicle model presented in the paper by the author. The experimentation only shows the suitability of the algorithm presented for low-speed stop & go situations. However, the vehicle model is verified in separation from a control algorithm, in simulation environment.

V. VEHICLE PLATOONS

Sang-Jin Ko *et al* [5] proposes a fuzzy logic based ACC which guarantees string stability (max. upto a string of 5 cars and not for infinite cars). The vehicle controlled by proposed fuzzy ACC controller keeps target speed very well in CC driving mode.

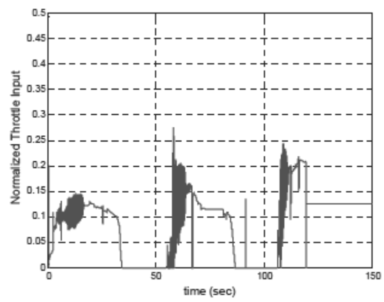

Fig. 7. Normalized throttle input of following vehicle

It is found that throttle and brake input by the proposed fuzzy logic based adaptive cruise controller fluctuate in some area (Fig. 7), as simulation results. Although it is acceptable because of slow response characteristic of a vehicle, improvement for oscillations of throttle and brake input is demanded. Higher performance of proposed fuzzy ACC controller is expected by tuning of width and center point of membership functions and scaling factor. The tuning by evolutionary computation, is expected.

Antonella *et al* [8] investigates the possibility of reducing the number of accidents involving pedestrians or other vulnerable road users. The control methodology adopted in the paper is sliding mode control of the first and the second order, which, by virtue of its robustness features, appears to be suitable to be applied in presence of possible modeling uncertainties.

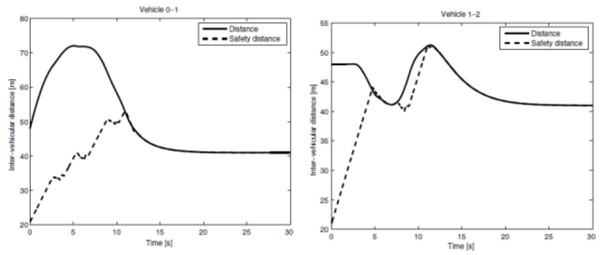

Fig. 8. Inter Vehicle Distance vs Time

Simulation evidence has been provided demonstrating the feasibility of the proposed approach. The addressed control problem could be also regarded as a hybrid control problem. The Inter-vehicle gap goes below the set value. Fig.8 shows the increase in the amount of mismatch between the vehicles. Set distance was violated more between vehicles 1 & 2 than 0 & 1.

Tankut Acarman *et al* [9] has studied fairly restrictive scenario "Stop and Go" in city driving, assume that slowing down and stopping will be accomplished by the automated system. Both a totally isolated car (without cooperation) and then the possibility of cooperation through wireless with cars ahead are considered. From the speed of vehicles involved in merging scenario, it is found that there happens a collision between the vehicles. Soo-Yeong Yi *et al* [45] proposed an impedance control system utilizing a serial chain of a spring-damper for vehicle platooning. Since the spring-damper relation, or the so-called ''impedance relation,'' is widely used to represent the interaction with uncertain environments. Furthermore since the spring-damper relation defines the local interaction between the predecessor and the follower vehicles, it requires less information without the global communication link. In this algorithm, the guidance model is incorporated with the equation of vehicle motion, which includes the position and the heading, by using the existing feedback linearization technique, which gives the unified control algorithm for the longitudinal and the lateral control. The transmission delay in communication has not taken into consideration during the time of simulation by the authors. Shahram Rezaei *et al* [32], Xiangheng Liu *et al* [33], have contributed in pertaining to the area of effects due to communication delay.

VI. COOPERATIVE ACC

Julien *et al* [27] suggests a reinforcement learning algorithms to learn optimal policy acting in an environment. The first one is focusing on low-level control where a vehicle follows another vehicle at a secure distance, by acting directly with the throttle and observing the concrete results on the inter-vehicle gap. This level is car-centered and can be modeled by a Markov Decision Process (MDP) that can be solved using algorithms that learn on-line, such as Temporal-Differences (TD) algorithms. On the other hand, the second level is of higher level and focuses on vehicle coordination. In that context, a learned policy could choose the best driving lane for every vehicle located on a highway system. Because of the multi-agent point of view of this sub-problem, it could benefit from the use of Stochastic Games to be modeled as an extension to MDP. Reinforcement learning allows an agent to learn by interacting with its environment. For a mono agent system, the basic formal model for reinforcement learning is the Markov Decision Process (MDP).

