
PERFORMANCE EVALUATION OF MODEL REFERENCE ADAPTIVE CONTROLLER FOR STRING STABILITY IN HEAVY- DUTY TRUCK PLATOONING

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ABSTRACT

The deployment of heavy-duty truck platooning has gained considerable attention as an intelligent transportation technology capable of improving highway safety, fuel efficiency, and traffic flow. However, maintaining string stability under varying operating conditions remains a critical challenge due to vehicle parameter uncertainties and external disturbances, which can amplify spacing and velocity fluctuations throughout the platoon. This study presents a performance evaluation of a Model Reference Adaptive Controller (MRAC) for string stability in heavy-duty truck platooning. The proposed control strategy employs a reference model to define the desired vehicle dynamics, while a Lyapunov-based adaptive law continuously adjusts the controller parameters to compensate for system uncertainties and minimize tracking errors. The controller is implemented and evaluated using MATLAB/Simulink, and its performance is compared with a Distributed Model Predictive Control–Proportional Integral Derivative (DMPC-PID) strategy. The evaluation considers inter-vehicle spacing error, velocity error, settling time, acceleration response, and disturbance attenuation. Simulation results demonstrate that the proposed MRAC maintains the desired 20 m inter-vehicle spacing and 20 m/s cruising speed, with convergence to the desired operating conditions within approximately 20 s. An average inter-vehicle spacing error of 0.15 m and an average velocity error of 0.13 m/s were obtained between the leader and follower vehicles. The acceleration response further indicates progressive attenuation of transient oscillations as the platoon approaches steady-state operation. Comparative results show that MRAC provides improved tracking performance, adaptation, and disturbance attenuation compared with the DMPC-PID benchmark. The findings demonstrate the potential of MRAC as an adaptive longitudinal control strategy for maintaining stable and coordinated operation of heavy-duty truck platoons under uncertain operating conditions.

Keywords: String Stability; Heavy-Duty Truck Platooning; Adaptive Control; Intelligent Transportation Systems (ITS); Longitudinal Vehicle Control

1.0 INTRODUCTION

The increasing demand for efficient and safe highway transportation has encouraged the development of intelligent transportation systems (ITS) that integrate advanced sensing, communication, computation, and control technologies into transportation operations. Among these technologies, vehicle platooning has attracted significant research attention because it enables multiple vehicles to travel cooperatively as a coordinated convoy while maintaining controlled inter-vehicle distances. Truck platooning is particularly promising for improving transportation efficiency, reducing aerodynamic drag and fuel consumption, and enhancing highway safety through coordinated longitudinal vehicle control. The development of effective control strategies is therefore essential for ensuring safe and stable operation of heavy-duty vehicle platoons.

Vehicle platooning involves the coordinated movement of a group of vehicles in which follower vehicles regulate their speed and position relative to a preceding vehicle Zhao et al. (2022). The control of a vehicle platoon can generally be divided into lateral and longitudinal control. Lateral control is concerned with maintaining the vehicle within the desired lane, whereas longitudinal control regulates vehicle speed and inter-vehicle spacing. For heavy-duty truck platoons, longitudinal control is

particularly important because variations in vehicle dynamics, operating conditions, and external disturbances can affect the ability of follower vehicles to maintain the desired spacing and velocity Mao et al. (2023). A suitable longitudinal controller must therefore provide accurate tracking while preventing the amplification of disturbances through the vehicle string Gardon et al. (2023).

String stability is a fundamental requirement in platoon control and describes the ability of a vehicle platoon to attenuate or prevent the amplification of disturbances as they propagate from one vehicle to subsequent vehicles. Feng et al. (2019) presented a comprehensive analysis of string stability in vehicular platoons and highlighted the importance of appropriate stability definitions and analysis methods in evaluating platoon control systems. Several control approaches have subsequently been investigated to improve the stability and safety of vehicle platoons. These include model predictive control, distributed control, sliding mode control, adaptive control, and other robust control techniques. For example, Gratzner et al. (2022) investigated string-stable and collision-safe model predictive platoon control, while Cheng et al. (2022) developed a distributed sliding-mode control strategy for longitudinal cruise control of truck platoons. These studies demonstrate the effectiveness of advanced control techniques but also indicate the importance of accounting for vehicle dynamics and operating conditions when designing platoon controllers.

