Flexible Fault-tolerant Prescribed Control for Connected Automated Vehicles

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***Abstract*— Connected automated vehicles (CAVs) have significant potential to improve traffic efficiency and stability. While various longitudinal control policies have been developed for CAV platoons to achieve desired tracking performance, their limitations regarding fault-tolerance and robustness, particularly under actuator faults and input saturation, have not been fully addressed. This paper proposed a flexible fault-tolerant prescribed control (FFPC) for CAV platooning systems considering control input saturation, unobservable actuator faults, and disturbances. The controller design employs a composite tracking error and an error transformation function (ETF) to guarantee prescribed performance bounds while incorporating string stability considerations for the platoon. A key contribution is a proposed novel flexibility auxiliary system, that bridges the gap between input saturation signals and the performance boundaries so that the performance boundaries can be adaptively enlarged or recovered to avoid control singularity according to the situation of control input saturation. Comparative simulations against conventional prescribed performance control (PPC) demonstrate the feasibility and effectiveness of this proposed control strategy.**

I. INTRODUCTION

Vehicular platooning stands out as a key strategy for maximizing traffic throughput and energy savings by allowing CAVs to travel cooperatively in close formation in modern intelligent transportation system [1]. Effective platooning hinges on sophisticated longitudinal control systems capable of precisely regulating inter-vehicle spacing and velocity while ensuring the stability of the entire vehicle string, particularly against the propagation of disturbances [2].

However, real-world deployment faces significant challenges stemming from inherent system nonlinearities, actuator constraints, and the potential for component faults within vehicles [3]–[5]. Control approaches based on feedback PID such as [6] and [7] often struggle to maintain desired performance and guarantee safety under such complex and uncertain conditions, motivating the development of advanced control frameworks that explicitly address fault tolerance and provide guaranteed performance bounds. Control Barrier Function (CBF) or Lyapunov Barrier Function (LBF) methods have gained attention for their ability to formally guarantee safety constraints (like collision avoidance) and ensure string stability in CAV platoons [5]. Nevertheless, standard CBF/LBF approaches can be sensitive to model uncertainties and may lack inherent robustness against unobservable actuator faults or persistent external disturbances [8]. Model Predictive Control (MPC) offers another powerful framework, capable of handling constraints and optimizing performance over a prediction horizon [9]. However, its effectiveness heavily relies on the accuracy of the prediction model [10].

Prescribed Performance Control (PPC) has emerged as a powerful technique for enforcing predefined transient and steady-state tracking accuracy in platoon control [11]–[15], yet its conventional application may be overly conservative or even fail when faced with unexpected faults or persistent saturation, highlighting the need for enhanced flexibility and robustness. Saturation-Tolerant Prescribed Control (SPC), an advanced form of PPC, has shown great potential in dealing with unobservable actuator faults and control input saturation by adaptively expanding or recovering the performance boundaries according to the input saturation [16]–[20]. However, this control framework has only been studied on nonlinear systems with single-state tracking error without consideration of nonlinear systems like CAV platoons with composite tracking error containing multiple states.

The main contributions of this paper are summarized as follows. Firstly, we propose an FFPC method for CAV platoon to achieve great tracking performance and string stability considering composite tracking error, input saturation, unmeasurable actuator faults and disturbances. Then, a novel flexibility auxiliary system for FFPC is designed to deal with uncertain actuator faults and environment disturbances by bridging the gap between the performance boundaries and the control input saturation. In comparison with existing PPC scheme for CAV platoon [11], [12], [14], [21], the proposed flexibility auxiliary system allows FFPC to adaptively regulate the performance boundaries when actuator faults or disturbances appear. Finally, simulations are completed on a CAV platoon with five vehicles. The experiment results present the effectiveness of proposed FFPC compared with conventional PPC without the flexibility auxiliary system.

The rest of the paper is organized as follows. Section II provides the vehicle nonlinear model and preliminaries of FFPC. Section III contains the technical details of FFPC. Simulations are given in Section IV and the conclusions are mentioned in Section V.

