A new method to deal with the saturation problem in feedforward control for measurable disturbances

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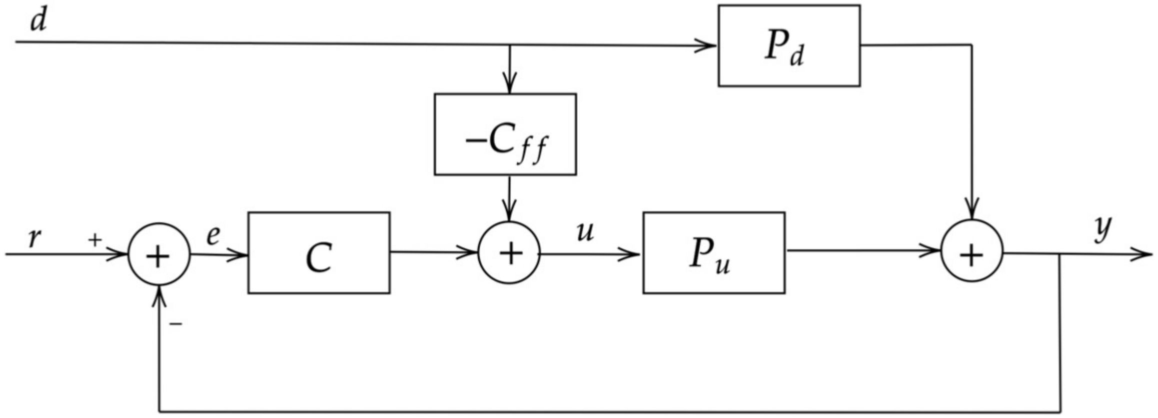
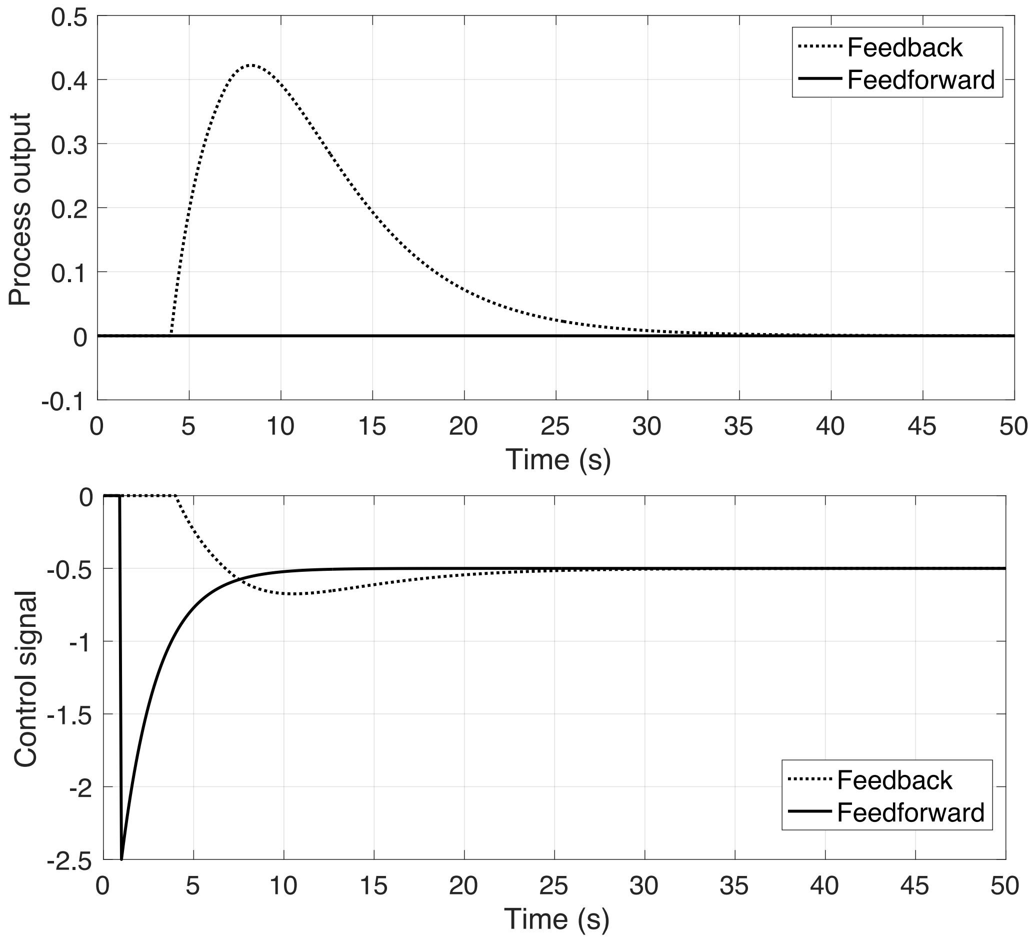