Adaptive control provides an alternative approach for dealing with uncertainties and variations in vehicle dynamics. Unlike fixed-parameter controllers, adaptive controllers can modify their control parameters in response to changes in system behaviour. Abdullahi and Akkaya (2020), for example, investigated a Model Reference Adaptive Control approach for adaptive cruise control, demonstrating the applicability of MRAC to vehicle longitudinal control. Similarly, Prayitno et al. (2022) investigated distributed model reference adaptive control for synchronization of heterogeneous vehicle platoons. These studies indicate the potential of adaptive control for coordinated vehicle operation, particularly where vehicle characteristics and operating conditions may vary.

Despite the progress made in platoon control, maintaining consistent tracking performance and string stability in heavy-duty truck platoons remains challenging because of uncertainties in vehicle parameters and variations in longitudinal vehicle dynamics. Controllers designed using nominal or fixed system parameters may experience performance degradation when the actual operating conditions differ from those assumed during controller design. In addition, transient variations in velocity, inter-vehicle spacing, and acceleration can propagate through the platoon and adversely affect coordinated vehicle operation. Therefore, an adaptive control strategy capable of continuously adjusting its parameters while maintaining a desired reference response is of significant interest for heavy-duty truck platooning.

In this study, a Model Reference Adaptive Controller (MRAC) is evaluated for maintaining string stability in a heavy-duty truck platoon. The proposed approach uses a reference model to define the desired vehicle response and a Lyapunov-based adaptive mechanism to update the controller parameters based on the tracking error. The performance of the MRAC is evaluated using MATLAB/Simulink simulations and compared with a Distributed Model Predictive Control–Proportional Integral Derivative (DMPC-PID) controller. The evaluation focuses on inter-vehicle spacing, velocity tracking, settling time, acceleration response, and disturbance attenuation. The objective is to determine the effectiveness of the adaptive controller in maintaining the desired platoon behaviour and to establish its performance relative to the selected benchmark control strategy.

2.0 PROBLEM STATEMENT

Heavy-duty truck platooning is an emerging intelligent transportation technology in which a group of vehicles travels cooperatively with small and controlled inter-vehicle distances. The technology has the potential to improve road safety, traffic efficiency, and fuel economy; however, maintaining string stability remains a major control challenge. String stability requires that disturbances introduced by the lead vehicle or an individual follower do not amplify as they propagate through the platoon. In practical highway operation, variations in vehicle speed, vehicle mass, road gradient, aerodynamic forces, actuator dynamics, and external disturbances can cause deviations from the desired inter-vehicle spacing and velocity. If these deviations are amplified from one vehicle to another, they may result in large spacing errors, uncomfortable acceleration and deceleration, and, in severe cases, rear-end collisions.

Several control strategies, including Proportional–Integral–Derivative (PID), Model Predictive Control (MPC), Distributed Model Predictive Control (DMPC), sliding mode control, and robust control techniques, have been investigated for achieving string stability in vehicle platoons. Although these controllers can provide satisfactory performance under specified operating conditions, their performance may deteriorate when there are uncertainties in vehicle parameters and changes in the operating environment. Controllers with fixed parameters may not adequately compensate for variations in the longitudinal dynamics of heavy-duty trucks.

Model Reference Adaptive Control (MRAC) provides a potential solution by allowing controller parameters to be adjusted online according to the difference between the actual vehicle response and a predefined reference model. However, the effectiveness of MRAC for heavy-duty truck platooning should not be established solely from its ability to track a reference response. Its ability to suppress disturbance propagation, maintain inter-vehicle spacing, minimize velocity errors, and preserve string stability under varying operating conditions requires systematic quantitative evaluation.

Therefore, this research addresses the problem of inadequate adaptive compensation of uncertainties and disturbances that can degrade string stability and tracking performance in heavy-duty truck platooning. The research evaluates the performance of a Lyapunov-based Model Reference Adaptive Controller in maintaining the desired inter-vehicle spacing and velocity while attenuating disturbances propagating through the platoon. Its performance is compared with a Distributed Model Predictive Control–PID (DMPC-PID) benchmark using inter-vehicle spacing error, velocity error, settling time, acceleration/deceleration characteristics, and disturbance attenuation as evaluation metrics.

