Platoon: A Brief Study

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***Abstract*—Platooning is one of the ways to reduce the emission of Heavy-Duty Vehicles carrying freight. These vehicles are equipped with various Advanced Driver Assistance Systems for the safety and effective use of platooning technology. A coordinated movement can be achieved by using various strategies like the selection of platoon-able vehicles, sorting techniques, and determining the stability of the platoon. This paper intends to discuss the various ramp-based grouping and merging strategies for platoon formation. This research also discusses the use of Long Short-Term Memory networks to recognize driving states. Thus, leading to safe, clean, economical, and faster transportation when implemented.**

Keywords—Platoon

I. INTRODUCTION

According to our world in data, transport accounts for around one-fifth of global carbon dioxide ($CO2$) emissions. Road travel accounts for three-quarters of transport emissions. The majority of this comes from passenger vehicles, such as cars and buses, which account for 45.1 percent of total emissions. The remaining 29.4 percent comes from freight trucks. The transportation sector as a whole accounts for 21% of total emissions, with road transport accounting for 15% of total $CO2$ emissions [6]. Platooning has been proposed with the primary objectives of cutting down fuel consumption and increasing road capacity and throughput. A group of consecutive vehicles can form a platoon, in which a nonleading vehicle maintains a small distance from the preceding vehicle. Platooning also targets road safety as coordinated vehicle behavior minimizes the chance of collision.

A platoon consists of one platoon leader and one or multiple platoon members, a platoon leader is the leading vehicle of the platoon, which is responsible for the direction and velocity, as well as updating the driving instructions to platoon members. The platoon leader can be a human-driven, semi-autonomous or completely autonomous. The platoon member follows the autonomous driving system and follows the driving instructions given by the platoon leader. Like, when a heavy-duty vehicle (HDV) in the motor joins the existing platoon, it becomes a platoon member, each platoon member relies on the driving instructions and information transferred by the preceding and succeeding vehicle.

The recent developments in sensor and control technology makes it possible to achieve adaptive cruise control (ACC). The adaptive cruise control system automatically adjusts the vehicle speed and maintain a safe distance to the vehicle ahead enhancing the driving comfort. The extension of adaptive cruise control is cooperative adaptive cruise control (CACC) taking further advantage of vehicle to vehicle (V2V) communication. With the additional exchange of information, the vehicle can achieve the desired time headway while maintaining a stable vehicle string.

II. ADVANCED DRIVER ASSISTANCE SYSTEM

In recent years, rising vehicle demand has imposed extra strain on existing traffic infrastructure. Advanced Driver-Assistance Systems (ADAS) and autonomous driving applications have been an active research topic in institutes and automotive businesses to address this challenge. Many ADAS technologies, such as Adaptive Cruise Control (ACC), Emergency Brake Assist (EBA), Active Lane Assist, and Lane Keeping Assist (LKA), are now available in passenger vehicles to improve comfort and safety. With the development of improved vision and control systems, ACC, which is an extension of classic Cruise Control (CC), has been one of the most promising technologies.

A. Adaptive Cruise Control

An ACC system, the ego car maintains a safe distance from the leading car without the driver's intervention. ACC is widely used and can be found in a wide range of commercially available cars. ACC automatically adjusts a vehicle's speed to achieve the desired distance from the preceding vehicle or achieves the desired velocity in the absence of one. A radar or a scanning laser is used to determine the inter-vehicle distance and relative velocity (lidar). ACC, on the other hand, is primarily designed as a comfort system. As a result, relatively large inter-vehicle distances are used, with a defined minimum time headway of 1 second, the latter referring to the geometric distance divided by the vehicle velocity. It is believed that lowering the time headway to a value much less than 1s will increase traffic throughput. Today's ACC systems are primarily concerned with tracking the desired distance from a preceding vehicle or the intended speed. Additional benefits of the ACC system include a large reduction in aerodynamic drag force, fuel economy, emissions, and driver desired reaction. Despite its many merits, designing an ACC system for multiple objectives is a difficult task, especially when the system model is unclear.