$$C_{ff} = \frac{P_d}{P_u}$$



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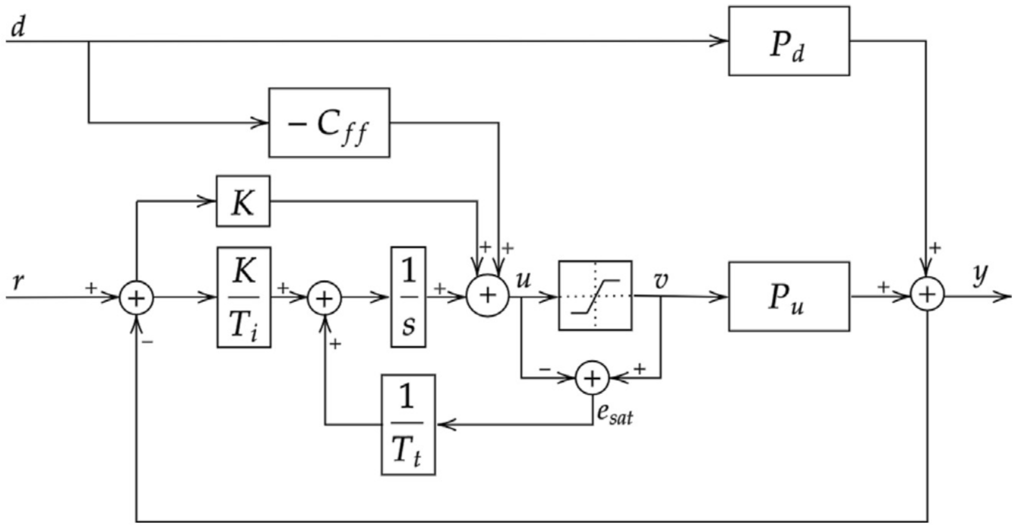

