Truck Platooning Report

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Contents

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Abstract:

This paper outlines the process of how to design and validate a truck platooning system. This is a process of designing and performing several activities of the platoon, this include: joining the platoon, coupling as well as decoupling and avoiding obstacles. Single-driver and system-level views demonstrate the model of the system. As for the initial design, UML diagrams are employed, while UPPAAL models are viewed as to ensure safety. Python versions are utilized for simulation and validation to mutually confirm the efficiency of the system in the actual application. The results reveal the efficiency of the presented system in preventing deadlock conditions and establishing high identification rates for the leader vehicle, leading to a safer and more efficient means of transport, particularly with the use of trucks.[Sh24a]

1 Motivation

The self-driving car industry is evolving and truck platooning is a new concept which can be fascinating. This technology has the potential to transform the transportation industry by improving fuel economy, lowering pollution levels, and making roadways safer in general. This lab project is a good start for us as engineering students who are passionate about self-driving systems. It will assist us in mastering the specifics of truck platooning and ways to improve it.[Sh24a] This is because our main focus is triggered by various facets that the truck platooning can work as a solution in the transport sector. This way, trucks can drive really close to each other, and cut down on the wind resistance which in turn cuts a lot of fuel and hence cuts pollution. Truck platooning also makes the roads safe for use due to elimination of human errors and is also able to respond to any dangers on the road faster.[Sh24a]

In this project, you will understand how to effectively design, incorporate a model and test implementation of the truck platooning systems. It will then analyze various circumstances to determine what is required and establish good communication on how the trucks would function in harmony. We will also have control to ensure that the distance separating the two trucks, principally the leading one, is safe and use learning to decide on the best leading truck.[Sh24b]

The goal of this project will be understanding the specifics of truck platooning technology and how it can be implemented in practice by the end of this project. Our work is presented in the hope that it will contribute to enhancing self-driving systems and therefore transport sustainability.[Al15]

2 Representing Scenarios through UML Diagrams

2.1 Truck Platooning use case diagram

In figure 1, the use case diagram shows the Truck Platooning Maneuver system and the relationships between the leader and follower trucks. These are; increase in speed and decrease in speed, overtaking, and stopping which are well coordinated by Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communication. The central "Platooning Operationëncompasses joining, splitting, cutting in/out, and leaving the platoon, essential for maintaining coordinated movement. It provides the general overview of how the platooning system operates which in turn establishes the basis for developing more detailed process diagrams of the operations within the platooning system.

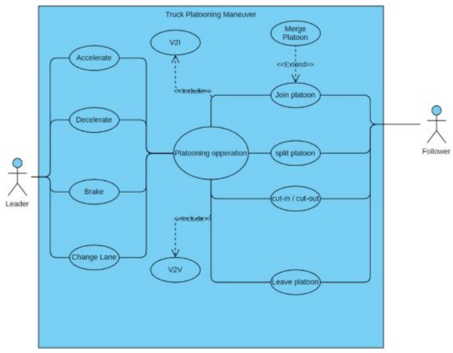

Fig. 1: Truck Platooning use case

2.2 Joining platoon use case diagram

The figure 2 shows the interactions between an individual truck and the PlatoonSystem during the process of joining a platoon. The truck starts by making a join request as a result of which the system will acknowledge the request. These are engaging the join request, joining the platoon, and finally commencing the platooning process. This diagram provides a general framework for the next sequence diagrams that shed light on the specific process and the relationship in each of the steps.

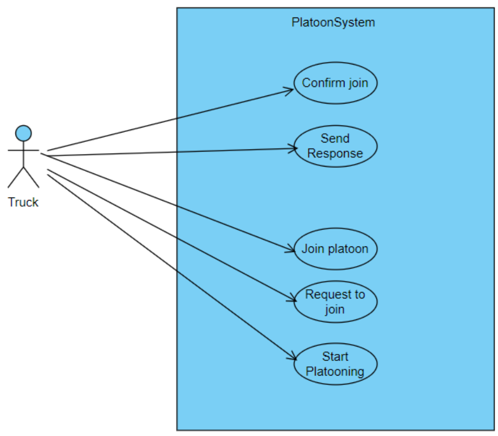

Fig. 2: joning platoon use case diagram

2.3 Joining platoon sequence diagram

The following is a sequence diagram showing the series of activities that occur between a truck and the PlatoonSystem in the joining process. It starts with the truck initiating the dais by sending a “Request to join” to the system followed by the response to the request to join. The system approves the join request and the truck thus becomes part of the platoon. The sequence ends when the starting platoon begins the platooning operation and serves to show the complex chain of communication and action needed for the integration of a new platoon.