II. PROBLEM FORMULATION

This research considered a study case as shown in Fig. 1. This vehicular platoon contains $N+1$ CAVs including a lead vehicle (vehicle number 0) and N following vehicles, where a_i, v_i and p_i are respectively the acceleration, velocity and

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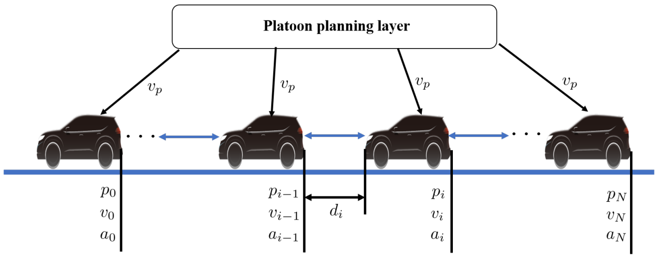

Fig. 1. Configuration of the CAV platoon.

position of CAV number i, $i = 0, 1, 2, ..., N$. Assuming that all the CAVs are equipped with required sensors, road maps and a global positioning system (GPS), each following vehicle receives the states (accelerations, velocities and positions) from the lead vehicle and its immediate front neighbor, which guarantees the smooth communications and interactions with each other. Meanwhile, each vehicles is able to receive the desired velocity v_p from the planning layer.

A. Connected Vehicles Dynamics

In this research, the nonlinear third-order dynamics of the CAV number i are shown as the following model [11]:

$$\dot{p}_i(t) = v_i(t) \tag{1a}$$
$$\dot{v}_i(t) = a_i(t) \tag{1b}$$
$$\dot{a}_i(t) = f_i(v_i, a_i) + u_i(t) \tag{1c}$$

with

$$f_i(v_i, a_i) = -\frac{a_i(t)}{\tau_i} - \frac{\kappa_i(2\tau_i v_i a_i + v_i^2)}{m_i \tau_i} \tag{2}$$

where m_i is the mass of vehicle i, τ_i denotes the engine time constant, κ_i is the air resistance, and u_i represents composite actual control input with saturation and disturbance in this form:

$$u_i(t) = g_i(t)h(\mu_i) + D_i(t) \tag{3}$$

where μ_i is the designed control input signal of vehicle number i, g_i represents the actuator fault function, $D_i(t)$ denotes the lumped disturbance function, and h_i is the simplified saturation function of control input signal that can be described by:

$$h_i(\mu_i) = \begin{cases} \mu_{i,\text{max}}, & \mu_i > \mu_{i,\text{max}} \\ \mu_i, & \mu_{i,\text{min}} \le \mu_i \le \mu_{i,\text{max}} \\ \mu_{i,\text{min}}, & \mu_i < \mu_{i,\text{min}} \end{cases} \tag{4}$$

where $\mu_{i,\text{max}}$ and $\mu_{i,\text{min}}$ are known upper and lower bounds of vehicle actuators.

B. Composite Tracking Error

This paper considers a kind of composite tracking error consisting of a spacing policy to enhance string stability and increase the traffic density at high speed [12]. The composite tracking error $e_i(t)$ is defined as:

$$e_i(t) = d^* - d_i(t) - t_h(v_d(t) - v_i(t)) \tag{5}$$

where $d_i(t)$ is the distance between the i^{th} vehicle and the $(i-1)^{\text{th}}$ vehicle with $d_i(t) = p_{i-1} - p_i(t) - l_i$ (l_i is the length of vehicle number i), d^* is the ideal safe distance and t_h is the headway time.