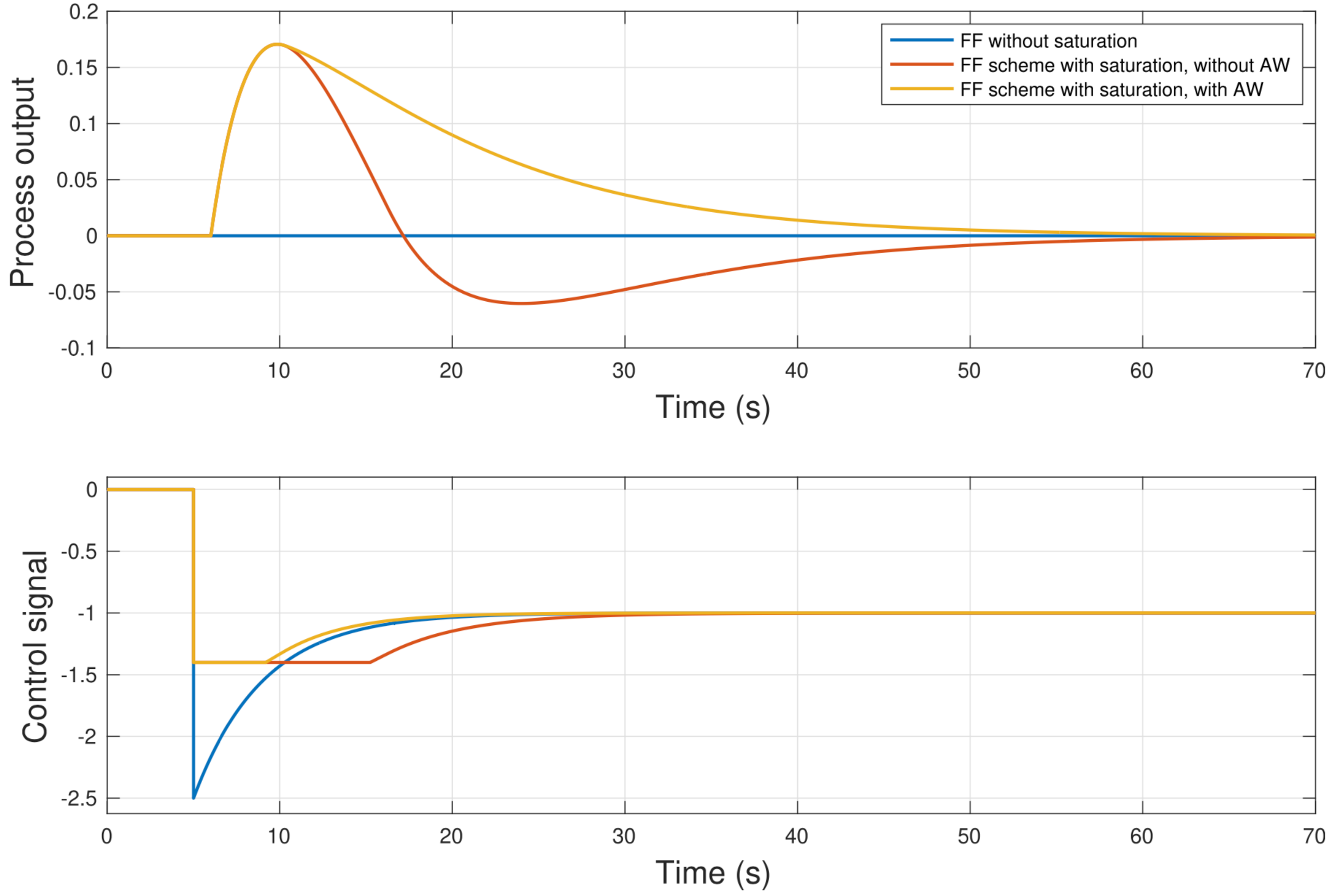

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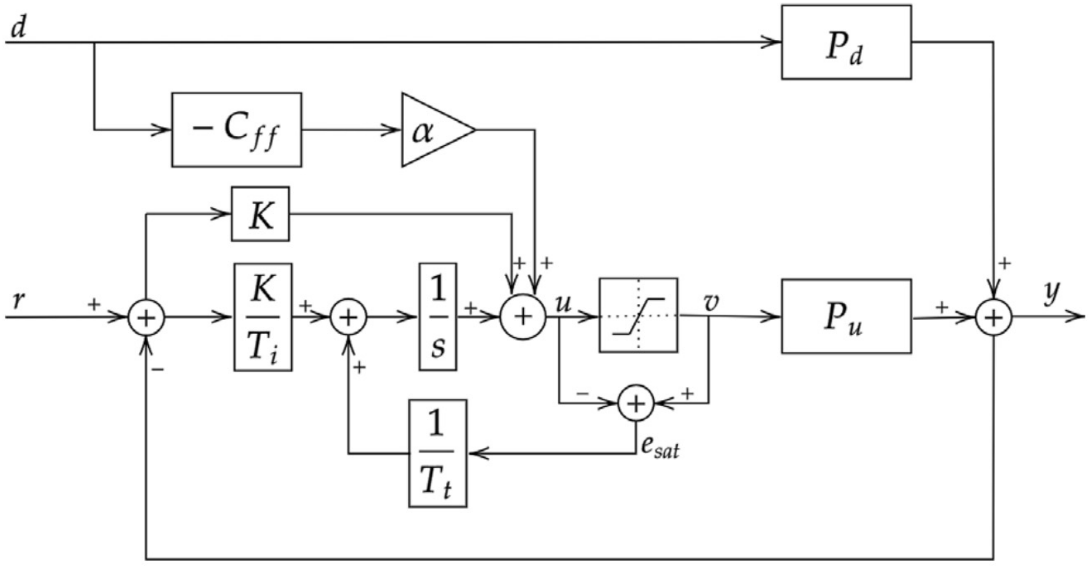