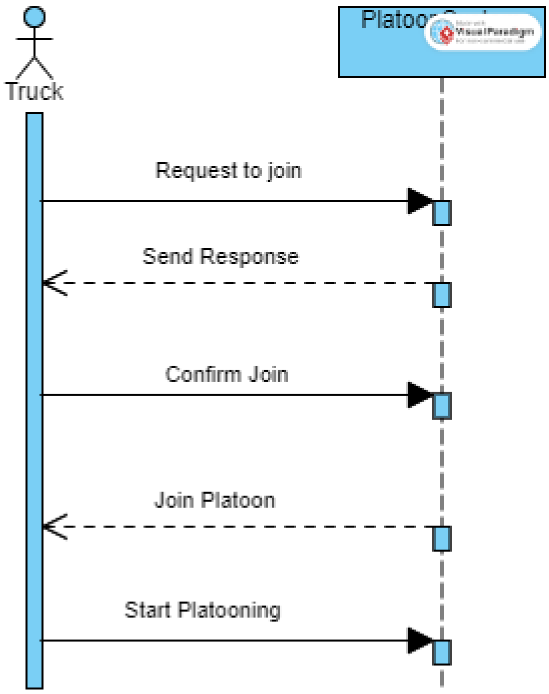

Fig. 3: joning platoon sequence diagram

2.4 Leaving the platoon UML diagram

The following use case diagram depicts the aspect of involvement of Lead Truck and Slave Truck within the Platoon System. This is normally done by the Lead Truck, which signals the beginnings of the” leaving sequence “, in reaction to which the Slave Truck sends a ” request to leave the platoon “to the system. The Platoon System then processes this request and the moment the Slave Truck is approved, the System allows it to proceed and say “leaving platoon.” It can be clearly seen that this visual representation captures and demonstrates the purpose of the System and the actors.

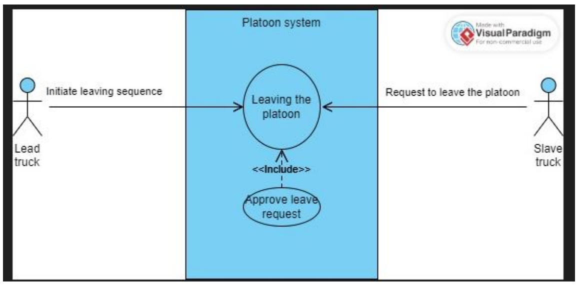

Fig. 4: Leaving the platoon Use case diagram

2.5 Leaving the platoon Sequence Diagram

The sequence diagram illustrates the interaction between three key systems: management system that consists of the Lead Truck, the Slave Truck, and the Management System. The outside process begins with the most superior Truck or the Lead Truck sounding the begging of the leave sequence. It then sends a request to the Management System that the Slave Truck wishes to exit the platoon. Finally, when the leave request is granted the Management System informs the Slave Truck, while the later informs the Lead Truck and the leave sequence for the platoon is over.

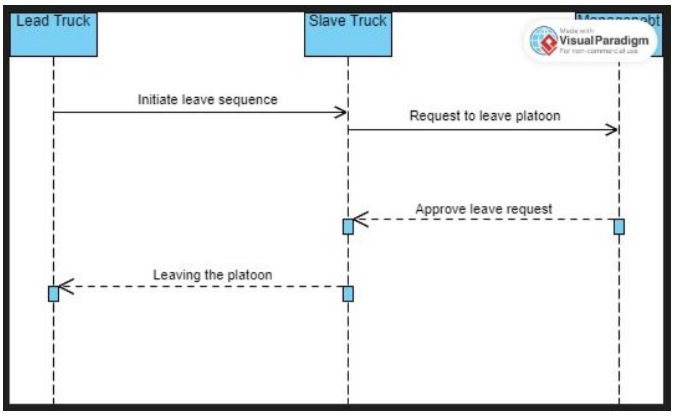

Fig. 5: Leaving the platoon Sequence Diagram

3 Validation through the UPPAAL Framework

We have developed the UPPAAL model to cover multiple scenarios, verifying that the system operates smoothly without encountering deadlocks. This model also ensures that the system can adapt dynamically to environmental changes while continuing to function safely.