3.0 METHODOLOGY

3.1 Development of a Vehicle Model

The vehicle model was formulated based on Newton third law of motion that say's tractive force is equal to resistive force;

$$F_{tr} = F_a + F_i + F_g + F_r \quad (1)$$

Where the respective forces are defined as:

$$\left. \begin{aligned} F_a &= \frac{1}{2} \rho C_d A v^2 \\ F_r &= mg C_{rr} \\ F_g &= mgsin\theta \end{aligned} \right\} F_i = ma \quad (2)$$

Where; aerodynamic drag force (F_a), rolling resistance force (F_r), gradient force (F_g), inertia force and tractive force (F_{tr}), ρ is the air density, v is the velocity, C_d is the drag coefficient, A is the frontal area, m is the mass, and a is the acceleration.

Let

$$\left. \begin{aligned} x_1 &= s \\ x_2 &= v \\ \dot{x}_1 &= v \\ \dot{x}_2 &= a \end{aligned} \right\} \quad (3)$$

From equation (1)

$$\left. \begin{aligned} F_{tr} &= \frac{1}{2} \rho C_d A v^2 + mg C_{rr} + mgsin\theta + ma \\ ma &= F_{tr} - \frac{1}{2} \rho C_d A v^2 - mg C_{rr} - mgsin\theta \\ \dot{x}_2 &= \frac{F_{tr} - \frac{1}{2} \rho C_d A v^2 - mg C_{rr} - mgsin\theta}{m} \end{aligned} \right\} \quad (4)$$

The acceleration of vehicle $\dot{x}_2$, is defined in the state equation as obtained from equation (4).

3.2 Designing the Reference Model

The reference model $\dot{X}_m$ of a vehicle in MRAC design is in the form of

$$\dot{X}_m = (A - BK_1)X_m + BK_2r \quad (5)$$

With; $A_m = A - BK_2$ and $B_m = BK_2$

Where A_m and B_m stands for constant plant parameter, r is the reference signal, K_1 and K_2 represent the adaptive gains and X_m is the system state vector. The vehicle dynamic model (plant model) is defined from equation (3.4) as;

$$\dot{x}_2 = -g\sin\theta - \frac{1}{2m} \rho C_d A v^2 + \frac{1}{m} F_{tr} \quad (6)$$

The derivative of the state of the reference model of the vehicle is obtained by neglecting the effect of rolling friction (F_r):

$$\left. \begin{aligned} \dot{x}_1 &= v = x_2 \\ \dot{x}_2 &= -gx_1 - \frac{1}{2m} \rho C_d A x_2^2 + \frac{1}{m} F_{tr} \end{aligned} \right\} \quad (7)$$

Where $\sin\theta \approx \theta = x_1$. The state equation model of the vehicle is written in the form of $\dot{X} = AX + Bu$ as:

$$\dot{X} = \dot{x}_2 = \begin{bmatrix} 0 & 1 \\ 0 & \frac{1}{2m} \rho C_d A x_2^2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{m} \end{bmatrix} F_{tr} \quad (8)$$

The reference state model is obtained by neglecting road grade ($\theta \approx 0$) since the vehicle operates in a flat road therefore written as:

$$\dot{X} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} X + \frac{1}{m} \begin{bmatrix} 0 \\ 1 \end{bmatrix} F_{tr} \quad (9)$$

Where the system plant parameter $A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$ and $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

The reference vehicle model is derived by its characteristic polynomial, which dictates the desired closed-loop dynamics of the system. The characteristic polynomials of a second-order system;

$$P(s) = s^2 + 2\xi s + \omega_n^2 \quad (10)$$

The state space model of the vehicle is obtained;

$$A_m = \begin{bmatrix} 0 & 1 \\ \omega_n^2 & 2\xi\omega_n \end{bmatrix} \text{ and } B_m = \begin{bmatrix} 0 \\ \omega_n^2 \end{bmatrix}$$

where ω_n is the natural frequency and ξ is the damping ratio. The MATLAB implementation uses

$$\omega_n = 0.4 \text{ rad/s}$$

and

$$\xi = 0.707.$$

Therefore,

$$2\xi\omega_n = 2(0.707)(0.4) = 0.5656$$

and

$$\omega_n^2 = (0.4)^2 = 0.16.$$

Consequently, the reference-model matrices are

$$A_m = \begin{bmatrix} 0 & 1 \\ -\omega_n^2 & -2\zeta\omega_n \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -0.16 & -0.5656 \end{bmatrix} \quad (11)$$

and

$$B_m = \begin{bmatrix} 0 \\ \omega_n^2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0.16 \end{bmatrix}. \quad (12)$$

