Truck platooning system using Distributed and Parallel Systems

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Abstract*— *The future of the road transport system is changing rapidly with great innovation and concern about climate change. Innovation with a great cause for the environment receives enormous funding from larger organizations. One such innovation in the field of automotive systems is truck platooning in which the trucks drive cooperatively at less than 10 meters distance between each other using automated driving technology. This helps the transportation companies in lowering fuel consumption and improvements in driver productivity. Not only that, but it also benefits society by reducing the level of accidents, safer traffic, less congested roads, and lowering carbon emissions. This paper explains what is platooning, what are the benefits, an illustration of requirements and use cases, implementation of a few use cases using distributed and parallel systems including GPU programming and simulation of the same.

Keywords—TPS: Truck Platooning System, LV: Leading vehicle, TV: Trailing vehicle, PMS: Platoon monitoring station

I. Introduction

Truck platooning is the linking of two or more trucks in the convoys, using wireless communication technology and automated driving systems. These vehicles set the distance to be maintained between each of them in the platoon when the connection is successfully established. The truck at the head of the platoon acts as the leader, with the vehicles behind reacting and adapting changes in the environment so that the driver can take a back seat. The first and last instance of operation like engaging and disengaging in the platoon must be performed by the user.

As automobiles achieve better and better stages of autonomy, numerous varieties of coordinated motions emerge as possible. A vital instance is that of platooning, i.e., a configuration wherein one or greater automobiles autonomously comply with a lead vehicle (hereafter: LV) at an alternatively near distance, so one can achieve, for instance, accelerated protection, decreased congestion, and decreased gasoline consumption. Thus, in current years, studies on platooning have intensified, and numerous strategies for secure and green platooning were developed. Most platooning paintings up to now have been targeted on classical control, in a wide sense. The best method is to apply popular cruise control (CC) for the LV, i.e., using a steady set velocity for the LV, and adaptive cruise control (ACC) for the opposite automobiles withinside the platoon; each standard may be defined in greater element below. This technique for platooning, so one can hereafter be called CC+ACC, may be taken into consideration as a baseline case, in opposition to which different platooning algorithms may be compared, with appreciate to their protection aspects, gasoline savings, etc.

II. Impact of Platooning

Platooning can make contributions to electricity saving in 3 ways: one is the discount of aerodynamic drag, particularly at some point of excessive-pace driving, the second one is the smoothing of traffic flow and the third is the boom of the street capability to offer extra room for surrounding visitors. The former are microscopic contributions, and the latter is a macroscopic contribution

A. Benefits and motivation of Truck Platooning

- Truck platooning lowers fuel consumption and CO2 emissions. The air-drag friction reduces significantly when the trucks are driven closer to each other.
- It helps improve safety by automatically applying immediate brakes whenever necessary.
- It enhances conveyance by using roads more efficiently, delivering goods faster, and reducing traffic jams. It also allows the driver to engage in other tasks such as making phone calls.

Previous simulations and measurements have shown that theoretical predictions of energy savings are not practically achievable, and speed fluctuations in normal driving result in less energy savings than those measured in the constant speed test. Refer table 1 for better understanding.

Fuel consumption	Theoretical [29]	Simulation by Daimler [29]	Measurement by Daimler [29]	Simulation with PELOPS [28] by KONVOI [30]
1st vehicle	2.17 % (14 t) 1.64 % (28 t)	2 % (28 t)	6 % (14 t)	2% (14 t)
2nd vehicle	38.1 % (14 t) 28.8 % (28 t)	19 % (28 t)	21 % (28 t)	11% (28 t)

Table I. Reduction of Fuel Consumption Based on Theory, Simulation, and Test (for 14 Ton and 28 Ton Trucks).

III. Requirements and Characteristics

- Communication establishment between the platoons – engaging and disengaging of platoons.
- Speed adjustment between the platoons.
- Gap adaptation – Open gap
- Traffic light recognition – Stop if RED light, start if GREEN
- Pedestrian detection – Apply emergency brake when a pedestrian crosses the platoon lane

A. Distributed and parallel systems for truck platooning

Distributed systems can be arranged in the form of client/server systems or peer-to-peer systems. All the nodes in the distributed system are connected to each other. In the case of a truck platooning system, a node refers to a truck.

- All the nodes in the system are connected to each other which helps in sharing of data between the trucks.
- More trucks can be easily added to the distributed system. i.e., it can be scaled as required.
- Failure of one truck does not lead to the failure of the entire distributed system. Other trucks can still communicate with each other.
- In our project we are using a client/server model for communication where the leader truck acts as a Server and the following trucks act as clients.