According to (5), the time derivatives of the composite tracking error e_i are described as:

$$\dot{e}_i(t) = v_i - v_{i-1} - t_h(\dot{v}_i - \dot{v}_d) \tag{6a}$$
$$\ddot{e}_i(t) = a_i - a_{i-1} - t_h(\ddot{v}_i - \ddot{v}_d) \tag{6b}$$

It needs to be noted that the variable e_i considers not simply trajectory tracking in a single state like [16], [22] but relative vehicle velocity between two neighboring vehicles and the difference between the current vehicle speed and the desired velocity of the platoon. This kind of composite tracking error with the spacing policy in traffic control can help avoid excessive inter-vehicle distances at high speeds.

C. Flexible Fault-tolerant Prescribed Control

The traditional prescribed transient and steady-state performance for the composite tracking error e_i can be described as [11], [12], [22]:

$$-e_{i,l}(t) < e_i(t) < e_{i,u}(t) \tag{7}$$

where $e_{i,l}(t) = -\underline{\xi_i}\rho_i(t)$ and $e_{i,u}(t) = \overline{\xi_i}\rho_i(t)$, $\overline{\xi_i}, \underline{\xi_i}$ are both positive constants. The prescribed function $\rho_i(t)$ is a positive definite and strictly decreasing with $\rho_i(t) = (\rho_0 - \rho_\infty)e^{-\tau t} + \rho_\infty$, where $\rho_0 > \rho_\infty > 0$ and $\tau > 0$. It is clear that this prescribed function satisfies $\rho_i(0) = \rho_0$ and $\lim_{t\to+\infty} \rho_i(t) = \rho_\infty$ and τ represents the convergence rate. The initial composite tracking error should satisfy $-\underline{\xi_i}\rho_0 < e_i(0) < \overline{\xi_i}\rho_0$.

In this paper, we proposed a flexible fault-tolerant prescribed function connected with control input saturation to deal with unobservable actuator faults, which can be formulated as:

$$-\bar{e}_{i,l}(t) < e_i(t) < \bar{e}_{i,u}(t) \tag{8}$$

with

$$\bar{e}_{i,l}(t) = e_{i,l}(t) + \underline{\theta}_{i,1}, \;\; \bar{e}_{i,u}(t) = e_{i,u}(t) + \overline{\theta}_{i,1} \tag{9}$$

where $\underline{\theta}_{i,1}$ and $\overline{\theta}_{i,1}$ are non-negative flexible factors of lower and upper boundary of the prescribed performance function. The flexible factors may increase to expand the prescribed boundaries when actuator faults or external disturbances appear and lead to continuous control input saturation, and then fast return to zero when this case disappears.

D. Control Objectives

The objectives of this study case are to find a platooning control strategy to fulfill the following requirements, despite the existence of unobservable actuator faults, unmeasurable external disturbances and control input saturation.

1) All the vehicles in this platoon are able to maintain ideal vehicle distance with $d_i(t) \to d^*$ and track the desired velocity with $v_i(t) \to v_d$.

2) The composite tracking error $e_i(t)$ must be strictly constrained in a prescribed region bounded by predefined transient and steady-state performance functions even with uncertain actuator faults and external disturbances, i.e., $-\overline{e}_{i,l}(t) < e_i(t) < \overline{e}_{i,u}(t)$.
3) According to previous research [11], [12], [21], the string stability of the platoon control can be achieved by setting the string stability variable as:

$$s_i(t) = (\dot{e}_i(t) + \lambda e_i(t)) - q(\dot{e}_{i-1}(t) + \lambda e_{i-1}(t)) \tag{10}$$

where both λ and q are positive constants. If the string stability variables can be bounded in a small neighborhood of zero and $0 < q < 1$, the string stability of the CAV platoon can be guaranteed.