Thus, the corresponding desired characteristic polynomial is

$$P_m(s) = s^2 + 0.5656s + 0.16$$

Then the reference model of the system is achieved by substituting the state space vectors in equation (4) where A_m is

$$\dot{X}m = A_m X_m + B_m K_2 \quad (11)$$

3.3 Nominal Control Law

The nominal controller is designed to match the dynamics of the actual vehicle model to those of the reference model. The feedback and feedforward gains are obtained from the system matrices according to

$$K_1 = B^\dagger(A - A_m) \quad (12)$$

and

$$K_2 = B^\dagger B_m \quad (13)$$

where $B^\dagger$ denotes the pseudoinverse of the input matrix B .

Using the system matrices defined in Equation (4), the resulting gains are

$$K_1 = [0.16 \quad 0.5656] \quad (14)$$

and

$$K_2 = 0.16. \quad (15)$$

The nominal control input is therefore expressed as

$$U_n = -K_1 x + K_2 r. \quad (16)$$

The nominal controller establishes the basic feedback behaviour of the vehicle, while the adaptive component subsequently compensates for deviations caused by uncertainties and disturbances.

3.4 Model Reference Adaptive Control

The MRAC controller incorporates an adaptive mechanism to compensate for uncertainties in the vehicle dynamics. The tracking error between the actual vehicle state and the reference-model state is defined as

$$e = x - x_m. \quad (17)$$

The adaptive control component implemented in the MATLAB model is

$$U_a = \hat{W}^T \beta \quad (18)$$

where $\hat{W}$ represents the adaptive weight vector and β represents the regressor vector used by the adaptive controller.

The overall control signal is obtained by combining the nominal and adaptive control components as

$$U = U_n - U_a \delta_a \quad (19)$$

where δ_a is the adaptation switch. When adaptation is enabled, the adaptive component is incorporated into the control action. In the simulation, the adaptation switch is set to

$$\delta_a = 1.$$

This configuration allows the controller to continuously modify its control action in response to tracking errors and variations in system behaviour.

3.5 Lyapunov energy function

To formulate the adaptive mechanism, a Lyapunov-based approach is employed. The positive-definite matrix P is obtained from the Lyapunov equation

$$A_m^T P + P A_m = -I \quad (20)$$

where I is the identity matrix.

The adaptive parameters are updated numerically according to the implementation used in the MATLAB simulation:

$$\hat{W}(k+1) = \hat{W}(k) + \Delta t [\gamma_1 \hat{W}(k) + \gamma_2 \beta e^T P B] \quad (21)$$

where Δt is the simulation sampling interval, γ_1 and γ_2 are the adaptation parameters, and β is the adaptive regressor.

The values used in the simulation are

$$\gamma_1 = 0.01$$

and

$$\gamma_2 = 1.4.$$

An adaptive-weight limit of 10 is also defined in the MATLAB implementation to limit excessive growth of the adaptive parameters. This provides an additional measure for preventing adaptive-weight drift during simulation.

3.5 Flowchart of MRAC for String Stability in Platooning

To illustrate the operational sequence of the proposed Model Reference Adaptive Control (MRAC) strategy for heavy-duty truck platooning, Figure 1 presents the flowchart of the control process used to achieve and maintain the desired inter-vehicle spacing, vehicle speed, and platoon stability.