B. Cooperative Adaptive Cruise Control

Adding a wireless intervehicle communication link to the standard ACC feature, commonly called a Vehicle-to-Vehicle (V2V) communication link, allows for driving at short intervehicle distances while maintaining string stability. Hence known as CACC. String stability may not be observed in ACC systems. This means that oscillations injected into a traffic flow – such as those caused by vehicles braking and accelerating – can be magnified in the upstream direction. In the best-case scenario, this results in phantom traffic bottlenecks or head-on crashes. String stability cannot be demonstrated for ACC systems aiming to maintain a set following distance. CACC resolves this issue and, in any instance, may increase stability by shortening the time it takes for the preceding vehicle to respond. This delay in human drivers is determined by response time and movements such as shifting one's foot from the throttle to the brake pedal. This delay is minimized in ACC, but because of the estimate process required to convert discrete range readings to a metric of change in range over time, there is still a significant phase delay. Through vehicle-to-vehicle communications of critical data such as location, velocity, and acceleration, CACC allows the vehicle to have information not only on the vehicle directly in front (through sensors) but also on a leading vehicle or cars further ahead.

III. Platoon Operations

A. Formations

In simulation scenarios, various platoon formation procedures have been developed and tested. Ramp-based formation and ramp-highway-based formation are two types of formation systems. The formation of the platoon takes place at the ramp in ramp-based formations. The vehicles are lined up at the ramp lanes. They wait for specified termination conditions such as time-out, platoon length limit, or the requirement to make room for freshly arrival vehicles. There are four different types of ramp-based formation strategies that have been proposed[2][3]:

1. Destination grouping: In this technique, the entrance ramp lanes are preassigned for a specific range of destinations.
2. Dynamic grouping: A destination range is pre-determined in the dynamic grouping. The difference between the nearest and farthest destination of platoon members must be less than or equal to the set destination range when forming a platoon.
3. Platoon splitting and dynamic grouping: In this technique, a platoon is established with the constraint that platoon members must be sorted according to their destination. It suggests that the platoon leader has the most distant goal and the last member has the closest.
4. Random formation: As the name implies, under this technique, vehicles are assigned to lanes at random, and platoons are formed on the move.

The ramp-highway-based platoon formation plan is the second sort of formation technique:

1. Vehicle assignment optimization based on destination: This technique is based on vehicle assignment optimization based on destination. On the ramp, a vehicle's logical assignment is made, while the physical assignment is made on the highway.
2. Transient platoon formation: In the absence of a feasible platoon, a temporary assignment of a vehicle to a non-viable platoon is permitted.

B. Merging Strategies and Splitting

The vehicles are required to merge with the existing platoon. The following are the three merging strategies [2]:

1. Front merge: The platoon-capable vehicle joins ahead of the present platoon leader in this technique. The acceptability of the vehicle's merger is determined by three essential parameters: the distance between the platoon and the vehicle, the vehicle's surrounding traffic, and the platoon's relative speed.
2. Tail merge: The platoon-able vehicle joins behind the final platoon member under this technique. The suitability of the vehicle's merger is the same, i.e., it is determined by three parameters: the distance between the platoon and the vehicle, and the vehicle's surrounding traffic.
3. Middle Merge: In this method, a platoon-capable vehicle joins two platooning vehicles in the middle. In general, more than one merger position is available, to be precise n-1 positions, if n is the platoon's length (in terms of vehicles). The decision was made based on three factors: the distance between the vehicle and the merging position, the vehicle's surrounding traffic, and the platoon's and vehicle's speed differences.

It is always desirable to have a successful merger. However, this is not always achievable. If a vehicle is unable to join a platoon, or if the current vehicle must deviate from the platoon's route, or even if the preceding vehicle is behaving abnormally, splitting is required. This vehicle becomes the leader of itself and splits the platoon [1].

Maiti et al. has discussed and produced a flow chart for front and tail merge with the vehicle selection. They referred to the platoon-able vehicle as *Vm* and the non-platoon-able vehicle as *Vnm* in the buffer region during their discussion. If there is only one contender, the merger is based on that vehicle. If there are more competitors, they are reduced to the closest two vehicles, one in front and one behind. Because it is easier for the preceding vehicle to slow down and merge than the trailing vehicle, the front vehicle is taken into the merger if it is closer to the platoon. If the back contender is closer than the front contender, various factors such as traffic and speed difference must be taken into consideration. For this, a heuristic score is calculated with the comparative distance score. The log to the raw distance value is used to scale down the value of the comparative distance. The weightage of surrounding traffic and the merging vehicle's speed are also taken into account when calculating the final heuristic score.

