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Safe Vehicular Platooning Control: Mitigating Uncertainty and Enhancing Stability

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Abstract—This paper explores a safe control strategy for autonomous vehicle platooning, focusing on mitigating the effects of uncertainty and maintaining platoon stability. Autonomous platooning, enabled by vehicle-to-everything communication, is critical in intelligent transportation systems to enhance safety, reduce fuel consumption, and minimize traffic delays. However, real-world conditions such as communication delays, external disturbances, and vehicle inconsistencies can introduce instability. This study presents a control algorithm that manages inter-vehicle distance through dynamic speed adjustment and string stability criteria. Simulation results validate the effectiveness of the proposed method under varying levels of external disturbances, demonstrating its ability to maintain desired distance gap and prevent amplification of disturbances within the platoon.

Index Terms—Uncertainty, Adaptive Control, Safety, Vehicular platooning.

I. INTRODUCTION

Autonomous vehicular platooning [1] is a promising technology in intelligent transportation systems that aims to enhance road safety, optimize traffic flow, and reduce fuel consumption, particularly in urban settings. Enabled by advanced vehicle-to-everything (V2X) communication [2], platooning allows multiple vehicles to travel in close formation under coordinated control. In such systems, a lead vehicle determines the trajectory and speed, while the trailing vehicles maintain synchronized movement through cooperative adaptive cruise control. Managing vehicle formations in complex urban traffic conditions, where external disturbances and signalized intersections are prevalent, poses significant challenges [3]. The unpredictable nature of urban traffic flows, including frequent stops, accelerations, and the presence of heterogeneous vehicle dynamics, requires robust control strategies that can adapt to uncertainties while maintaining string stability throughout the platoon.

Although numerous control strategies have been proposed to mitigate uncertainties in vehicle dynamics and external conditions, most existing approaches focus on controlled environments or highway scenarios, where traffic patterns are more predictable. In urban environments, factors such as communication delays, dynamic traffic conditions, and signalized intersections exacerbate the difficulty of maintaining platoon stability. Prior work on adaptive control and model predictive control has shown the potential to handle vehicle dynamics and uncertainties. However, these methods often struggle in real-time urban settings due to the added complexity of frequent communication delays, external disturbances, and the need for rapid response to signal changes at intersections.

This paper addresses these challenges by introducing a safe and robust control algorithm. The primary contribution is the development of a distributed platoon control strategy to ensure safe inter-vehicle distance management and dynamic speed adjustment in urban traffic. Our approach leverages real-time V2X communication, enabling vehicles to respond quickly to changes in traffic conditions and external disturbances. Our approach integrates bidirectional communication, allowing each vehicle to adjust its behavior based on both preceding and following vehicles. This bidirectional flow of information enhances the platoon's ability to maintain string stability, ensuring that disturbances are dampened rather than amplified as they propagate through the formation. By dynamically adjusting vehicle speed and maintaining coordinated behavior across the platoon, the algorithm provides a scalable solution for managing uncertainties. Through dynamic speed adjustment and real-time feedback, the proposed method maintains safe distances between vehicles, ensuring that the platoon re-

sponds smoothly to external perturbations while avoiding abrupt speed changes or dangerous gaps. To validate our proposal, we conduct extensive simulations by evaluating the platoon’s ability to converge and maintain stability under various disturbance levels. The results demonstrate the algorithm’s robustness, showing that it effectively manages the inter-vehicle gap and string stability.

The remainder of this paper is structured as follows: Section II reviews the most representative related work on platooning control strategies. Section III describes the platoon and the platoon control strategy models. Section IV describes our proposed control algorithm. Section V presents the simulation results. Finally, Section VI concludes the paper and outlines potential directions for future research.

II. RELATED WORK

Vehicular platooning systems present unique challenges in terms of ensuring stability, safety, and efficiency, especially in the face of external disturbances, communication uncertainties, and the heterogeneous nature of vehicle dynamics. In recent years, several studies have addressed these issues, proposing a range of control strategies [4]. This section reviews some recent and relevant approaches.