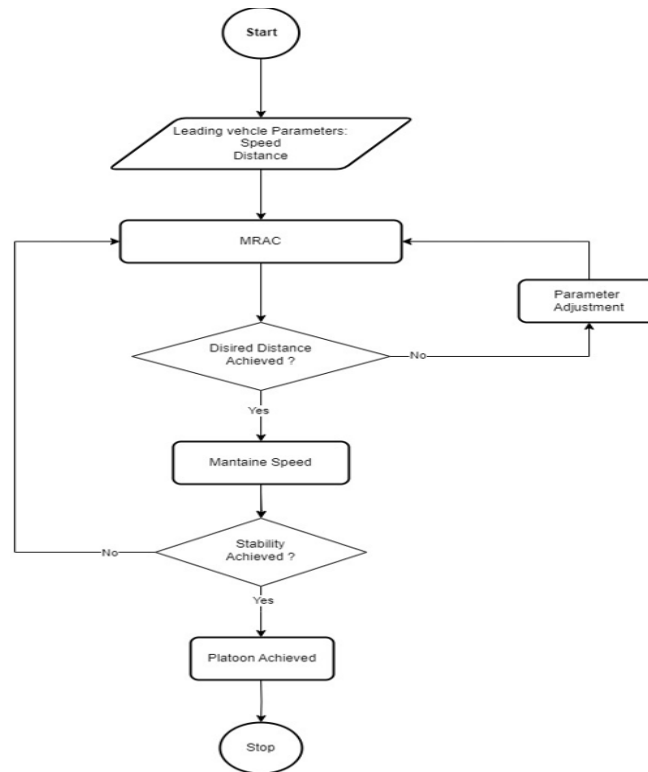


Figure 1: Flowchart of MRAC for String Stability in Platooning

Figure 1: illustrates the proposed Model Reference Adaptive Control (MRAC) flow process for maintaining string stability in the truck platoon. The control process begins by obtaining the leading vehicle parameters, particularly its speed and inter-vehicle distance, which serve as the reference inputs for the MRAC. The controller compares the actual follower-vehicle response with the desired reference behaviour and generates the appropriate control action to minimize the tracking error. The resulting inter-vehicle distance is continuously evaluated against the desired spacing; if the desired distance is not achieved, the controller performs parameter adjustment and updates the control action accordingly. Once the desired distance is achieved, the vehicle maintains the required speed while continuously monitoring the stability of the platoon. If the stability criterion is not satisfied, the control loop is repeated to further adjust the controller parameters and vehicle response. When the desired distance, speed, and stability conditions are simultaneously satisfied, the platoon is considered successfully established and maintained. This continuous feedback and parameter adaptation enable the MRAC to compensate for system uncertainties and disturbances while improving tracking performance and maintaining string stability.

4.0 RESULTS

4.1 Simulation Parameters

Parameter	Symbol	Value
Vehicle mass	m	1200 kg
Air density	ρ	1.21 kg/m ³
Frontal area	A_f	3 m ²
Drag coefficient	C_d	0.3
Effective tyre radius	r_{eff}	0.353 m
Rolling friction coefficient	σ	0.5
Transmission efficiency	η_T	0.99
Nominal velocity	v_{nom}	20 m/s
Desired acceleration	a_{des}	2.0 m/s ²
Braking deceleration	a_{brake}	-1.5 m/s ²
Natural frequency	ω_n	0.4 rad/s
Damping factor	ζ	0.707
Desired inter-vehicle spacing	d_r	20 m
Desired velocity	v_r	20 m/s

Table 1: Simulation Parameters

4.2 Control gain

Figure 2 presents the MRAC control input and adaptive uncertainty response for the selected adaptation gains, $\gamma_1 = 0.01$ and $\gamma_2 = 1.40$. The results show the controller's adaptive response to system uncertainties and its ability to regulate the control action during the transient period.

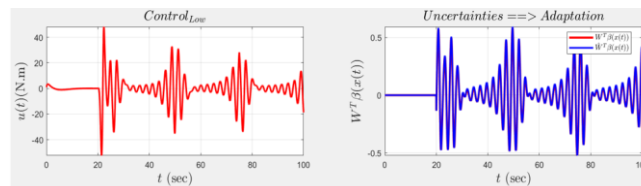


Figure 2: MRAC control gain $Y_1 = 0.01$ and $Y_2 = 1.40$

From the controller performance presented in Figure 2, it can be seen that there is an improve performance in the adaptive law to track a reference trajectory under uncertainty and external

disturbance. In general, the controller performance clearly indicates that the actual velocity aligns with the reference velocity, demonstrating MRAC ability to manage model uncertainty effectively even in the presence of small oscillation along the platoon.

4.3 Distance Profile of the Trucks

Figure 3 shows the plots for the velocity profile of the four trucks in the platoon with all the trucks shows discrepancy in terms of initial velocity.