III. Methodology

A. Error Transfer Function

It is difficult to directly design a feedback control system based on the composite tracking error to maintain the transient and steady-state performance inequality (8). To address this issue, a kind of error transfer function (ETF) has been proposed in this form [16]:

$$e_i = 0.5(\overline{e}_{i,u} + \overline{e}_{i,l})F(z_{i,1}) + 0.5(\overline{e}_{i,u} - \overline{e}_{i,l}) \tag{11}$$

where function $F(\cdot)$ satisfies the properties in [23] that: 1) $-1 < F(z_{i,1}) < 1$ for $-\infty < z_{i,1} < +\infty$ and 2) $\lim_{z_{i,1}\to+\infty} F(z_{i,1}) = 1$ and $\lim_{z_{i,1}\to-\infty} F(z_{i,1}) = -1$. By this ETF, the composite tracking error e_i can be transformed into a equivalent unconstrained virtual error $z_{i,1}$. Therefore, a control system designed to ensure the convergence of $z_{i,1}$ is able to guarantee that the composite tracking error e_i satisfies the inequality (8). In this paper, we set

$$F(z_{i,1}) = \frac{2}{\pi}\arctan(z_{i,1}) \tag{12}$$

B. Flexibility Auxiliary System

In this paper, FFPC was proposed to deal with probable actuator faults caused by brake and throttle system issues of CAVs. The prescribed performance functions should own the ability to enlarge the boundaries when actuator faults or external disturbances appear and lead to continuous control input saturation, and then fast recover to normal status when this case disappears. Motivated by previous research on PPC with control input saturation [11], [12], [16], [22], [24], [25], a flexibility auxiliary system is built to bridge the gap between control input saturation and flexibility factors of prescribed performance boundaries in this form:

$$\begin{cases} \dot{\overline{\theta}}_{i,1} = -\frac{\Lambda}{\Lambda_u}(-\Gamma_1\overline{\theta}_{i,1} + \overline{\theta}_{i,2}) \\ \dot{\overline{\theta}}_{i,2} = -\Gamma_2\overline{\theta}_{i,2} + \overline{\theta}_{i,3} \\ \dot{\overline{\theta}}_{i,3} = -\Gamma_3\overline{\theta}_{i,3} + \psi_u \\ \dot{\underline{\theta}}_{i,1} = \frac{\Lambda}{\Lambda_u}(-\Gamma_1\underline{\theta}_{i,1} + \underline{\theta}_{i,2}) \\ \dot{\underline{\theta}}_{i,2} = -\Gamma_2\underline{\theta}_{i,2} + \underline{\theta}_{i,3} \\ \dot{\underline{\theta}}_{i,3} = -\Gamma_3\underline{\theta}_{i,3} + \psi_l \end{cases} \tag{13}$$

where $\Lambda = \frac{\partial z_{i,1}}{\partial e_i}$, $\Lambda_u = \frac{\partial z_{i,1}}{\partial \overline{e}_{i,u}}$, $\Lambda_l = \frac{\partial z_{i,1}}{\partial \overline{e}_{i,l}}$, Γ_1, Γ_2 and Γ_3 are all predefined positive constants. ψ_u and ψ_l can be designed as:

$$\begin{cases} \psi_u = [\frac{1}{2}\text{sign}(\mu_i - \mu_{i,\min}) - \frac{1}{2}][\mu_i - \mu_{i,\min}] \\ \psi_l = [\frac{1}{2}\text{sign}(\mu_i - \mu_{i,\max}) + \frac{1}{2}][\mu_i - \mu_{i,\max}] \end{cases} \tag{14}$$

Based on the design of flexibility auxiliary system, continuous control input saturation caused by actuator faults or environment disturbances will stimulate augmentation of the flexibility factors $\overline{\theta}_{i,1}$ and $\underline{\theta}_{i,1}$, which will enlarge the boundaries to guarantee that the composite tracking error e_i would not violate the prescribed performance constraint to avoid control singularity. Meanwhile, the flexibility factors $\overline{\theta}_{i,1}$ and $\underline{\theta}_{i,1}$ will fast converge to zero when control input saturation disappears. This process can be beneficial to enhance the fault-tolerance and robustness of the control system for CAV platoon.