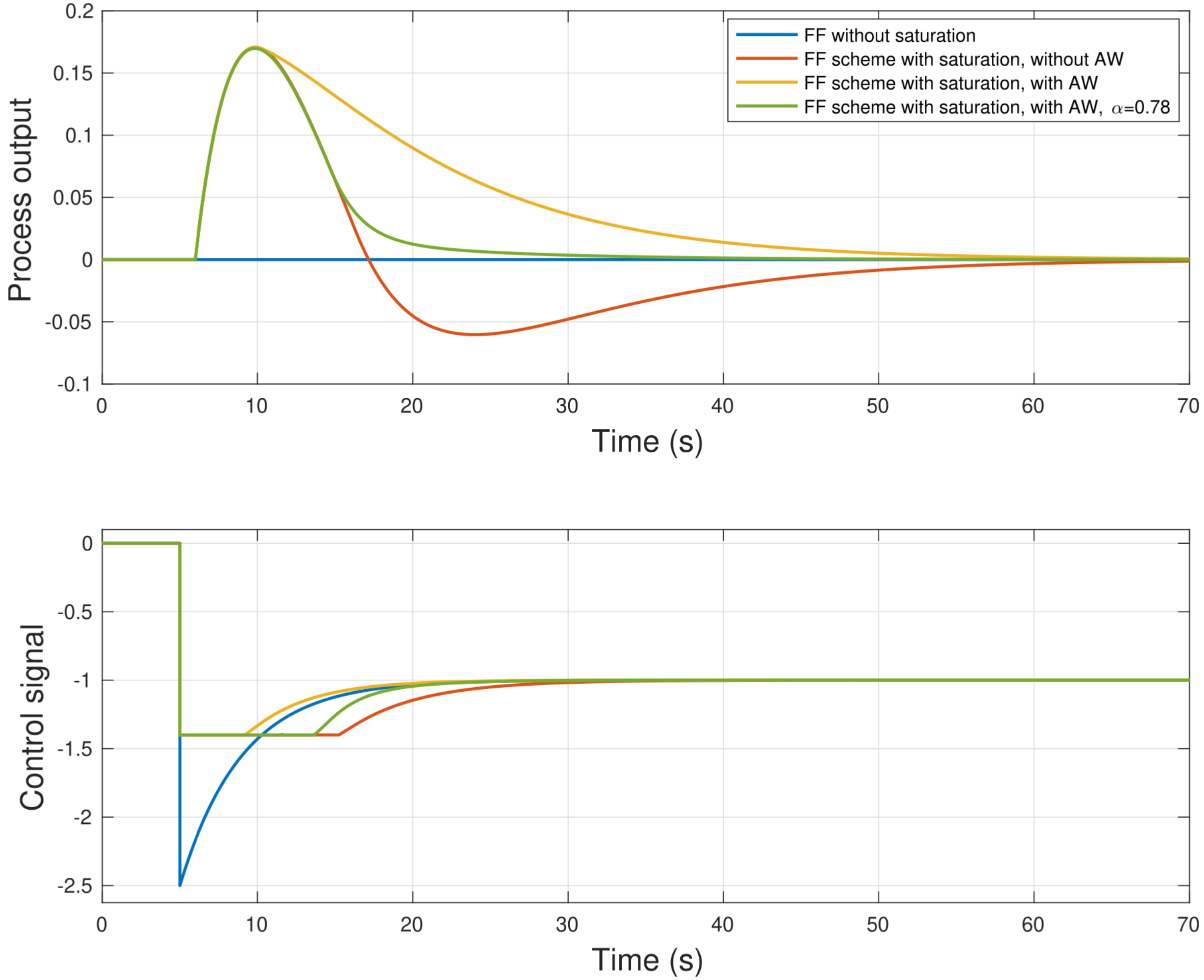

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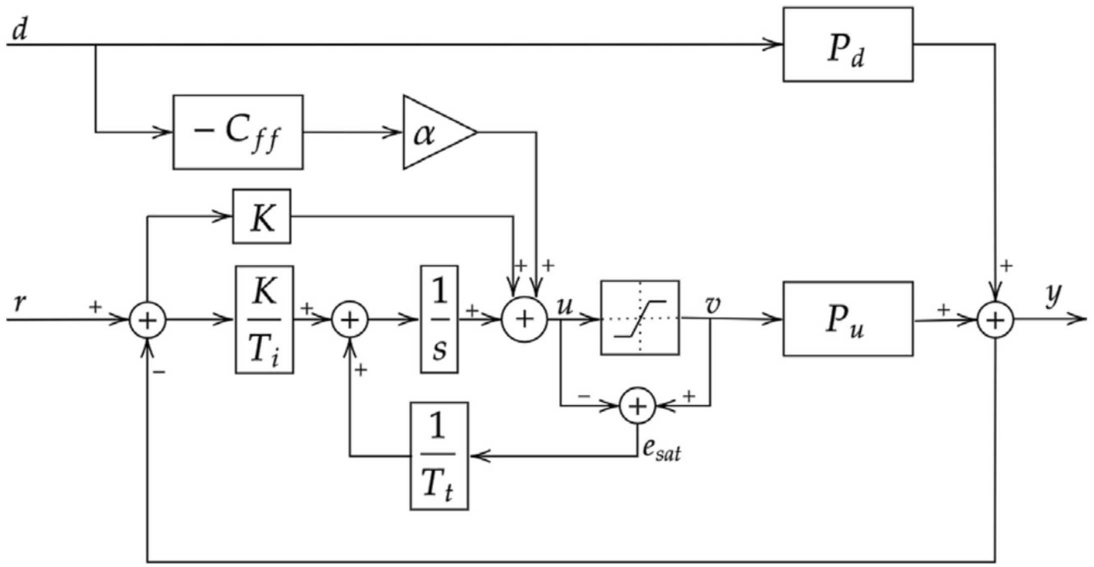
1 Preliminaries