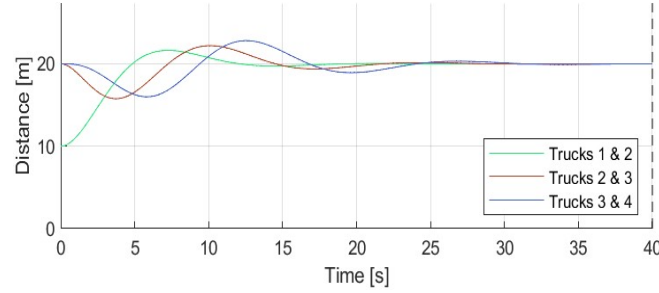


Figure 3: Distance Profile of the Trucks

Figure 3 illustrates the inter-vehicle distance response of the heavy-duty truck platoon under the proposed MRAC strategy. The three curves represent the spacing between Trucks 1 and 2, Trucks 2 and 3, and Trucks 3 and 4, respectively, with a desired inter-vehicle distance of **20 m**. At the beginning of the simulation, the vehicles exhibit different spacing conditions, resulting in transient oscillations as the MRAC adjusts the follower vehicles' responses toward the desired spacing. The spacing between Trucks 1 and 2 initially increases before experiencing a reduction and subsequent oscillations, while the other vehicle pairs similarly exhibit transient deviations around the reference distance. Despite these initial variations, the oscillations are progressively attenuated as the adaptive controller continuously adjusts the control parameters. All three inter-vehicle distances converge toward the desired **20 m** spacing at approximately **20 s**, after which the responses remain closely regulated with negligible steady-state error. The attenuation of the spacing oscillations and convergence of all vehicle pairs to the same desired distance indicate that the proposed MRAC effectively compensates for transient disturbances and maintains coordinated vehicle spacing, demonstrating its potential to achieve string stability and safe platoon formation.

4.3 Performance evaluation of MRAC over DMPC-PID with Intervehicle distance

The performance of MRAC was evaluated by comparing with that of DMPC-PID using transient parameters by the platoon to achieve a steady state inter vehicular spacing of 20 m. The simulation result obtained is shown in Figure 4;

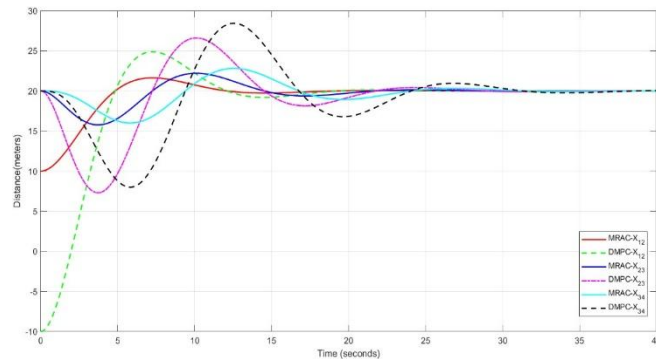


Figure 4: Comparison for MRAC and DMPC-PID Intervehicle Distance

From Figure 4, it is evident that the MRAC achieved a uniform inter-vehicle gap at a faster rate, reaching the desired spacing within 25 seconds. Additionally, the MRAC exhibited lower

overshoot and reduced tracking error, demonstrating its effectiveness in ensuring precise and stable platoon behavior compared to other control strategies.

4.5 Performance evaluation of MRAC over DMPC-PID with vehicle Speed

The performance of MRAC was evaluated by comparing with that of DMPC-PID using speed error by the platoon to achieve a steady state speed of 20 m/s. The simulation result obtained is shown in Figure 5;

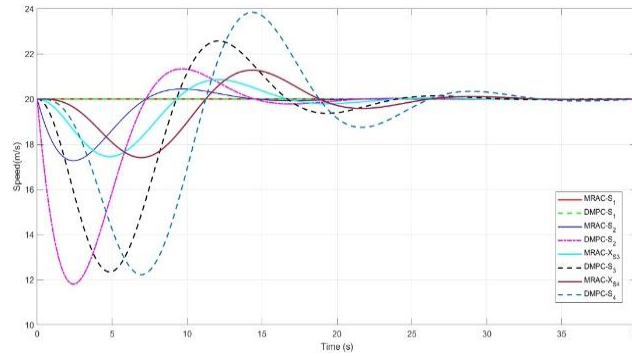


Figure 5: Comparison of Speed Profile

The speed response of the vehicles under the proposed MRAC strategy is presented in Figure 5. The desired cruising velocity was set to 20 m/s. The figure illustrates the ability of the controller to regulate the velocity of the follower vehicles according to the reference velocity while maintaining coordination with the preceding vehicle.

At the beginning of the simulation, transient variations in vehicle speed are observed as the controller adjusts the vehicle states towards the desired operating condition. As the simulation progresses, these variations are progressively reduced, and the vehicle velocities converge towards the reference value of 20 m/s.