C. Control Design

In this section, an FFPC was proposed for CAV platoon considering control input saturation, unobservable actuator faults and external disturbances. Firstly, the virtual error is defined as:

$$e_i = 0.5(\overline{e}_{i,u} + \overline{e}_{i,l})F(z_{i,1}) + 0.5(\overline{e}_{i,u} - \overline{e}_{i,l}) \tag{15}$$

$$z_{i,2} = v_i + \underline{\theta}_{i,2} - \overline{\theta}_{i,2} - \alpha_{i,2}^f \tag{16}$$

$$z_{i,3} = a_i + \underline{\theta}_{i,3} - \overline{\theta}_{i,3} - \alpha_{i,3}^f \tag{17}$$

where $\alpha_{i,2}^f$ and $\alpha_{i,3}^f$ are the first-order filter outputs by setting virtual control input $\alpha_{i,1}$ and $\alpha_{i,2}$ as the input to this filer. The virtual and actuator control input can be designed as:

$$\begin{aligned} \alpha_{i,1} =& v_i - \Gamma_i(\overline{\theta}_{i,2} - \underline{\theta}_{i,2}) - \frac{1}{\Lambda}(\Lambda_u\dot{e}_{i,u} + \Lambda_l\dot{e}_{i,l}) \\ &- \frac{c_{i,1}z_{i,1}}{\Lambda} - \dot{e}_i \end{aligned} \tag{18}$$

$$\alpha_{i,2} = -\Gamma_2(\overline{\theta}_{i,2} - \underline{\theta}_{i,2}) - \frac{\omega_{i,2}}{t_\tau} - \Lambda z_{i,1} - c_{i,2}z_{i,2} \tag{19}$$

$$\begin{aligned} \mu_i =& -f_i - \Gamma_3(\overline{\theta}_{i,3} - \underline{\theta}_{i,3}) - \frac{\omega_{i,3}}{t_\tau} - c_{i,3}z_{i,3} \\ &+ \frac{s_i}{z_{i,3}}(-\dot{s}_i - k_s s_i) \end{aligned} \tag{20}$$

where $c_{i,1}$, $c_{i,2}$, $c_{i,3}$, k_s, t_τ are all positive constants, $\omega_{i,2} = \alpha_{i,2}^f - \alpha_{i,1}$. and $\omega_{i,3} = \alpha_{i,3}^f - \alpha_{i,2}$.

Based on previous stability analysis [12], [16]–[18], this controller design can ensure that virtual errors $z_{i,1}$, $z_{i,2}$, $z_{i,3}$ and the string stability variable s_i are bounded and able to converge to a small neighborhood of zero. Due to the special design of the ETF (11), the composite tracking error e_i containing multiple states of this CAV platoon can be strictly constrained in the predefined region bounded by the prescribed performance functions (9), which guarantees both transient and steady-state tracking performance of the platooning control. As demonstrated in previous control methods on CAVs [11], [12], [21], the convergence of s_i can achieve the string stability of the CAV platoon. This is critical for ensuring that disturbances, such as sudden speed changes,

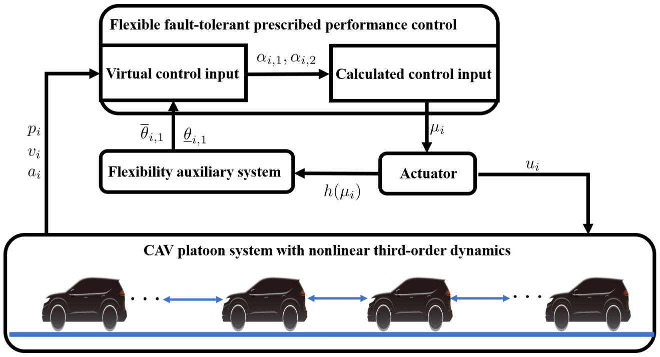

Fig. 2. Block diagram of FFPC.

are not amplified as they propagate along the vehicle string, thus improving safety and traffic flow efficiency.