3.1 UPPAAL Model: platoon join and response

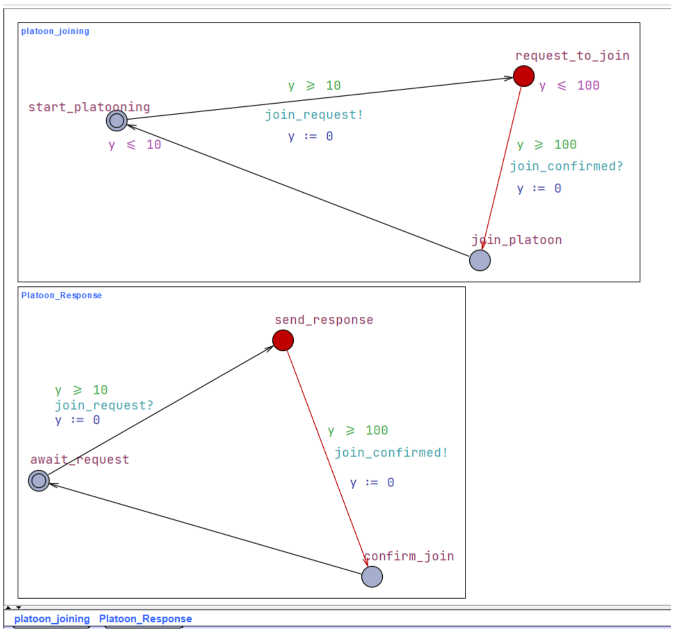

Fig. 6: For the complete XML file, visit our GitHub repository for platoon join and response `https://join_platoning.xml`

3.2 UPPAAL Model: Leaving the platoon

The figures 6 show part of the interaction in Platoon system as presented in Uppaal model. The Lead Truck system indicates a leave platoon signal within the ‘x’ timer which is set to a level five. The Slave Truck system, regulated by the ‘y’ timer sends the message request leave to the Management system and looks forward to approval leave. The Management system then assesses this request, and once affirmed, resets ‘y’ timer and commands the Slave Truck to leftplatoon. These timed automata facilitate the representation of the concurrent activities of the system’s components.

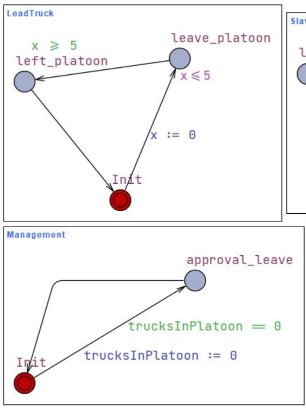

Fig. 7: For the complete XML file, visit our GitHub repository for Leaving the platoon`https://Leader,slave,Management,truckfinal.xml`

3.3 UPPAAL Model: Final Simulation

The Uppaal model illustrates the interactions between three systems: The respective subordinates involved are Lead Truck, Slave Truck, and Management when performing the platoon formation and when departing. The Lead Truck starts play by playing formation signaling the Slave Truck to ask to join the play. This request is assessed by the Management system and the confirmation for the Slave Truck admission to the platoon is provided. Afterward, either Lead Truck or Slave Truck can request the start of the move, with the same sequence involving the Management system. The Lead Truck, and Slave Truck; these have timers, x and y to control these processes within a given time line.

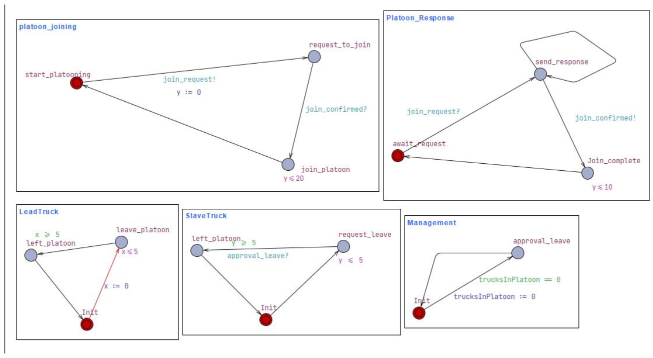

Fig. 8: For the complete XML file, visit our GitHub repository for Joining and leaving platoon uppaal `https://platoon_joiningfinaluppaalalltogather.xmlFINAL.xml`

Verification Status: The Uppaal model has been validated thoroughly and it has been realising that there is no deadlock possible to occur in this organisation which ensures the working efficiency. This is as confirmed in the Figure 9 below [Insert Figure 12 here]. Moreover, all of the predetermined criteria are satisfied by the model, thus providing evidence of the adequacy of the truck platooning system's protection measures and the strength of the platooning structure.

```
Status
Property is satisfied.
Disconnected.
Established direct connection to local engine.
UPPAAL version 5.0.0 (rev. 714BA9DB36F49691), June 2023 -- server. Licensed to Subir Balo / Hamm-Lippstadt University of Applied Scuence (stud.hshl.de)
```

Fig. 9: Verification Status

4 Machine learning for optimal leader truck selection

Specifically, this portion of the paper focuses on the use of a hierarchy clustering of machine learning to determine the best leader vehicle in the truck platoon system. Thus, the goal to use a dataset for evaluation is to compare results of different methods of hierarchical clustering in this case.