Peter Morsink *et al* [34] discuss about the development of cooperative driver assistance systems with two levels of communication range. The short-term target communication system will be based on the 802.11b WLAN standard; the long-term system based on UMTS. The system architecture will be based on an open CarTALK reference architecture that supports partner specific implementations A sensor fusion approach of differential GPS, velocity and acceleration signals based on Extended Kalman Filtering has been applied. With all individual cars performing their own filtering and subsequent communication to other vehicles, an inter-vehicle headway determination with an accuracy of 1~1.5m could be achieved.

Anouck *et al* [26] has proposed hierarchical control architecture for the control and maneuver coordination of multiple cars using integrated cruise control and collision warning systems. The author has considered several modes of operation for each vehicle: ACC, CACC, or CFCW proposed architecture distributes information and control authority among cars and deals with exceptions and faults. It is organized hierarchically, with the lower layers of the hierarchy consisting of continuous controllers that interact with the sensors and actuators to produce the desired positioning and tracking performance. These layers sequentially organize the generation of the optimal coordinated trajectories for all vehicles (global control), the optimal trajectories for each car (vehicle control), the optimal trajectory tracking schemes and the optimal engine controls (local control), to name just a few. The de-coupling of optimization problems eventually compromises the overall optimality but makes the problem tractable. Hence, the architecture represents an empirical compromise between tractability and optimality

Shin Kato *et al* [36] describes the technologies of the vehicle control and the intervehicle communications with 5.8-GHz dedicated short range communication (DSRC) [8] as well as the scenario of the demonstration. The inter-vehicle communications for the vehicle control should not have any delay. Since the occasional data loss can be compensated by estimation and prediction with the Kalman filtering technique, the protocol must be designed with the assumption that the occasional data loss can be allowed and the continuous data loss cannot be allowed. Precise longitudinal control would improve the performance of the formation of the cooperative driving. The longitudinal control of the following vehicles is found with the intervehicle distance measured by the laser radar and calculated from the localization data transmitted from the preceding vehicle over the intervehicle communications.

R. Hallouzi *et al* [29] discusses about the field experiments conducted to evaluate a co-operative longitudinal controller for a cluster of vehicles with inter-vehicle communication (IVC). This information is obtained by a DGPS-based Extended Kalman Filter (EKF). In order to allow Communication Based Longitudinal Control (CBLC) some vehicle states have to be known. These experiments involved three vehicles of which the two rear vehicles had to anticipate automatically on the longitudinal maneuvers of the front vehicle. The distance sensor is not used; the position of the vehicle is acquired using DGPS, may have latencies. If the communication with the DGPS is lost then the system may not be stable.

VII. CONCLUSION

The literature survey was focused on the various Adaptive Cruise Control system and the techniques applied to them based on the demerits experienced at each levels application (ACC,STOP & GO, String etc.,) has their own merits and demerits. It is found that the tests conducted didn't have a common criteria / consideration to do a comparative analysis. The full range ACC system [13] is still to be developed with utmost consideration to safety. Stop & GO ACC system should consider the acceleration / deceleration, fuel minimization etc., since excess braking rate is not advisable. It may also lead to severe jerks to the passengers. The string / platoon of vehicles should take into account the slinky effect [1]. Multiple sensor technique [44] to raise the safety levels and comfort to the automobile users can be extended as a future work. The Cooperative ACC system needs IVC [9] or RVC which makes the vehicle to rely on the external inputs, ultimately making the system dependent. The latency that occurs in the transmission system used in cooperative system has to be reduced in-order to have a reliable. While using GPS system the resolution should be taken into consideration. The GPS for this purpose will not be economical. Using GPS in STOP & GO, String etc., needed to be investigated.