String stability remains a fundamental requirement in ensuring that disturbances affecting one vehicle do not amplify as they propagate through the platoon. Zhao et al. [9] present an approach that utilizes L2 string stability to address the challenge of disturbances in platoons with diverse vehicle dynamics. Their method accounts for both disturbances and communication delays, ensuring that fluctuations in one vehicle’s performance do not result in a chain reaction that destabilizes the entire platoon. By focusing on the impact of communication delays and introducing robustness into the control structure, their approach is well-suited for heterogeneous vehicular platoons. However, a limitation of this work is its assumption that communication delays are known and bounded, which may not always hold true in unpredictable environments.

Prayitno et al. [10] propose a solution that uses a distributed model reference adaptive control scheme combined with a neighborhood controller-local observer framework. Their approach focuses on maintaining stable platoon formation even when vehicles communicate infrequently or only have access to limited information about neighboring vehicles. The local observer within each vehicle estimates the states of nearby vehicles, and the neighborhood controller ensures that the vehicle’s trajectory remains aligned with its neighbors, despite

uncertainties in dynamics. This method is especially useful in reducing the need for constant communication between vehicles, making it scalable for larger platoons. However, the approach’s effectiveness hinges on accurate state estimation, and in cases of significant communication delays or data loss, performance may degrade, potentially compromising platoon stability.

Zhang et al. [11] take a different approach, focusing on hierarchical anti-disturbance control using a nonlinear least squares framework. This method is designed to manage disturbances and uncertainties across both local and global layers of control within the platoon. While local disturbances are managed at the vehicle level, global coordination ensures that the overall platoon formation remains intact. This hierarchical structure is particularly effective in rejecting disturbances and maintaining robustness, even in dynamic environments. However, the complexity introduced by the layered control structure may limit its applicability in real-time scenarios, especially in large-scale platoons with many vehicles. Moreover, the method has yet to be fully evaluated under conditions of severe communication delays or packet losses, which could affect its reliability in practical applications.

In the realm of general control approaches, adaptive control has been widely explored for managing uncertainties in heterogeneous platoons. Adaptive control techniques dynamically adjust control parameters based on real-time data, making them well-suited for environments where vehicle dynamics or external conditions are constantly changing. Arevalo-Castiblanco et al. [5] introduce a control strategy that synchronizes vehicles with diverse dynamics by using neural network approximations to cancel out nonlinear input uncertainties. An additional feature of their approach is an input estimator that compensates for communication failures between vehicles, ensuring that synchronization is maintained even when communication is unreliable. While this method shows promise, especially in terms of handling heterogeneous vehicle dynamics, the computational overhead associated with neural network approximations may present challenges for real-time applications, particularly in larger platoons where efficiency is critical.

Model Predictive Control (MPC) has also gained prominence as a powerful tool for managing the complexities of vehicular platooning, particularly in mixed traffic environments that involve both autonomous and human-driven vehicles. Hua et al. [6] propose a decentralized MPC framework that focuses on handling uncertainties related to human-driven vehicles. Their method

optimizes vehicle trajectories by incorporating both feed-forward and feedback control mechanisms, allowing the platoon to adapt to the unpredictability of human drivers. The decentralized nature of their approach improves scalability by reducing the communication load, but the computational demands remain a concern, especially in larger systems.

Sun et al. [7] expand on the MPC framework by introducing a distributed approach that addresses model uncertainties. Their method allows each vehicle to operate semi-independently, requiring only minimal information exchange with its neighbors, which reduces communication overhead. This distributed strategy is advantageous in larger platoons with continuous communication could overwhelm the network. However, like other MPC-based methods, the approach's performance heavily depends on accurate initial model parameters.

Zhang et al. [13] further build on the MPC framework by integrating robust control techniques to address both communication delays and model uncertainties. Their approach is particularly well-suited for connected vehicle platoons, where unstable communication links and external disturbances are common. By combining distributed MPC with robust control, they ensure that platoon coordination is maintained, even in environments with unreliable communication. However, as with other MPC strategies, the computational complexity of the approach could limit its applicability in real-time systems, particularly when deployed in large, dynamic urban environments.