Preliminaries

$$P_u = \frac{K_u}{1+sT_u}e^{-sL_u} \qquad P_d = \frac{K_d}{1+sT_d}e^{-sL_d}$$

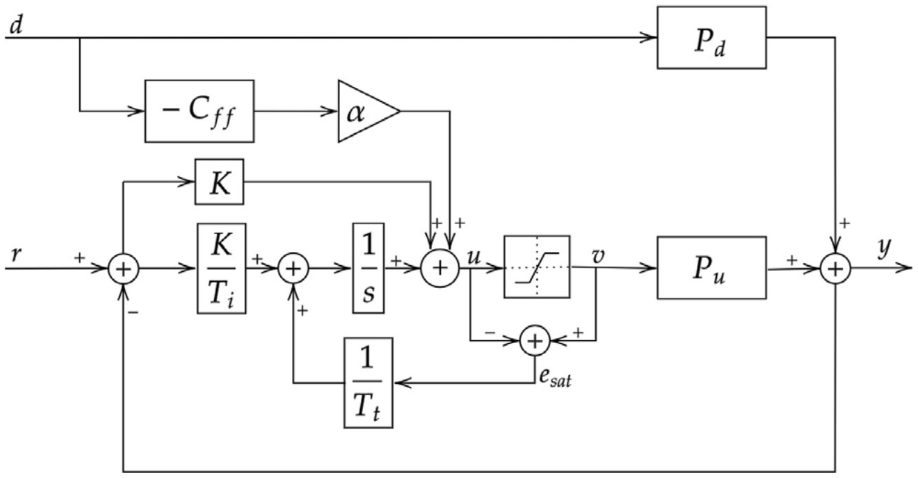
$$C = K\left(1+\frac{1}{s\tau_i}\right) \qquad K = \frac{T_u}{K_u(\lambda+L_u)}, \quad \tau_i = T_u$$

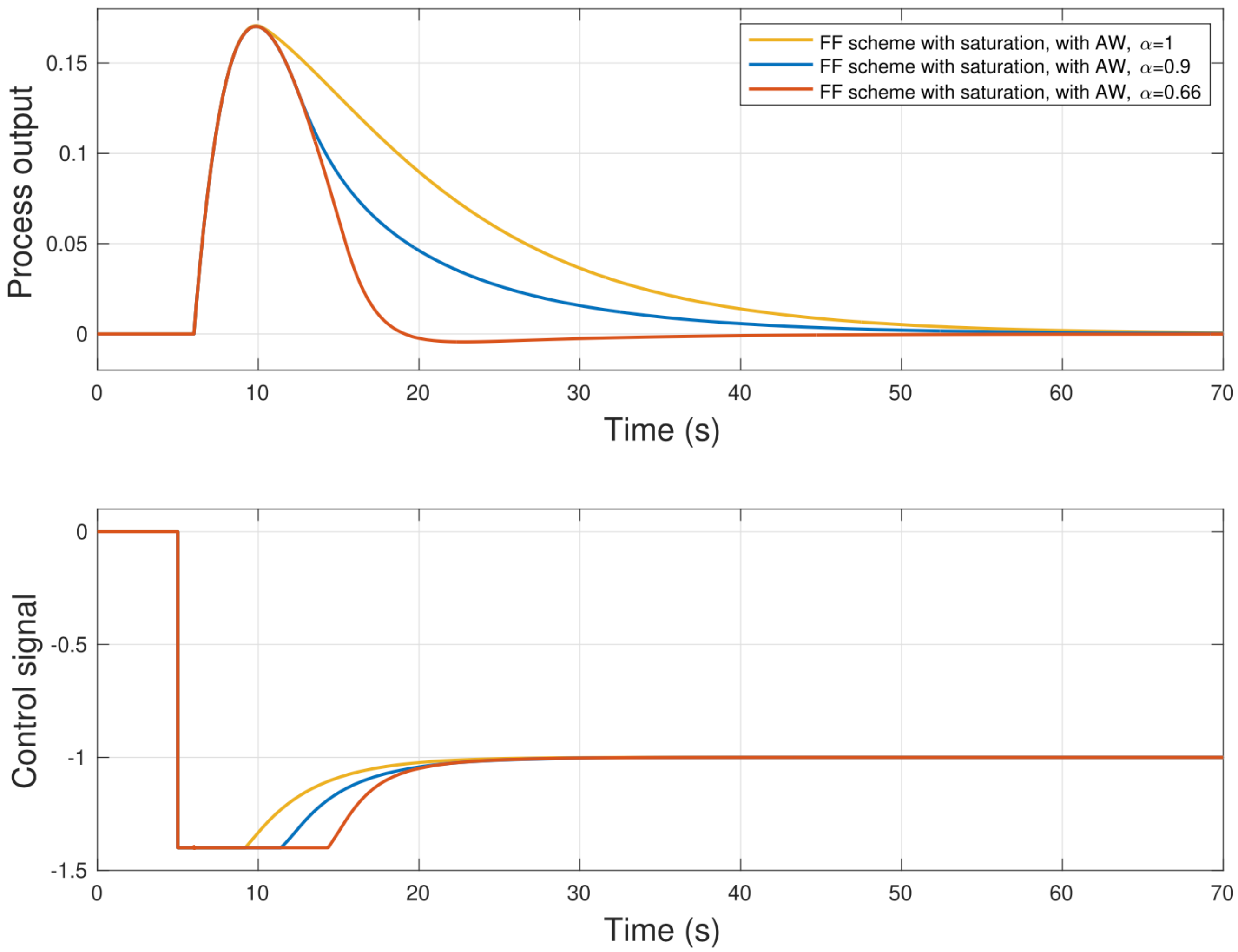
$$C_{ff} = \frac{P_d}{P_u} \qquad C_{ff} = \frac{K_d}{K_u}\frac{sT_u+1}{sT_d+1}e^{-s(L_d-L_u)}$$