The flexibility auxiliary system (13)-(14) bridges the gap between the flexibility factors $\overline{\theta}_{i,1}$, $\underline{\theta}_{i,1}$ and input saturation signals. This design built a mechanism that continuous control input saturation caused by actuator faults or environment disturbances will stimulate the increase of the flexibility factors $\overline{\theta}_{i,1}$ and $\underline{\theta}_{i,1}$, while they will fast converge to zero after control input saturation disappears. This mechanism will avoid control singularity by dynamically expanding or recovering the boundaries to guarantee that the composite tracking error e_i would not violate the prescribed performance constraint. Namely, FFPC can flexibly expand or recover the prescribed performance boundaries according to control input saturation signals, which is beneficial to decrease the control conservatism and achieve favorable fault-tolerance and robustness of the control system for CAV platoon.

The Proposed FFPC design has been shown in Fig. 2 to make this strategy in a clear manner.

IV. Simulations and Evaluations

In order to further present the feasibility and effectiveness of the proposed FFPC scheme for CAV platoon, simulations are conducted in comparison with traditional PPC methods.

In the simulations, the control strategies are employed in a vehicular platoon with five CAVs including a lead vehicle (vehicle number 0) and four following vehicles (vehicle number 1, 2, 3, 4). The parameters of vehicular dynamics are shown in Table I.

TABLE I
Vehicular Dynamics Parameters ($i = 0, 1, \ldots, 4$)

l_i	m_i	c_i	τ_i	t_h	$\mu_{i,\max}$	$\mu_{i,\min}$	d^*	q	λ
4	1600	0.33	0.25	0.2	5	-5	10	0.9	2

For the simulation settings, the desired velocity trajectory of this CAV platoon is $v_d(t) = 3\sin(0.1\pi t - 0.5\pi) + 4.5$. The initial states of the CAV platoon are shown in Table II. In order to test the fault-tolerance and robustness of FFPC for CAV platoon, we choose to add actuator faults to vehicle number 1 and vehicle number 3 during 5-6.5 s, and disturbances to these two during 31-35.5 s. Thus the actuator fault function $g_i(t)$ and the lumped disturbance function $D_i(t)$ are set as $(i = 2, 4)$:

$$g_i(t) = \begin{cases} 0.6, & 5 \leq t \leq 6.5 \\ 1, & \text{Others} \end{cases} \tag{21}$$

$$D_i(t) = \begin{cases} 1 + |\sin(0.55t - 1)|, & 31 \leq t \leq 35.5 \\ 0, & \text{Others} \end{cases} \tag{22}$$

TABLE II
Initial states of the platoon ($i = 0, 1, \ldots, 4$)

i	4	3	2	1	0
$p_i(0)\ (m)$	14	28	42	56	70
$v_i(0)\ (m/s)$	0	0	0	0	0
$a_i(0)\ (m/s^2)$	0	0	0	0	0

TABLE III
FFPC Parameters ($i = 0, 1, \ldots, 4$)

ρ_0	ρ_∞	τ	$\underline{\xi}_i$	$\overline{\xi}_i$	Γ_1
2	0.1	0.8	1	1	5
Γ_2	Γ_3	t_τ	$c_{i,1}$	$c_{i,2}$	$c_{i,3}$
5	5	0.1	0.3	3	3

The predefined parameters of FFPC scheme are shown in Table III. The corresponding simulation results are provided in Fig. 3. It is obvious that this proposed scheme can realize effective tracking performance for this CAV platoon. The changes in speed or acceleration would not amplify as they propagate through this vehicle platoon with safe distance between each two neighboring vehicles in this platoon. This means that the string stability of this CAV platoon is achieved even with sometimes unobservable actuator faults and disturbances on vehicle number 1 and 3. According to the subplot in the acceleration part in Fig. 3, during and after periods of actuator faults or disturbances, the accelerations fluctuate around the desired trajectory to ensure that the velocity always meet the prescribed performance constraints.