Robust control strategies also play a crucial role in ensuring that platoons remain stable despite external disturbances. Wang et al. [12] propose a robust control method designed to handle communication delays, packet losses, and polytopic uncertainties in mixed vehicle platoons. Their approach ensures that safe distances between vehicles are maintained, even in the presence of significant disturbances, making it highly applicable to real-world platooning scenarios. However, as the number of vehicles in the platoon grows, the computational demands of the method increase, potentially limiting its scalability. Li et al. [8] extend the robust control framework to handle nonlinear vehicle dynamics in heterogeneous platoons. By addressing the complex interactions between autonomous and human-driven vehicles, their method ensures coordinated platoon movement, even when external conditions fluctuate. The robustness of this approach makes it highly suitable for real-world applications, but the nonlinear model predictive control framework it relies on requires significant computational

resources, which may limit its efficiency in large-scale deployments.

The strategies reviewed in this section show various approaches to managing string stability, disturbances, and control challenges in vehicular platooning. Each method offers unique strengths in addressing the issues of uncertainty, external disturbances, and communication delays. However, many approaches face challenges related to computational complexity and real-time applicability, particularly in large-scale systems. Our work builds upon these foundations by focusing on a robust platooning control strategy. By incorporating bidirectional communication, dynamic speed adjustment, and string stability criteria, we aim to address the limitations of existing strategies, providing a scalable and safe solution that can be applied in real-time urban traffic scenarios.

III. PLATOON CONTROL STRATEGY MODEL

We consider a vehicular platoon navigating an urban environment. This platoon consists of n vehicles traveling in close formation, with each vehicle's position and speed coordinated to ensure safe and efficient driving. Each vehicle within the platoon is represented as $v_{(i,j)}$, where i and $j \in \{1, \dots, n\}$ refer, respectively, to the platoon and vehicle's identities. At the forefront is the Platoon Leader (PL), denoted as $v_{(i,0)}$, responsible for determining the platoon's speed, trajectory, and desired inter-vehicle gap, ensuring that all following vehicles adhere to these parameters. The PL communicates with an intelligent traffic light system at the intersection, which manages traffic flow and provides feedback to adjust the platoon's behavior to minimize delays and enhance safety. The PL transmits periodic control messages containing its current position $x_{(i,0)}(t)$, speed $s_{(i,0)}(t)$, and acceleration $a_{(i,0)}(t)$ to the following vehicles. These messages are distributed through a V2X communication network, allowing all platoon members to maintain synchronized movement. At the rear of the platoon is the Platoon Tail (PT), the last vehicle $v_{(i,n)}$, which plays a critical role in maintaining the integrity of the platoon. The PT serves as a communication point for adjacent platoons, especially during merging, splitting, or lane changes. It ensures that messages from the intelligent traffic light system or other platoons are efficiently relayed to the PL, allowing the entire formation to adapt to any changes in traffic conditions.

The control law governing the dynamics of each vehicle depends on the control input, external disturbances such as wind or road conditions, and accounts for uncertainties such as communication delays. The objective is for each vehicle to minimize deviation from the

desired trajectory while considering these disturbances and uncertainties. The platoon control strategy is based on a bidirectional leader-predecessor information flow, ensuring that each vehicle maintains consistent behavior relative to both its preceding and following vehicles. Each vehicle not only considers the data received from the PL but also information from its predecessor and successor. This allows for decentralized decision-making, where each vehicle adjusts its position, velocity, and acceleration based on both forward and backward information flows.

The dynamics of each vehicle are governed by the data received through this information flow. This structure enables vehicle $v_{(i,j)}$ to compute the control input $u_{(i,j)}(t)$ based on the state information of its predecessor $v_{(i,j-1)}$ and successor $v_{(i,j+1)}$. The control law for longitudinal guidance expressed as: $u_{(i,j)}(t) = K_p \cdot (x_{(i,j-1)}(t) - x_{(i,j)}(t) - h_i) + K_v \cdot (s_{(i,j-1)}(t) - s_{(i,j)}(t))$, where K_p and K_v are proportional control gains for position and velocity, respectively. The control law helps each vehicle adjust its speed and position. It tells the vehicle $v_{(i,j)}$ how to adjust its control input (like its acceleration or braking) at time t , using two pieces of information: (1) The position difference between itself and the vehicle in front $v_{(i,j-1)}$, and (2) The velocity difference between itself and the vehicle in front. The first part of the control law's equation compares the actual distance between the two vehicles $x_{(i,j-1)}(t) - x_{(i,j)}(t)$ with the desired safe distance h_i . If the distance is too large, the vehicle will accelerate to close the gap. If it's too small, the vehicle will slow down. K_p is a constant that decides how strongly the vehicle should respond to differences in position. Larger values of K_p make the vehicle more aggressive in correcting its position. The second part of the equation compares the speed of the vehicle with the one in front. If the vehicle in front is going faster, $v_{(i,j)}$ should speed up. If it's going slower, $v_{(i,j)}$ should slow down to match the speed. K_v is a constant that decides how strongly the vehicle should respond to speed differences.