The average velocity error obtained from the simulation is approximately 0.12 m/s. This result demonstrates that the MRAC controller can achieve close velocity tracking while simultaneously maintaining the required inter-vehicle spacing.

The convergence of the velocity response is also important for string stability because variations in the velocity of a preceding vehicle can propagate through the platoon. The attenuation of these variations as the follower vehicles approaches the desired velocity indicates that the controller provides effective longitudinal coordination.

	TR2- TR1 (m/s)	TR3- TR1 (m/s)	TR4- TR1 (m/s)	Velocity error (m/s)
DMPC- PID	0.1	0.15	0.2	0.15
MRAC	0.08	0.12	0.15	0.12

Table 2: Velocity Error for DMPC-PID and MRAC

From Table 2, it is evident that the MRAC significantly reduces tracking errors for all trucks compared to the DMPC-PID controller. This highlights the superior accuracy of MRAC in achieving precise tracking performance across the platoon.

4.6 Acceleration Profile of the Truck

The performance of MRAC was evaluated by comparing with that of DMPC-PID using settling time by the platoon to achieve a steady state acceleration of zero. The simulation result obtained is shown in Figure 6;

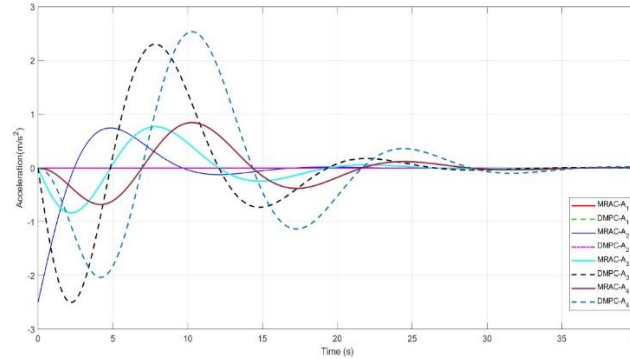


Figure 6: Comparison of Acceleration Profile

From Figure 6, it is evident that MRAC achieved a constant acceleration at 20 seconds while DMPC-PID exhibits some high oscillations and reached a constant acceleration at 25 seconds.

Trucks	Overshoot (%)		Undershoot (%)	
	DMPC-PID	MRAC	DMPC-PID	MRAC
Truck 2	2.1	0.6	-4.1	-2.4
Truck 3	2.2	0.7	-2.2	-0.3
Truck 4	2.4	0.9	-2.0	-0.4
Average error	2.23	0.73	2.8	1.03

Table 3: Acceleration and Deceleration error for DMPC-PID and MRAC

It is observed from Table 3, the MRAC generates a control signal with lower overshoot compared to the DMPC-PID controller. This demonstrates that the MRAC provides a faster response, improved settling time, and reduced tracking errors. These attributes highlight the superior performance of MRAC in achieving accurate and stable control, making it more effective for dynamic scenarios where precise tracking is crucial.

5.0 CONCLUSION

The Model Reference Adaptive Controller (MRAC) was successfully developed and evaluated for maintaining string stability in a heavy-duty truck platoon under system uncertainties and external disturbances. The controller employs a reference model and a Lyapunov-based adaptive mechanism to continuously adjust its control parameters and minimize deviations between the actual and desired vehicle responses. Simulation results obtained in MATLAB/Simulink demonstrate that the proposed MRAC provides improved tracking performance and disturbance attenuation compared with the DMPC-PID benchmark, achieving the desired 20 m inter-vehicle spacing and 20 m/s cruising speed with a settling time of approximately 20 s. The controller recorded an average inter-vehicle spacing error of 0.15 m and an average velocity error of 0.13 m/s, indicating accurate coordination between the

leader and follower vehicles. Furthermore, the acceleration response shows that transient oscillations are progressively attenuated as the platoon converges to steady-state operation, with average acceleration and deceleration values of approximately 0.73 m/s^2 and 1.03 m/s^2 , respectively, demonstrating a relatively smooth longitudinal response. Overall, the results indicate that MRAC provides enhanced adaptability, tracking accuracy, disturbance rejection, and string-stability performance compared with DMPC-PID, demonstrating its potential for robust longitudinal control of heavy-duty truck platoons under varying operating conditions and system uncertainties. The present study does not explicitly investigate communication delays, packet losses, or communication-channel failures between vehicles. These factors can significantly influence platoon stability in practical connected-vehicle applications.

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