Parallel processing is the use of two or more processors (cores, computers) in combination to solve a single problem. It is a type of processing architecture in which several processors execute or process an application or computation simultaneously.

- Parallel computing saves time, allowing the execution of applications in a shorter time.
- Compared to serial computing, parallel computing is much better suited for modeling, simulating, and understanding complex, real-world phenomena.
- In practical scenarios, when the trucks are driven on the road, several operations have to be executed simultaneously. This includes monitoring vehicle and surrounding status like communication, object detection, etc.,
- Parallel processing aids in achieving results from multiple processes at the same time.

B. GPU for Truck Platooning

The Graphics Processing Unit is designed for parallel processing for a wide range of applications including graphics and video rendering. GPUs are specifically designed to accelerate computer graphics workload. Today's GPUs are more programmable than ever before, affording them the flexibility to accelerate a broad range of applications that go well beyond traditional graphics rendering.

Advantages of Graphics card:

- Increases system performance to a greater extent since it is independent of the CPU.
- A computer's built-in graphics card shares a part of system memory for its functioning. If a dedicated graphics card is in use, it has its own memory thus freeing up memory from the computer. Additionally, these memories are much faster than the system memory.
- In our project, we have used the architecture of the NVIDIA graphics processing unit.

Therefore, a CUDA (Compute Unified Device Architecture) programming Interface (API) that exposes the inherent parallel processing capabilities of the GPU has been deployed.

C. Connection establishment

To activate platooning in the trailing truck, the dashboard provides information to the driver about the available trucks. The leader truck is continuously sending acceleration, speed, and PRND status to establish a connection. The radio verbal exchange is used to ship the activation code to the radio transceiver of the trailing trucks which turns on the platooning. When a trail truck successfully reads these values, feedback about the activation is provided back to the driver in the lead vehicle on the dashboard display via the feedback signal from the trailing vehicle.

Communication between the lead truck and the trailing truck is established via a Wi-Fi network. The communication between the truck should be established within a certain calibratable duration.

To show this a fork system call is used. Fork helps in creating a new child process, which apparently helps in running 2 processes concurrently. The lead truck uses 1 process to continuously send the acceleration, speed, and PRND, while the trailing truck uses the other process to receive them.

D. Communication between Lead truck and trail truck is lost

When the communication between the lead truck and trail truck is lost the system should react in the following way -

- Trailing vehicle should send a reconnection flag.
- Leading truck should send a reconnection request.
- If a connection is established after this then the trailing truck should send an acknowledgment saying the connection is successful else, it should try to reconnect a few more times.
- If the connection is not established even after multiple attempts, then it implies that the connection is completely lost.
- The trailing truck should look for the nearest sideway platform, and in the limp home mode, it should stop there.
- The lead vehicle should send out critical last available truck information like location, speed, and acceleration to the platoon monitoring station.

State machine diagram [Fig. 1] and activity diagram [Fig. 2] are used to show this use case for better understanding.

State machine diagram – This state machine is modeled to show how the state transition takes place when there is a communication failure between the lead truck and following the truck. In this modeling, the "state with region" state diagram is implemented. The Regions State pattern creates elements and diagrams that contain orthogonal composite states, each containing two regions with multiple substates. The area is indicated by a compartment separated by a dotted line. When a complex state transitions to a state, each region has its own independent state, and both regions have their own active state. In case of communication failure, both lead truck and follow truck go through transitions simultaneously, thus this state machine is used.

As shown in figure 1 when there is connection failure the system will transit to the "Attempt to connect" state. Region 1 shows the transition lead truck undergoes and region 2 shows the transition follow truck undergoes.

Region 1 (Lead truck) – Sends data to follow truck while attempting to reconnect. Failure to reconnect 3 times results in communication failure. The truck should send follow truck information to the platoon monitoring station. If the truck successfully connects inside 3 attempts the truck will move to the main state i.e., communication intact state.

Region 2 (Follow truck) – Follow truck continuously attempts to connect to lead vehicle. Failure to do so, it should enter a limp-home mode and move out of platooning and move to the nearest sideway platform.