In addition to feedback from the preceding vehicle, information from the following vehicle $v_{(i,j+1)}$ allows $v_{(i,j)}$ to anticipate changes in the platoon's formation and adjust accordingly. This two-way communication system enhances the robustness of the platoon by allowing vehicles to proactively adjust to fluctuations caused by uncertainties like communication delays or sensor inaccuracies. This is crucial for maintaining overall stability and ensuring that small deviations do not propagate through the platoon.

To prevent instability and oscillations within the platoon, the control strategy incorporates string stability criteria. String stability is achieved when disturbances do not amplify as they propagate through the platoon. This guarantees that any disturbance in spacing or velocity diminishes over time, rather than amplifying as it moves through the platoon. If string stability is not maintained, the error might grow over time, which means the vehicles will start reacting more and more to the disturbance. This can lead to a ripple effect, where each vehicle reacts more aggressively than the one before, creating dangerous oscillations in speed and distance.

IV. PLATOON CONTROL ALGORITHM FOR SAFE VEHICULAR COORDINATION

The algorithm is designed to control and manage a vehicular platoon traveling through an urban environment. Its primary objective is to ensure that vehicles within the platoon maintain a safe inter-vehicle distance while adjusting their speed dynamically to match the desired platoon speed. The algorithm achieves this by relying on real-time data transmitted via a V2X communication network, which allows the platoon to respond to changes in traffic conditions and external disturbances efficiently. In the first step, we give the detailed description of our approach and then prove its convergence to stability.

A. Platoon Control Algorithm

The algorithm works with two primary stacks: L (Leaders) and T (Tail). The stack L initially contains PL, while stack T contains the remaining vehicles in the platoon, denoted as $v_{(i,j)}$ for $j \in \{1, \dots, n\}$. The algorithm iterates by transferring vehicles from T to L as they approach the desired gap H between L and T, ensuring all vehicles in L follow the same control strategy. At each iteration, the algorithm checks the distance between the last vehicle in L and the first vehicle in T. If the gap is smaller than the desired distance H , all vehicles in L accelerate to increase the gap. Conversely, if the gap is larger than H , the vehicles decelerate to reduce the gap. This ensures that the platoon remains cohesive and that the vehicles maintain safe and consistent spacing. Algorithm 1 formalizes the proposed process and Figure 1 illustrates an example of execution.

To avoid abrupt speed changes, the algorithm adjusts speed incrementally using a small step size Δ . This method ensures smooth acceleration and deceleration, improving the comfort and safety of the platoon. Additionally, a tolerance value ϵ is introduced to prevent minor deviations from triggering unnecessary speed adjustments. If the difference between a vehicle's current