To showcase the flexibility and robustness of the proposed control strategy, comparative experiments with PPC are carried out to present the merit of FFPC. We designed the comparative simulation by using traditional PPC scheme without the flexibility auxiliary system(13)-(14), where the prescribed performance constraints are always fixed in the control process. The simulation results are shown in Fig. 4, which presents the composite tracking error trajectories under FFPC and PPC respectively. It is obvious that the composite tracking error e_i $(i = 0, 1, \ldots, 4)$ under FFPC can be strictly evolved within the predefined performance constraints in this tracking control process (transient and steady-state) and finally converge to a small neighborhood around zero within finite time despite of the existence of actuator faults, disturbances and control input saturation. According to the plot for FFPC in Fig. 4, we can see that when actuator faults appears during 5-6.5s and disturbances

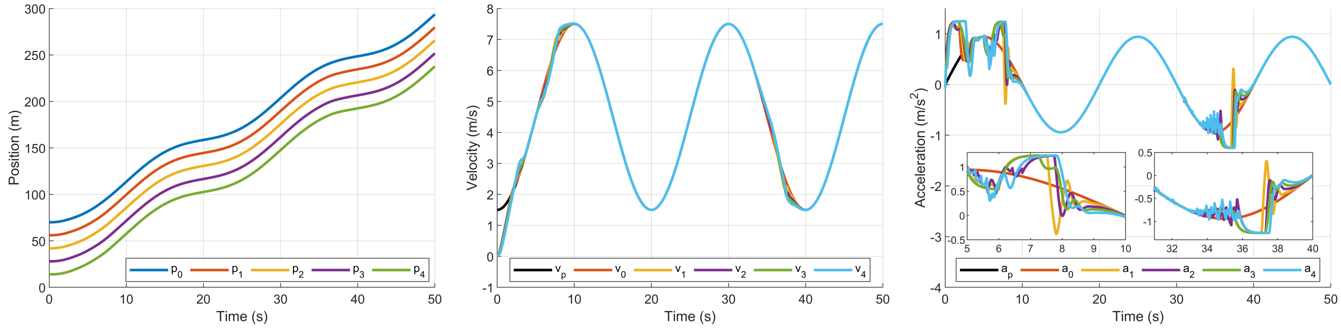

Fig. 3. The state trajectory plots of CAV platoon under FFPC $(i = 0, 1, \dots, 4)$.

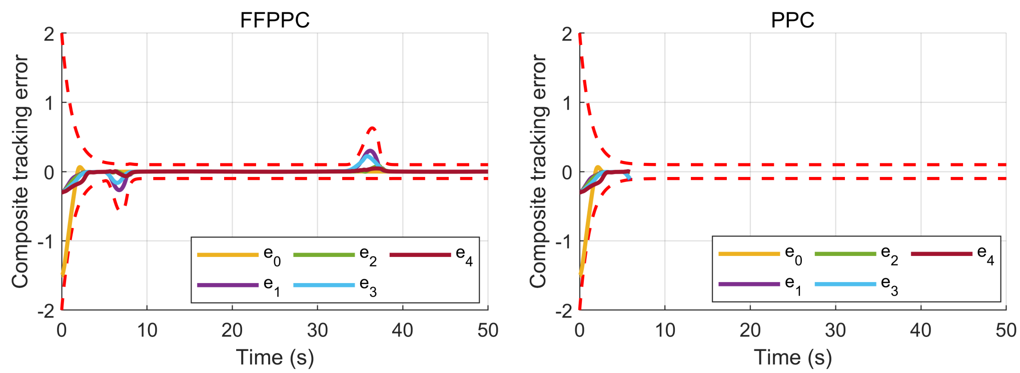

Fig. 4. Composite tracking error trajectories of the CAV platoon $(i = 0, 1, \dots, 4)$.