For middle merge the flow chart shown in Fig. 1. The platoon-able vehicle *Vm* within the buffer region and which are in the adjacent lane of the platoon are considered. According to the ramp-based formation strategies, the vehicle is assigned a position. The vehicle *Vm* accelerates and aligns parallel with *Vp* (platoon vehicles), which is ahead of the target location, forming a gap with the vehicle behind *Vp*. *Vm* slows down, changes lanes, and enters behind *Vp* as *Vp* maintains its pace.

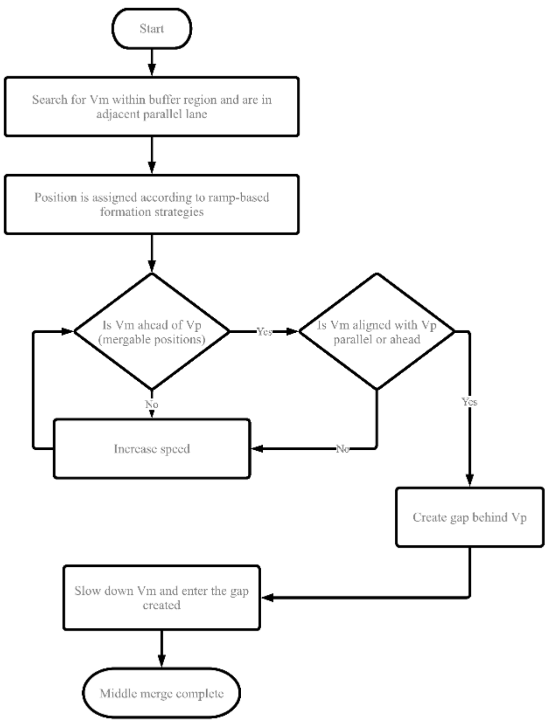

Fig. 1. Middle merge flow chart

IV. DRIVING STATE RECOGNITION

The cooperative car following (CCF) state, normal car following (NCF) state, and abnormal car following (ACF) state are the three driving states. The states of driving are as follows [1]:

1. A vehicle in a platoon is in a CACC driving condition if it is in a CACC control mode with a fixed distance or time headway.
2. A vehicle in a platoon is in a regular car following driving condition if it is in an ACC control mode with a fixed distance or time headway, or if it is manually controlled by a driver and follows a preceding car steadily.
3. A vehicle in a platoon is in abnormal car-following driving state if its state differs from CACC or normal car-following driving state, such as when it is attempting to change lanes or when it is out of control, causing an associated relative position to be too long or too short.

Various driving states require different vehicle grouping and control tactics. In this study, the long short-term memory (LSTM) mode and the time window method are used to distinguish driving situations in order to attain this goal.

The LSTM model is a recurrent neural network (RNN) architecture that inherits the superior recognition performance of NNs with classed time-series data. To recognize driving conditions and eliminate jitters in the recognition results, a long short-term memory (LSTM)-based neural network and time-window approach are applied [1]. Unlike the SVM, the LSTM approach works with related variables that are separated by adjacent time steps. In more depth, the LSTM uses internal states or memories to recall values for long or short periods. As a result, if there are time lags of unknown lengths for crucial behaviors, the LSTM can uncover long-term correlations among input variables or internal states [9].

This neural network can predict the probability of danger using the Monte Carlo simulation, when a vehicle in a platoon is in an abnormal car-following state or in a normal car-following state with a higher danger-probability, a platoon is split and a new platoon leader is chosen [1]. During the platoon splitting time or in a regular driving state with a decreased danger probability, a vehicle behind the dangerous vehicle in the CACC can be elected as a new platoon leader.

V. CONCLUSION

In this paper, we have discussed the advanced driver assistance system which is important for the basic functionality of the platoon system. The platoon formation must establish the position of the merging vehicle inside the platoon which is generally dependent on the leader. These formations can be performed by any of the three merging strategies, namely front merge, tail merge, middle merge. A heuristic is proposed to select the most preferable merging vehicle considering the various parameter like distance, speed, and traffic. From the middle, the merge is most preferable at traffic, as platoon travel less distance, and the merging vehicle has to wait only until the gap is created. As the gap creation and speed adjustment are performed simultaneously. the driving state recognition can be used to predict the preceding vehicle behavior which can determine the danger probability using the Monte Carlo method, and identify the different driving states. This can lead to the reduction of unnecessary platoon splitting operations. Integrating these techniques, we can achieve a solution that can increase the safety and smoothness of the platooning system. first page.