REFERENCES

1. Kwang So Chang, Jae Sung Choi "Automatic Vehicle following using the Fuzzy Logic" in *Proc. 6th Int. Conf. Vehicle Navigation and Information Systems*, WA, 1995, pp. 206-213.
2. Nassaree Benalie, Worrawut Pananurak, Somphong Thanok, and Manukid Parnichkun "Improvement of Adaptive Cruise Control System based on Speed Characteristics and Time Headway" *IEEE/RSJ Int. Conf. On Intelligent Robots and Systems*, pp 2403-2408.
3. José E. Naranjo, Carlos González, Ricardo García, and Teresa de Pedro "ACC+Stop&Go Maneuvers With Throttle and Brake Fuzzy Control", *IEEE Transactions On Intelligent Transportation Systems*, vol. 7, no. 2, 2006, pp 213-225.
4. Worrawut Pananurak, Somphong Thanok, Manukid Parnichkun "Adaptive Cruise Control for an Intelligent Vehicle" in *Proc. International Conference on Robotics and Biomimetics*, Bangkok, 2009, pp 1794-1799.
5. Sang-Jin Ko and Ju-Jang Lee "Fuzzy Logic Based Adaptive Cruise Control with Guaranteed String Stability" in *Proc. International Conference on Control, Automation and Systems*, Seoul, 2007, pp 15–20.
6. Jassbi S. Khanmohammadi Kharrati "A Hybrid Method for Determination of Fuzzy rules & Membership Functions" *IEEE Congress on Evolutionary Computation*, Hong Kong, 2008, pp 1649 -1654.
7. P. Venhovens, K. Naab and B. Adiprasito "Stop and Go Cruise Control", *International Journal of Automotive Technology*, Vol. 1, No. 2, 2000, pp. 61-69.
8. Antonella Ferrara, Claudio Vecchio "Second order sliding mode control of vehicles with distributed collision avoidance capabilities", Mechatronics, Vol. 19, Issue 4, 2009, Elsevier, P 471 – 477.
9. Tankut Acarman, Yiting Liu and U mit O zguner "Intelligent Cruise Control Stop and Go with and without Communication" in *Proc. American Control Conference*, Minneapolis, MN, 2006, pp 4356 – 4361.
10. *SWOV Fact sheet "Advanced Cruise Control (ACC)" SWOV*, Leidschendam, the Netherlands August 2008.
11. Gerrit Naus, Roel van den Bleek, Jeroen Ploeg, Bart Scheepers, Rene van de Molengraft, Maarten Steinbuch "Explicit MPC Design and Evaluation of an ACC Stop & Go" *American Control Conference*, Washington, USA, 2008, pp 225 – 229.
12. Donghoon Han', Kyongsu yi and Seungjong "Evaluation of Integrated ACC(Adaptive Cruise Control)/ CA(Collision Avoidance) on a Virtual Test Track" *YiSICE-ICASE International Joint Conference,* Busan, 2006, pp 2127 – 2132.
13. Seungwuk Moon, IlkiMoon, KyongsuYi "Design, tuning, and evaluation of a full-range adaptive cruise control system with collision avoidance" *Elsevier Control Engineering Practice,* Vol 17, Issue 4, *2009,* pp 442–455.
14. T. Luong, J.Weber, D. Koller', and J. Malik "An integrated stereo-based approach to automatic vehicle guidance" 5*th Int. Conf. Computer Vision*, Cambridge, MA, 1995, pp. 206-213.
15. C. C. Chien and P. loannou "Automatic Vehicle-Following", *American Control Conference*, USA, 1992, pp 1748 -1752.
16. José E. Naranjo, Carlos González,, Jesús Reviejo, Ricardo García, and Teresa de Pedro "Adaptive Fuzzy Control for Inter-Vehicle Gap Keeping" *IEEE Transactions On Intelligent Transportation Systems, vol. 4, no. 3*, 2003, pp 132-142.