4.1 Dataset

The machine learning models are trained and evaluated on a dataset encompassing a range of features, as detailed in the figure 10.

```
Synthetic Data:
    fuel_consumption       size     weight  engine_power  aerodynamics  \
0          27.490802  11.560186  16.011150    549.732792      0.360848
1          39.014286  11.559945  17.080726    363.701733      0.404951
2          34.639879  10.580836  10.205845    354.547490      0.386389
3          31.973170  18.661761  19.699099    355.021353      0.358246

   distance_from_previous
0               34.474116
1               15.579754
2               21.685786
3               24.654474

Normalized Data:
 [[-1.38422726 -0.47219862  0.07548192  1.73038875 -0.87116274  1.5201087 ]
 [ 1.37131932 -0.47227303  0.38368991 -0.50535018  1.42121831 -1.24807138]
 [ 0.32529163 -0.77435418 -1.59736973 -0.61536675  0.45638641 -0.35348731]
 [-0.31238369  1.71882583  1.1381979  -0.60967182 -1.00644197  0.08144999]]
```

Fig. 10: synthetic Data

Hierarchical Clustering: i specifically selected the hierarchical clustering as the model of machine learning. This is because it categorizes the vehicles in by their similarities, and is a good starting point for identifying the leader vehicle.

Scikit-learn in Google Colab: I worked in the Google Colab environment wherein i employed the Scikit-learn machine learning library. This is common used as it enables easy access to a wide range of data and functions that support the computing of algorithms for Machine learning.

Simulation outcome:

```
Cluster Assignments:
 [1 1 1 1]

Distances to Cluster Centroid:
 [2.86507493 2.46651554 1.99222167 2.3955583 ]

Leader Truck Index: 2

Leader Truck:
 fuel_consumption           34.639879
size                      10.580836
weight                    10.205845
engine_power             354.547490
aerodynamics               0.386389
distance_from_previous    21.685786
Name: 2, dtype: float64
```

Fig. 11: Simulation outcome

Implementation Highlights:

```
# Generate synthetic data for 4 trucks
data = {
    'fuel_consumption': np.random.uniform(20, 40, 4), # liters per 100 km
    'size': np.random.uniform(10, 20, 4), # length in meters
    'weight': np.random.uniform(10, 20, 4), # weight in tons
    'engine_power': np.random.uniform(300, 600, 4), # horsepower
    'aerodynamics': np.random.uniform(0.3, 0.5, 4), # drag coefficient
    'distance_from_previous': np.random.uniform(10, 50, 4) # distance in meters
}
```

For code and data, see my project repository on GitHub: `https://Untitled0.ipynb`

Fig. 12: Code

5 The Virtual Simulation Framework

Hence, a generalized Python based modeling and simulation platform was developed to evaluate the effectiveness of our developed truck platooning system. This work ensures a large flexibility of the structural setting so by expanding the number of potential situations, one can analyze the system's profile under various tests. The first strategy was to define different Python models for each case, as described in the following subtopics.

For code and Simulation, see my project repository on GitHub: `https://Untitled3.ipynb`

The activity shows how a viable bound unit integration can be done. The platoon continuously transmits a "join request" and gets back a corresponding "Received join request!" from the

```
...  Enter 1 to trigger the simulation: 1
     Platoon joining: Sending join_request!
     Platoon response: Received join_request!
     Enter 1 to trigger the simulation: 1
     Platoon joining: Sending join_request!
     Platoon response: Received join_request!
     Enter 1 to trigger the simulation: 1
     Platoon joining: Sending join_request!
     Platoon response: Received join_request!
     Enter 1 to trigger the simulation:
```

Fig. 13: Platoon Simulation

system implying unison between the joining vehicle and the platoon system. The simulation is always activated depending on the input from a user as the system demands.

6 Conclusion

Thus, this study proves that the notion of truck platooning is indeed plausible as a solution to many issues in transportation. This is why the combination of the formal verification of the proposed system model and the outcomes of systemic simulation could be viewed as strong evidence of the system's reliability and efficiency. However, more work has to be done to see how much more can be done by truck platooning like employing better machine learning schemes and look at other potential tests. Still, this work can be the first step towards the change and make truck platooning a very valuable effort in the sphere of transportation.

7 Declaration of Originality

I,Subir Balo, herewith declare that I have composed the present paper and work by myself and without the use of any other than the cited sources and aids. Sentences or parts of sentences quoted literally are marked as such; other references with regard to the statement and scope are indicated by full details of the publications concerned. The paper and work in the same or similar form have not been submitted to any examination body and have not been published. This paper was not yet, even in part, used in another examination or as a course performance. I agree that my work may be checked by a plagiarism checker.

12/07/2024&Lippstadt - Subir Balo

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[Sh24b] Shanker, Shreyas: DESIGN REQUIREMENTS OF HUMAN-DRIVEN, HYBRID, AND AUTONOMOUS TRUCKS FOR COLLISION-AVOIDANCE IN PLATOONING. PhD thesis, Purdue University Graduate School, 2024.