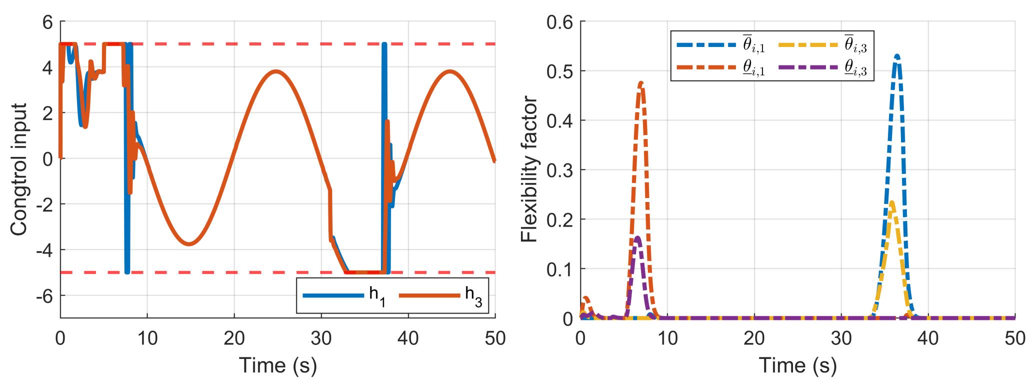

Fig. 5. Actual control inputs and flexibility factors of vehicle number 1,3 under FFPC $(i = 1, 3)$.

appears during 31-35.5s on vehicle 1 and 3, the prescribed performance boundary will adaptively expand to guarantee that the composite tracking errors e_1 and e_3 would not violate the constraints to avoid control singularity in this process. Meanwhile, the expanded boundary will recover to its original status after the faults or disturbances disappear to minimize the negative impacts on the tracking performance. However, PPC cannot present the favorable tracking performance under the same conditions just as shown in Fig. 4. It is clear that the composite tracking error e_1 and e_3 of PPC approach the boundary and violate the predefined performance constraint after 5.89s resulting in the singularity of the control design. It means that the user-specified performance constraints of PPC may be not achieved due to control input saturation, uncertain actuator faults and environment disturbances. In this case, the closed-loop control systems for the CAV platoon may be severely degraded or even instable, which may even cause damage to the traffic safety. In short, this simulation result presents that FFPC owns better fault-tolerance and robustness for CAV platooning control in comparison with conventional PPC with fixed performance boundaries.

Fig. 5 showcases the plots of actuator control inputs and flexibility factors of vehicle number 1 and 3 with faults and disturbances in this simulation. The actuator control input saturation during the initial time period is due to an initial tracking error between the initial velocity $v_i(0)$ of the platoon and the desired velocity v_p. Apart from the initial time period, the control input saturation appears during 5-6.5s and 31-35.5s when vehicle number 1 and 3 are affected by actuator faults or external disturbances. The plots of the flexibility factors in Fig. 5 present that continuous control input saturation caused by actuator faults or environment disturbances will stimulate the increase of the flexibility factors $\overline{\theta}_{i,1}$ and $\underline{\theta}_{i,1}$ (i=1,3), while they will fast converge to zero after control input saturation disappears. This verifies effectiveness of the flexibility auxiliary system in building the connection between control input saturation and the flexibility factors. Namely, FFPC can flexibly expand or recover the prescribed performance boundaries according to control input saturation signals, which can decrease the control conservatism and achieve better fault-tolerance and robustness of the control system for CAV platoon.

V. Conclusion

This paper proposes a novel FFPC scheme for nonlinear third-order CAV platoons simultaneously considering control input saturation, uncertain actuator faults, and environment disturbances. The ETF is built to transfer the composite tracking error containing multiple states of the CAV platoon into the equivalent virtual error for prescribed performance controller design. The developed flexibility auxiliary system creates the connection between the performance boundaries and control input saturation, which owns the ability of expanding performance boundaries when control input saturation occurs and recovering to the predefined performance when control input saturation disappears. This mechanism is able to achieve reducing conservative control design and avoid control singularity of CAV platoons. The simulation presents that the proposed FFPC can serve the platoon control objectives. The comparative experiment results against traditional PPC can showcase the effectiveness, fault-tolerance, and robustness of FFPC for CAV platoon control.

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