REFERENCES

[1] W. Hao, L. Liu, X. Yang, Y. Li and Y. -J. Byon, "Reducing CACC Platoon Disturbances Caused by State Jitters by Combining Two Stages Driving State Recognition With Multiple Platoons' Strategies and Risk Prediction," in IEEE Transactions on Intelligent Transportation Systems, doi: 10.1109/TITS.2020.3033436.

[2] S. Maiti, S. Winter, L. Kulik and S. Sarkar, "The Impact of Flexible Platoon Formation Operations," in IEEE Transactions on Intelligent Vehicles, vol. 5, no. 2, pp. 229-239, June 2020, doi: 10.1109/TIV.2019.2955898.

[3] R. Hall and C. Chin, “Vehicle Sorting for Platoon Formation: Impacts on Highway Entry and Throughput,” Transportation Research Part C: Emerging Technologies, vol. 13, no. 5, pp. 405–420, 2005.

[4] L. Hobert, “A Study on Platoon Formations and Reliable Communication in Vehicle Platoons,” Master’s thesis, University of Twente, 2012.

[5] T. S. Dao, J. P. Huissoon, and C. M. Clark, “A Strategy for Optimisation of Co-operative Platoon Formation,” International

Journal of Vehicle Information and Communication Systems, vol. 3, no. 1, pp. 28–43, 2013.

[6] Ritchie, Hannah. "Cars, planes, trains: where do CO2 emissions from transport come from?." Our World in Data. 06 Oct. 2020. Accessed on: May. 2, 2021. [Online]. Available: https://ourworldindata.org/co2-emissions-from-transport

[7] Q. Deng, "A General Simulation Framework for Modeling and Analysis of Heavy-Duty Vehicle Platooning," in IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 11, pp. 3252-3262, Nov. 2016, doi: 10.1109/TITS.2016.2548502

[8] A. Abdullahi and S. Akkaya, "Adaptive Cruise Control: A Model Reference Adaptive Control Approach," 2020 24th International Conference on System Theory, Control and Computing (ICSTCC), 2020, pp. 904-908, doi: 10.1109/ICSTCC50638.2020.9259641.

[9] K. Greff, R. K. Srivastava, J. Koutník, B. R. Steunebrink and J. Schmidhuber, "LSTM: A Search Space Odyssey," in IEEE Transactions on Neural Networks and Learning Systems, vol. 28, no. 10, pp. 2222-2232, Oct. 2017, doi: 10.1109/TNNLS.2016.2582924.

[10] J. Lioris, R. Pedarsani, F. Y. Tascikaraoglu, and P. Varaiya, “Platoons of connected vehicles can double throughput in urban roads,” Transp. Res. C, Emerg. Technol., vol. 77, pp. 292–305, Apr. 2017.

[11] G. Piacentini, P. Goatin and A. Ferrara, "Traffic Control Via Platoons of Intelligent Vehicles for Saving Fuel Consumption in Freeway Systems," in IEEE Control Systems Letters, vol. 5, no. 2, pp. 593-598, April 2021, doi: 10.1109/LCSYS.2020.3004754.

[12] B. Tian, X. Deng, Z. Xu, Y. Zhang and X. Zhao, "Modeling and Numerical Analysis on Communication Delay Boundary for CACC String Stability," in IEEE Access, vol. 7, pp. 168870-168884, 2019, doi: 10.1109/ACCESS.2019.2954978.

[13] J. Lunze, "Adaptive Cruise Control With Guaranteed Collision Avoidance," in IEEE Transactions on Intelligent Transportation Systems, vol. 20, no. 5, pp. 1897-1907, May 2019, doi: 10.1109/TITS.2018.2842115.

[14] G. J. L. Naus, R. P. A. Vugts, J. Ploeg, M. J. G. van de Molengraft and M. Steinbuch, "String-Stable CACC Design and Experimental Validation: A Frequency-Domain Approach," in IEEE Transactions on Vehicular Technology, vol. 59, no. 9, pp. 4268-4279, Nov. 2010, doi: 10.1109/TVT.2010.2076320