17. Li Bin Wang Rongben Chu Jiangwei "A New Optimal Controller for Intelligent Vehicle Headway Distance" *Proceedings of the IEEE Intelligent Vehicle Symposium,* vol. 2, 2002, pp 387-392.
18. John-Jairo Martinez and Carlos Canudas-de-Wit " A Safe Longitudinal Control for Adaptive Cruise Control and Stop-and-Go Scenarios" *IEEE Transactions On Control Systems Technology,* vol. 15, no. 2 ,2007, pp246 -258
19. Kyongsu Yi, Ilki Moon and Young Do Kwon "A Vehicle-to-Vehicle Distance Control Algorithm for Stop-and-Go Cruise Control", *IEEE Intelligent Transportation Systems Conference Proceedings*, Oakland, CA, 2001, pp 478-482.
20. Arne Kesting, Martin Treiber, Martin Schohof, Dirk Helbing "Adaptive cruise control design for active congestion avoidance" *Transportation Research Part C,* Vol. 16 Issue 6 , pp 668–683.2008.
21. Jorn Freyer, Barbara Deml, Markus Maurer, Berthold Farber "ACC with enhanced situation awareness to reduce behavior adaptations in lane change situations", *Proceedings of the IEEE Intelligent Vehicles Symposium,* 2007, pp 999- 1004.
22. Ho Gi Jung, Yun Hee Lee and Pal Joo Yoon "Forward Sensing System for LKS+ACC", *World Congress Detroit SAE Technical paper Series* April 2008.
23. Arne Kesting, Martin Treiber, Martin Sch¨onhof, Florian Kranke, and Dirk Helbing "Jam-avoiding adaptive cruise control (ACC) and its impact on traffic dynamics" *Traffic and Granular Flow, Springer (Berlin)*, 2005, pp 633-643.
24. Ankur Shrivastava Perry Y. Li, "Traffic flow stability induced by constant time headway policy for adaptive cruise control vehicles", American *Control Conference*, vol. 3, 2000, pp 1503-1508.
25. L. C. Davis, "Effect of adaptive cruise control systems on traffic flow", *The American Physical Society*, 2004 (unpublished)
26. Anouck Renée Girard, João Borges de Sousa, James A. Misener and J. Karl Hedrick "A Control Architecture for Integrated Cooperative Cruise Control and Collision Warning Systems" *40th IEEE Conf. on Decision and Control,* vol.2, 2001, pp 1491 – 1496.
27. Julien Laumonier, Charles Desjardins and Brahim Chaibdraa "Cooperative Adaptive Cruise Control: a Reinforcement Learning Approach," unpublished.
28. Kazuaki Takano Tatsuhiko Monji Hiroshi Kondo, Dr. Eng. Yuji Otsuka "Environment Recognition Technologies for Supporting Safe Driving" *Hitachi Review Vol. 53 , No. 4* pp217-22. 2004.
29. R. Hallouzi V. Verdult H. Hellendoorn J. Ploeg "Experimental Evaluation of A Co-Operative Driving Setup Based On Inter-Vehicle communication" *5th IFAC/EURON Symposium on Intelligent Autonomous vehicle*, Portugal, 2004.
30. Sadayuki TSUGAWA "Trends and Issues in Safe Driver Assistance Systems" *IATSS Research* vol.30 no.2, 2006, pp 6-18.
31. William k. Grefe thesis on "Integrating Collision Avoidance, Lane Keeping, And Cruise Control with An Optimal Controller and Fuzzy Controller" April 29, 2005.
32. Shahram Rezaei, Raja Sengupta, Hariharan Krishnan, Xu Guan "Reducing the