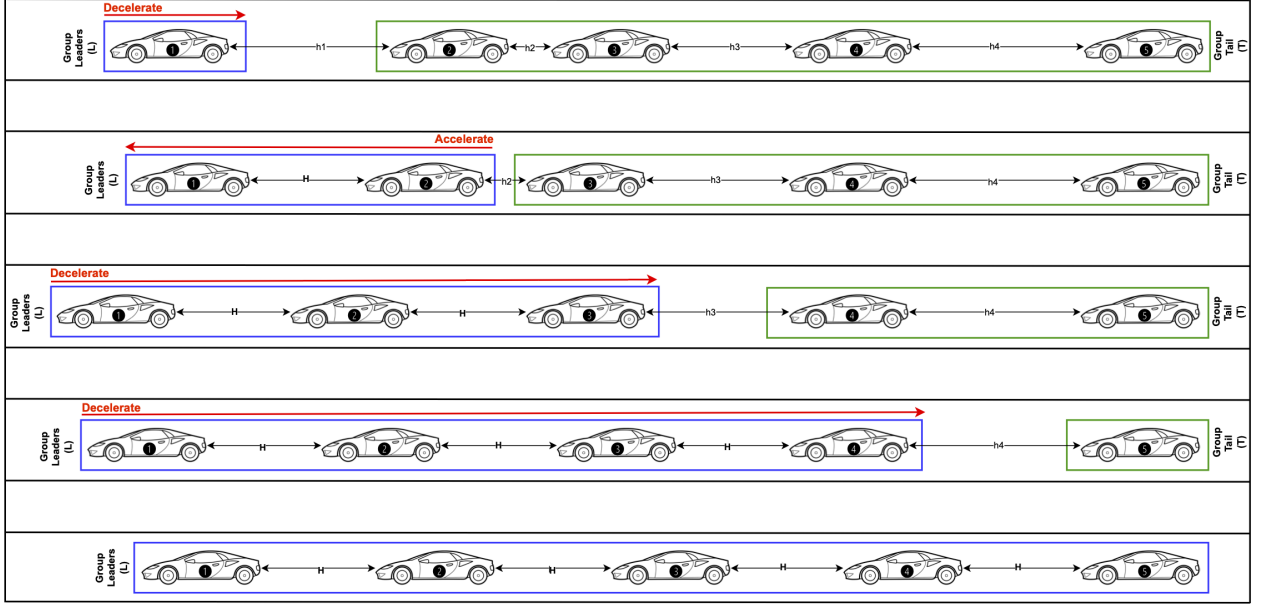


Figure 1: Impact of Disturbance Factors on Platoon Stability and Inter-Vehicle Distance Maintenance

speed and the default speed S is smaller than ϵ , the speed adjustment is skipped to avoid oscillations and overreactions. Once the inter-vehicle gap is properly adjusted, the algorithm sets the speed of all vehicles in L to the default speed S . This final speed calibration ensures that all vehicles in the platoon move synchronously, minimizing speed variations and ensuring a smooth flow. After this step, the algorithm moves the first vehicle from stack T to stack L , continuing the process until all vehicles have been transferred from T to L .

An important feature of this algorithm is its attention to string stability, which ensures that any disturbances within the platoon, such as sudden changes in speed or distance, do not amplify as they propagate through the platoon. The incremental speed adjustments and the use of tolerance values help maintain string stability, preventing oscillations and ensuring that small disturbances are dampened over time.

The algorithm is computationally efficient because it avoids unnecessary recalculations by only adjusting speeds when the deviation exceeds a certain threshold. This reduces the communication overhead and processing load, making the algorithm suitable for real-world applications where frequent updates may cause delays or overloads. Moreover, the algorithm is designed to handle real-world disturbances and uncertainties, such as communication delays or external factors like road conditions. By using incremental speed adjustments and

error tolerance, the platoon can respond effectively to minor disturbances without destabilizing the formation. This robustness ensures that the platoon remains safe and efficient, even in dynamic and unpredictable environments like urban traffic.

B. Stability Convergence Proof

We now prove that the proposed algorithm ensures that vehicles converge toward the desired inter-vehicle distance gap H , assuming ideal conditions without unbounded disturbances. The error in the inter-vehicle gap between vehicle $v_{(i,j-1)}$ and $v_{(i,j)}$ is defined as:

$$e_{(i,j)}(t) = x_{(i,j-1)}(t) - x_{(i,j)}(t) - H.$$

The control law in the algorithm adjusts the speed $s_{(i,j)}(t)$ of the following vehicle $v_{(i,j)}$ based on the value of $e_{(i,j)}(t)$, using a small step size Δ . Specifically, if $e_{(i,j)}(t) < 0$, i.e., the distance is smaller than H , then $v_{(i,j)}$ accelerates by Δ :

$$s_{(i,j)}(t+1) = s_{(i,j)}(t) + \Delta.$$

If $e_{(i,j)}(t) > 0$, i.e., the distance is greater than H , then $v_{(i,j)}$ decelerates by Δ :

$$s_{(i,j)}(t+1) = s_{(i,j)}(t) - \Delta.$$

At each time step, the error $e_{(i,j)}(t)$ is updated based on the control law. The change in the gap error is determined by the relative speeds of the two vehicles:

Algorithm 1: Platoon Control Algorithm

Input: S is the default speed, H is the desired distance gap, Δ is the speed adjustment.

```
1 foreach  $v_{(i,j)} \in L$  and  $T$  do
2   | Set  $s_{(i,j)}(t) = S$ ;
3 end
4 while  $T$  is not empty do
5   | Let  $v_{last}$  be the last vehicle in stack  $L$ ;
6   | Let  $v_{first}$  be the first vehicle in stack  $T$ ;
7   | while  $DistGap(v_{last}(t), v_{first}(t)) < H$  do
8     | foreach  $v_{(i,j)} \in L$  do
9       | Accelerate  $v_{(i,j)}$  by  $\Delta$ ;
10    | end
11  | end
12  | while  $DistGap(v_{last}(t), v_{first}(t)) > H$  do
13    | foreach  $v_{(i,j)} \in L$  do
14      | Decelerate  $v_{(i,j)}$  by  $\Delta$ ;
15    | end
16  | end
17  | Pop  $v_{first}$  from stack  $T$ ;
18  | Push  $v_{first}$  onto stack  $L$ ;
19  | foreach  $v_{(i,j)} \in L$  do
20    | Set  $s_{(i,j)}(t) = S$ ;
21  | end
22 end
```

$$\dot{e}_{(i,j)}(t) = s_{(i,j-1)}(t) - s_{(i,j)}(t).$$

Using the control law from the algorithm, the speed adjustment $s_{(i,j)}(t+1)$ depends on whether the error $e_{(i,j)}(t)$ is positive or negative. Therefore, the error dynamics can be written as:

$$e_{(i,j)}(t+1) = e_{(i,j)}(t) + \Delta \cdot \text{sign}(e_{(i,j)}(t)),$$

where $\text{sign}(e_{(i,j)}(t))$ is the sign of the error, determining whether the following vehicle speeds up or slows down. We now prove that the error $e_{(i,j)}(t)$ converges to zero as $t \rightarrow \infty$, which means that the inter-vehicle distance converges to H .

First, the error is bounded, as the control law adjusts the speed in small increments of Δ , ensuring that the error does not increase indefinitely. Since the control law operates continuously, the speed of the vehicles is updated to reduce the error, ensuring boundedness. Additionally, the error is monotonically reduced over time, as the control law corrects deviations from the desired gap. For every step t , the control action ensures that the error magnitude decreases by at least Δ :

$$|e_{(i,j)}(t+1)| \leq |e_{(i,j)}(t)| - \Delta.$$

Thus, the error decreases at each step until it reaches a value close to zero. Given the finite step size Δ , after a finite number of iterations, the error will be reduced to a small value within the tolerance range of Δ . More formally, after N iterations, where:

$$N \geq \frac{|e_{(i,j)}(t=0)|}{\Delta},$$

the error $e_{(i,j)}(t)$ will be within Δ of zero, meaning that the inter-vehicle distance is close to H .

String stability is achieved when disturbances do not amplify as they propagate through the platoon. The bidirectional flow of information between vehicles ensures that each vehicle adjusts its speed based on both its preceding and following vehicle, which prevents the amplification of small disturbances. For each vehicle $v_{(i,j)}$, the control law incorporates the gap error $e_{(i,j)}(t)$ as well as feedback from the vehicle behind it. This two-way communication ensures that disturbances are dampened as they propagate, and the error does not grow over time.

V. SIMULATION RESULTS

In this section, we describe the simulation setup used to evaluate the platoon stability algorithm under varying external disturbances. The objective of the simulation is to validate the ability of the algorithm to maintain the desired inter-vehicle distance H between the platoon members despite external perturbations.

The simulation are performed via Python, where we modeled a platoon of 10 vehicles traveling in a coordinated manner, with each vehicle's speed and position adjusted dynamically to maintain a desired gap $H = 10$ meters. The vehicles are governed by a distributed control strategy where each vehicle adapts its speed based on the gap with its immediate predecessor, and any disturbances to vehicle positions are considered external perturbations that can affect the stability of the platoon. The default speed for all vehicles is set to $S = 70$ km/h, and a fixed speed adjustment of $\Delta = 0.25\%$ per second is used for accelerating or decelerating the vehicles.