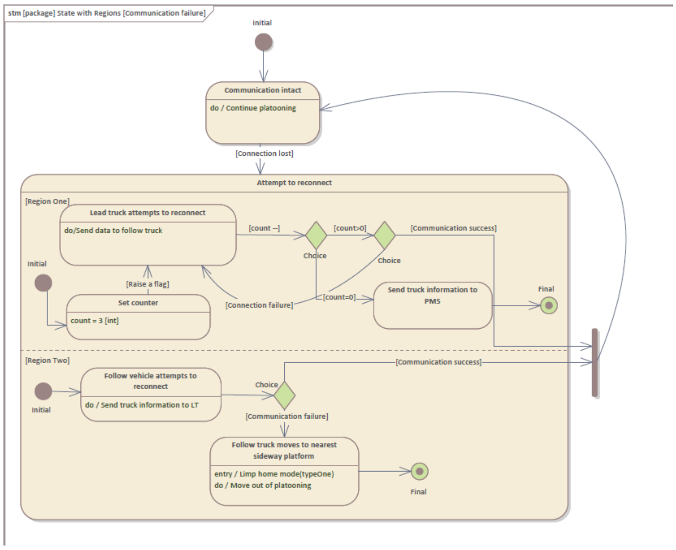

Fig. 1. State machine diagram when there is a communication failure.

Activity diagram - If the communication between the vehicle in front and the trailing truck is lost, then the lost flag for that truck should be raised. If the driver can't connect with the machine after trying to reconnect, then details about the vehicle should be provided to the driver. The vehicle's owner should also send details about the vehicle, such as its GPS coordinates, fuel consumption, and speed. The vehicle that's trailing should also ask to be reconnected. If the communication between the two parties is not established, then the trailing vehicle should look for the nearest sideway platform. The vehicle that's leading should also send details about its driving conditions to the nearest station.

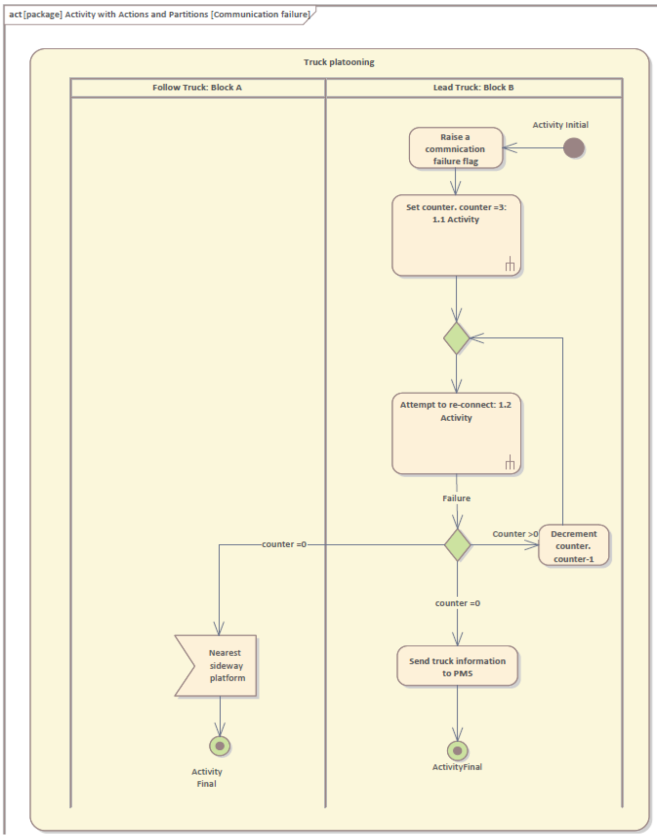

Fig. 2. Activity diagram of Communication failure between lead truck and trailing truck.

To show this characteristic networking computing model also known as client/server architecture because all the requests are delivered over a network. Improved data sharing, Integration of services, Shared resources amongst different platforms, Inter-Operation of data, and security are some of the main reasons for choosing this architecture.

The client is used to show that the lead truck is continuously sending data to the trailing truck, while the server is used to show that the trailing truck is constantly receiving data and sending an acknowledgment. Visual representation of client-server communication protocol using sockets is shown in figure 3.

For better display of the implementation –

- Input character 1 is used to indicate loss of communication.
- Input character 2 is used to indicate failure of reconnection.
- Any other characters apart from these are used to show the connection is intact.