2 Proposed method

Proposed method

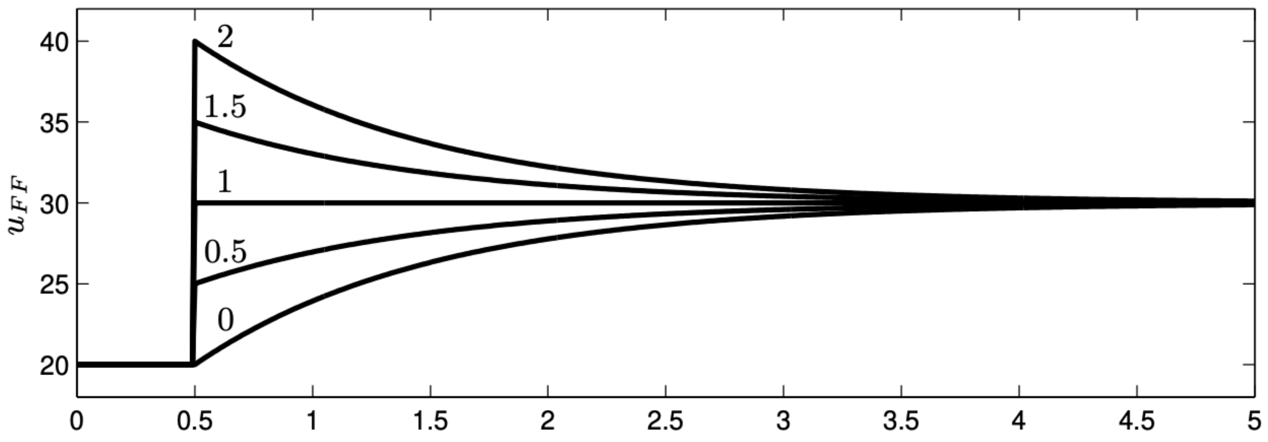


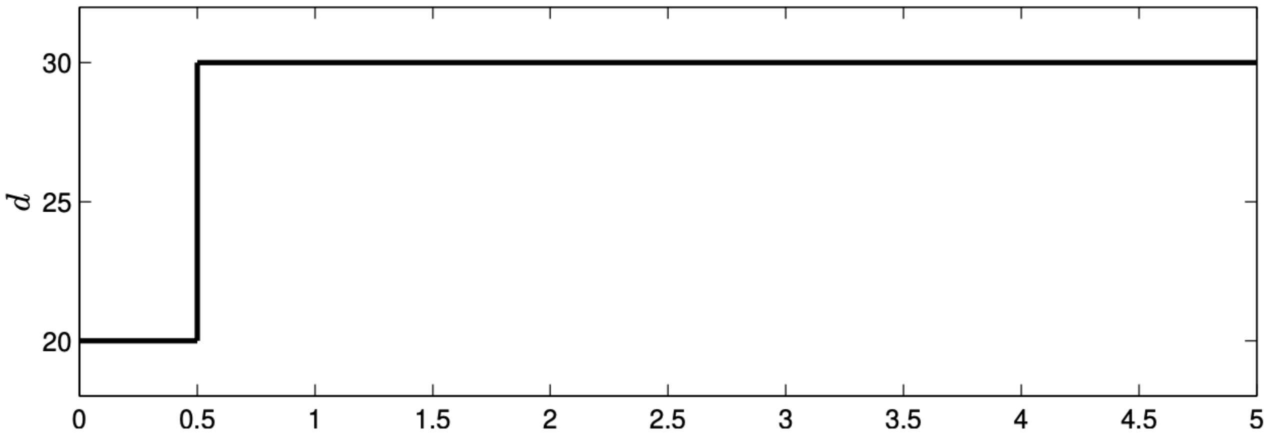


Proposed method

$$C_{ff} = K_{ff}\frac{sT_z + 1}{sT_p + 1}\cdot e^{-sL_{ff}}$$

$$T_z > T_p$$





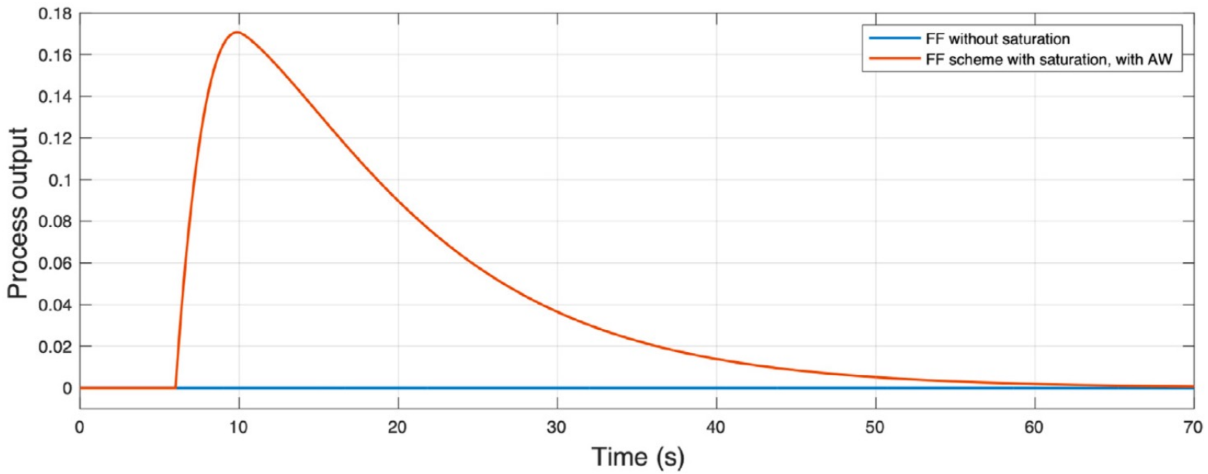