communication required by DSRC-based vehicle safety ystems" in *Proc. Intelligent Transportation Systems Conference,* Seattle, WA,2007, pp361-366.
33. Xiangheng Liu Andrea Goldsmith "Effects of Communication Delay on String Stability in Vehicle Platoons", *IEEE Intelligent Transportation System Conference (ITSC)*, USA, 2001, pp 625 – 630.
34. Peter Morsink, et al "CARTALK 2000: Development of a Cooperative ADAS based on Vehicle-to Vehicle Communication" *10th World Congress and Exhibition on Intelligent Transport Systems and Service,* Spain, 2003.
35. Jun Luo Jean-Pierre Hubaux "A Survey of Inter-Vehicle Communication" School of Computer and Communication Sciences, Lausanne, Switzerland. EPFL, CH-1015, LCA-REPORT-2000-009.
36. Shin Kato, Sadayuki Tsugawa, Kiyohito Tokuda, Takeshi Matsui, and Haruki Fujii "Vehicle Control Algorithms for Cooperative Driving With Automated Vehicles and Intervehicle Communications" *IEEE Transactions on Intelligent Transportation Systems,* vol. 3, no. 3, 2002, pp 155-161.
37. Yang Bin, Keqieng Li, Xiaomin Lian Hiroshi Ukawa, Masatoshi Handa, Hideyuki Idonuma "Longitudinal Acceleration Tracking Control of Vehicular Stop-and-Go Cruise Control System", in *Proc. Int. Conf. on Networking, Sensing & Control*, Taipei, Taiwan, 2004, pp 607-612.
38. Sadayuki TSUGAWA "Issues and Recent Trends in Vehicle Safety Communication Systems" IATSS Research vol.29 no.1, 2005, pp 7-15
39. Zille Eizad Ljubo Vlacic "A Control Algorithm and Vehicle Model for Stop & Go Cruise Control" *IEEE Intelligent Vehicles Symp., University of Parma Parma*, Italy, 2004, pp 401-406.
40. Wei-Yen Wang, , Ming-Chih Lu, Hung Lin Kao, and Chun-Yen Chu "Nighttime Vehicle Distance Measuring Systems" *IEEE Transactions on Circuits and Systems—II: Express Briefs,* vol. 54, no. 1, 2007, pp 81 -85.
41. S .Tokoro, K.Kuroda, A. Kawakubo, K.Fuj ita, H.Fujinami "Electronically Scanned Millimeter-wave Radar for Pre-Crash Safety and Adaptive Cruise Control System" in *Proc. of Intelligent Vehicles Symposium*, 2003, pp 304-309.
42. Alessio Carullo and Marco Parvis*, "*An Ultrasonic Sensor for Distance Measurement in Automotive Applications", *IEEE Sensors Journal,* vol. 1, no. 2, 2001, pp 143-147.
43. Vivek Agarwal, , N. Venkata Murali, and C. Chandramouli "A Cost-Effective Ultrasonic Sensor-Based Driver-Assistance System for Congested Traffic Conditions" *IEEE Transactions on Intelligent Transportation Systems,* vol. 10, no. 3, 2009, pp 486 -497.
44. Ka C. Cheok, *G.* E. Smid & D.J. McCune "A Multisensor-Based Collision Avoidance System With Application to a Military HMMWV" *2000 IEEE Intelligent Transportation Systems Conference Proceedings* Dearborn (MI), USA, 2000, pp 288-292.
45. Soo-Yeong Yi, Kil-To Chong "Impedance control for a vehicle platoon system" *Mechatronics* vol. 15, issue 5, Elsevier 2005, pp 627–638
46. Willie D. Jones "Keeping Cars from crashing" *IEEE Spectrum,* September 2001, pp 40-45
47. CHI-YING LIANG and HUEI PENG "Optimal Adaptive Cruise Control with Guaranteed String Stability*" Vehicle System Dynamics*, Swets & Zeitlinger, 1999 pp.313–330.
48. K.-T. Song, C.-H. Chen, and C.-H. C. Huang, "Design and experimental study of an ultrasonic sensor system for lateral collision avoidance at low speeds," in *Proc. IEEE Intelligent. Vehicles Symp.*, Parma, Italy, 2004, pp. 647–652.
49. Morag Chivers, Trimble "Differential GPS Explained" *ArcUser Online March2003* http://www.esri.com/news/arcuser/0103/differential1of2.html
50. Matthias Steinhauer, Hans-Oliver Ruo B, Hans Irion, and Wolfgang Menzel*, "*Millimeter-Wave-Radar Sensor Based on a Transceiver Array for Automotive Applications*" IEEE Transactions on Microwave Theory and Techniques,* vol. 56, no. 2, 2008, pp261-269

AUTHORS PROFILE

S. Paul Sathiyan completed his M.E and currently working in Karunya University and pursuing his Ph.D. His area of specialization is Power Electronics and Drives. He has published eight papers in conferences and five journals

Dr. S. Suresh Kumar completed his Ph.D and currently working as Director- Research and Head ECE at Dr. NGP Institute of Technology Coimbatore. He has published more than twenty international journals and nineteen international conferences.

Dr. A. Immanuel Selvakumar completed his Ph.D and currently working as Head EEE at Karunya University Coimbatore. He has published papers in eight international journals and nine international conferences