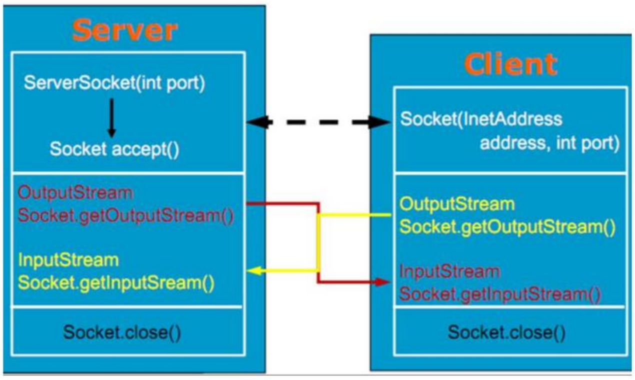

Fig. 3. Client-server protocol using sockets.

E. Gap adaptation techniques

Once the platoon connection is established it is substantial to react to the real-time road scenarios. The platoons maintain distance between them based on the default trajectory settings which is generally 10m. We also receive information about the constant speed and braking information from the leading vehicle through V2V communication. There is also some information that could be transmitted from the following vehicle to the leading vehicle, for instance, if there is a vehicle on the adjacent lane that wants to change its lane and wants to overtake the platoon, there should be a mechanism to support this feature. In our paper, we propose a solution that is feasible to achieve in a real-time scenario. The platoon trucks will inherit some features from the radars and cameras installed within them. We consider at least 4-6 cameras with wide-angle lenses integrated into the body panel of the trucks. Usually, these cameras are placed on the front grille, under the rear-view mirrors on either side and on the tail. The cameras are located at spots that enable the surveillance of the entire perimeter of the vehicle. Therefore, when a vehicle is detected adjacent to the platoon wants to overtake to change the lane, the following truck senses the information like vehicle speed which is assumed to be greater than the platoon speed, indicator status and sends that information to the leading truck vehicle. On receiving this alert, the leading vehicle sends an open gap request to the corresponding truck. The non-platoon vehicle could now enter the platoon lane, however, now the following trucks have to adapt to the speed of the vehicle in the platoon lane. This can be achieved by using Automatic Cruise Control. The NP vehicle checks for the desired conditions to change the lane and moves out of the platoon lane. Once the NP vehicle moves out, the following truck again sends information to the leading vehicle and upon the close gap request, it gets back to its original position by maintaining a distance of 10m between the platoons.

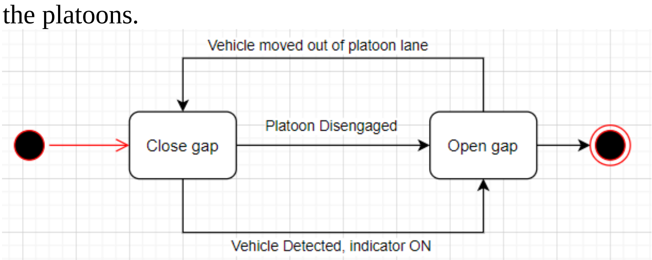

Fig. 4. State machine diagram for Gap adaptation

F. Emergency Braking using Object Detection

As mentioned earlier, each truck is provided with at least 4-6 cameras which includes a front grille camera. This can be both a narrow-angle and wide-angle camera. Using the narrow-angle camera, the truck can detect objects from a far distance. If there are any objects like a pedestrian in the platoon lane, the leading truck senses this and sends information to the following trucks to either slow down or apply emergency brake based on certain conditions. In our scenario, if the pedestrian stays in the platoon lane for more than 3 seconds an emergency brake is applied, otherwise, the leading truck sends a message to slow down the speed. Once the platoon lane is clear from obstacles, the platoon picks up the original speed.
During the course of operation, it is also necessary to monitor the platoon lane. Since a series of trucks drive in a single lane, it is important to stay in the same lane throughout the journey. To accomplish this, we again use multifunctional camera sensors to monitor the lane attributes. This information is processed using the lane-keeping assist algorithm and the steering wheel angle will be adjusted based on the sensor output.

G. Cruise Control during traffic signal detection

When the vehicle is cruising at a constant speed on a highway, there could be a situation where it could encounter a traffic signal or a toll signal. The lead platoon vehicle should be able to detect the light and take necessary action to slow down or stop the vehicle when the red signal is found and continue to accelerate the vehicle when a green signal is found. The calculation of speed according to the traffic lights is done in this project using an algorithm. The multifunctional cameras present in the leader truck detect the traffic signal, calculate the speed, and send it to the following platoon vehicles. This use case also holds good when the leader truck detects any objects, for instance, a pedestrian. When the leader truck detects a pedestrian in its lane, it immediately sends a signal to the following trucks to apply an emergency brake. This is intended to prevent fatal accidents and provide safer cruising.