The simulation is run for a total of 40 time steps, with six different disturbance factors: 0.01, 0.05, 0.1, 0.2, 0.3, and 0.5. The disturbance factor represents the magnitude of random external noise affecting each vehicle's position at every time step. For each disturbance factor, the inter-vehicle distance between consecutive vehicles is computed and tracked over time to assess how effectively

the algorithm maintains the gap H . To sum up, the algorithm should exhibit the following characteristics:

- Maintain a stable inter-vehicle distance that does not significantly deviate from H .
- Effectively dampen any disturbances to avoid large fluctuations or oscillations in the platoon.
- Demonstrate robustness to increasing levels of disturbances, with minimal impact on the overall stability of the platoon.

As depicted in Figure 2, the results of the simulations are presented in six plots, each corresponding to a different disturbance factor. These plots show the evolution of the inter-vehicle distance over time for each pair of consecutive vehicles in the platoon. The red dashed line in each plot represents the desired gap $H = 10$ meters, which serves as the benchmark for evaluating the performance of the control algorithm.

In the first two plots, corresponding to disturbance factors 0.01 and 0.05, the inter-vehicle distance remains tightly clustered around the desired gap H . The algorithm successfully mitigates the small disturbances, and the vehicles quickly adjust their speeds to maintain the gap with minimal deviations. This validates the algorithm's ability to maintain stability under low levels of perturbation. With moderate disturbance factors of 0.1 and 0.2, the plots show slightly larger fluctuations in inter-vehicle distance, but the platoon remains stable overall. While the gap deviations are more pronounced compared to lower disturbance factors, the algorithm still keeps the distances within an acceptable range of H , demonstrating the robustness of the control strategy in handling moderate disturbances. At a disturbance factor of 0.3, the inter-vehicle distances exhibit more significant fluctuations. Some vehicles experience temporary deviations from the desired gap, but the algorithm consistently corrects these deviations over time, bringing the gaps back toward H . Although the platoon is more affected by the disturbances, the algorithm prevents instability or cascading errors, indicating that the control strategy is still effective under higher levels of perturbation. The plot for the disturbance factor 0.5 shows the greatest impact of external perturbations. The inter-vehicle distances fluctuate more widely, and the vehicles take longer to return to the desired gap after experiencing a disturbance. However, despite the large disturbances, the platoon does not lose stability, and the vehicles manage to avoid excessive oscillations or dangerous gaps. This demonstrates that the control algorithm remains functional, though less efficient, under severe external disturbances.

Overall, the results validate the primary objectives of

the simulation. The platoon control algorithm maintains stability across all disturbance levels, ensuring that the inter-vehicle distance stays within a reasonable range of the desired gap $H = 10$ meters. As the disturbance factor increases, the algorithm exhibits some limitations in fully neutralizing the perturbations, leading to larger deviations from H , but it continues to provide effective control and avoids instability. The ability to maintain string stability and prevent large oscillations even under severe disturbances demonstrates the robustness of the distributed control strategy in practical platooning scenarios.

VI. CONCLUSION

In this paper, we addressed the challenges of maintaining safe and stable platooning in urban environments, focusing on the uncertainties inherent in real-world vehicular dynamics. We proposed a robust control algorithm that adjusts vehicle speed dynamically based on inter-vehicle distance and information flow from both preceding and following vehicles. The algorithm integrates a bidirectional communication strategy that allows each vehicle to proactively adapt to changes in the platoon formation, ensuring string stability even under the influence of external disturbances and communication delays.

The effectiveness of the control strategy was validated through simulations conducted under various disturbance levels. The results demonstrate that the algorithm successfully maintains the desired inter-vehicle distance while avoiding oscillations and instability. Even as the disturbance factors increased, the platoon remained cohesive, and string stability was preserved. The simulation also highlighted the robustness of the algorithm in adjusting to large disturbances while minimizing the communication overhead and computational load.