Proposed method

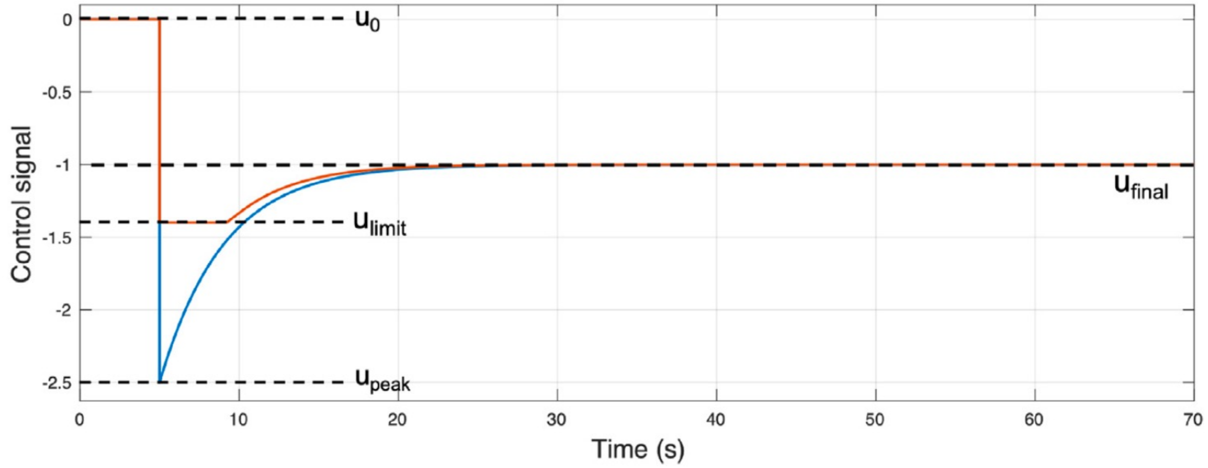
$$u_{peak} = \lim_{t\to 0} u(t) = \lim_{s\to\infty} -sC_{ff}(s)\frac{d}{s} = \lim_{s\to\infty} -s\frac{K_d}{K_u}\frac{T_u s+1}{T_d s+1}\frac{d}{s} = -K_{ff}\frac{T_u}{T_d}d$$