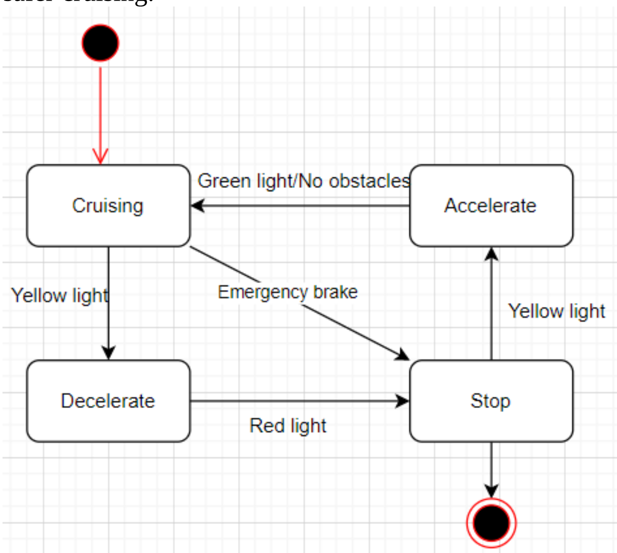

Fig. 5. State machine diagram for Cruise control during Traffic signal/pedestrian detection

G. *External obstacle in the vicinity(Simulation) -*

A simulation is a controlled environment in which a real-world process is recreated. It entails developing laws and models that reflect reality, then putting those models to the test to see what happens. Simulations are utilized in scientific research, safety testing, and the creation of images for video games and films. A simulation is a controlled environment in which a real-world process is recreated.

TinkerCAD tool is used to show the simulation of how the system should behave when there is an external object in the vicinity. An ultrasonic sensor is used to validate if an external object is in the vicinity. When an external object is in the vicinity the lead truck should be indicated the presence of this and the lead truck should slow down the speed or move to the braking state. Limitation of the tools allows us to only show part of the implementation, i.e., an LCD display is constantly showing the distance between the object and the system and indicating the presence of an external object as shown in Fig. 4 and Fig. 5. With this information, the platooning system should be able to change the speed of the system or force the system to be in a braking state.

Once the obstacle moves away from the vicinity of the truck, after certain duration**,** the gap will be reset to the default value and the lcd will display “No obstacle detected”.

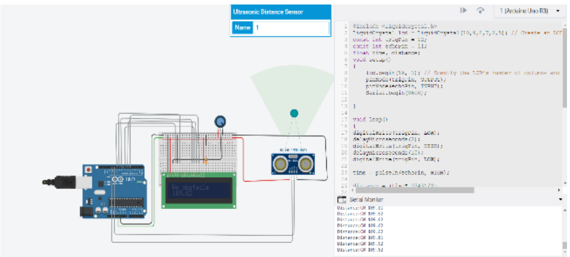

Fig. 6. No obstacle is detected when the distance is more than 100 cms.

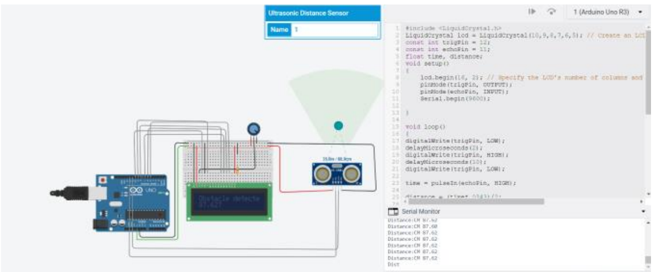

Fig. 7. Obstacle detected when the distance is less than 100 cms.

IV. CONCLUSION

Platooning holds great promise of increasing both road traffic safety as well as efficiency. This paper tries to model the platoon system, followed by testing it. In this study, we identified the platooning formation is done in the starting point where the leading truck activates the platoon and establishes a connection with the trailing truck in the vicinity. Sensors like ultrasonic, camera, RADAR are used to learn about the surrounding of the truck and activate necessary action during situations for example intruder detection. Communication between the truck is established via a Wi-Fi module and using GPS the positioning of the truck is identified and GSM technology is used to connect to the platoon monitor station. Modeling is done considering a few critical use cases like external vehicle in the vicinity, Speed of trail vehicle is less than expected value, loss of communication between the trucks. To confirm product (system) meets the functional, performance, design, and implementation necessities, exceptional varieties of checks had been implemented.

Furthermore, the simulation on the TinkerCAD provided us with some amazing results in order to speculate our assumptions. In future research, the real Arduino board and cameras can be used to obtain accurate results.

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