This work provides a reliable solution for ensuring the stability and safety of autonomous platooning systems in complex urban environments. Future research could explore further enhancements to the control algorithm by incorporating more adaptive responses to varying traffic conditions and developing real-time feedback mechanisms from the environment, such as traffic lights and surrounding infrastructure.

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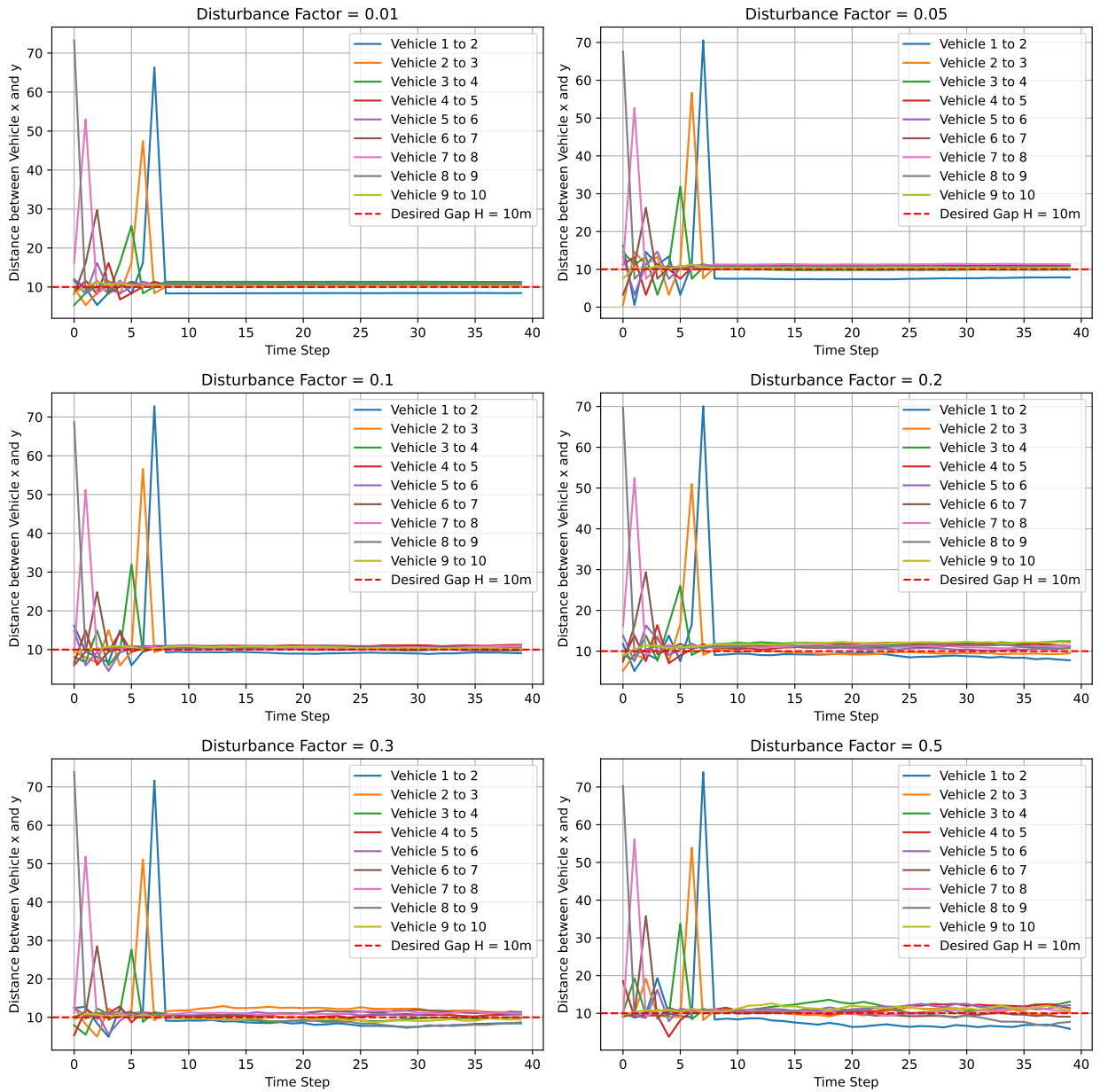


Figure 2: Impact of Disturbance Factors on Platoon Stability and Inter-Vehicle Distance Maintenance

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