$$u_{final} = \lim_{t\to\infty} u(t) = \lim_{s\to 0} -sC_{ff}(s)\frac{d}{s} = \lim_{s\to 0} -s\frac{K_d}{K_u}\frac{T_u s+1}{T_d s+1}\frac{d}{s} = -K_{ff}d$$

$$R_T = \frac{T_p}{T_z} \quad \text{where}: \; R_T \in (0,1)$$

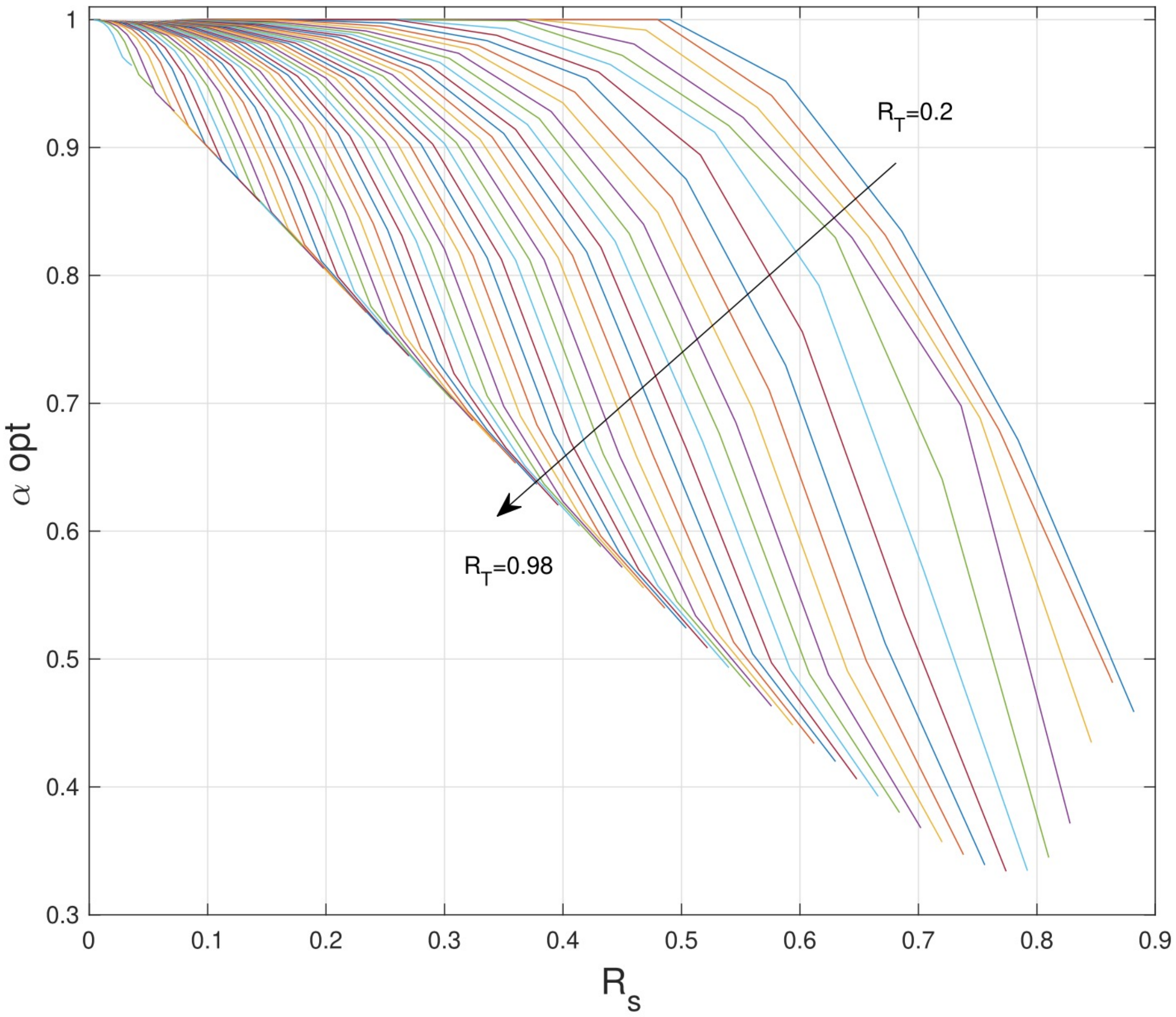
$$R_S = \frac{u_{peak} - u_{limit}}{u_{peak} - u_0} \quad \text{where}: \; R_S \in (0,1)$$





Proposed method

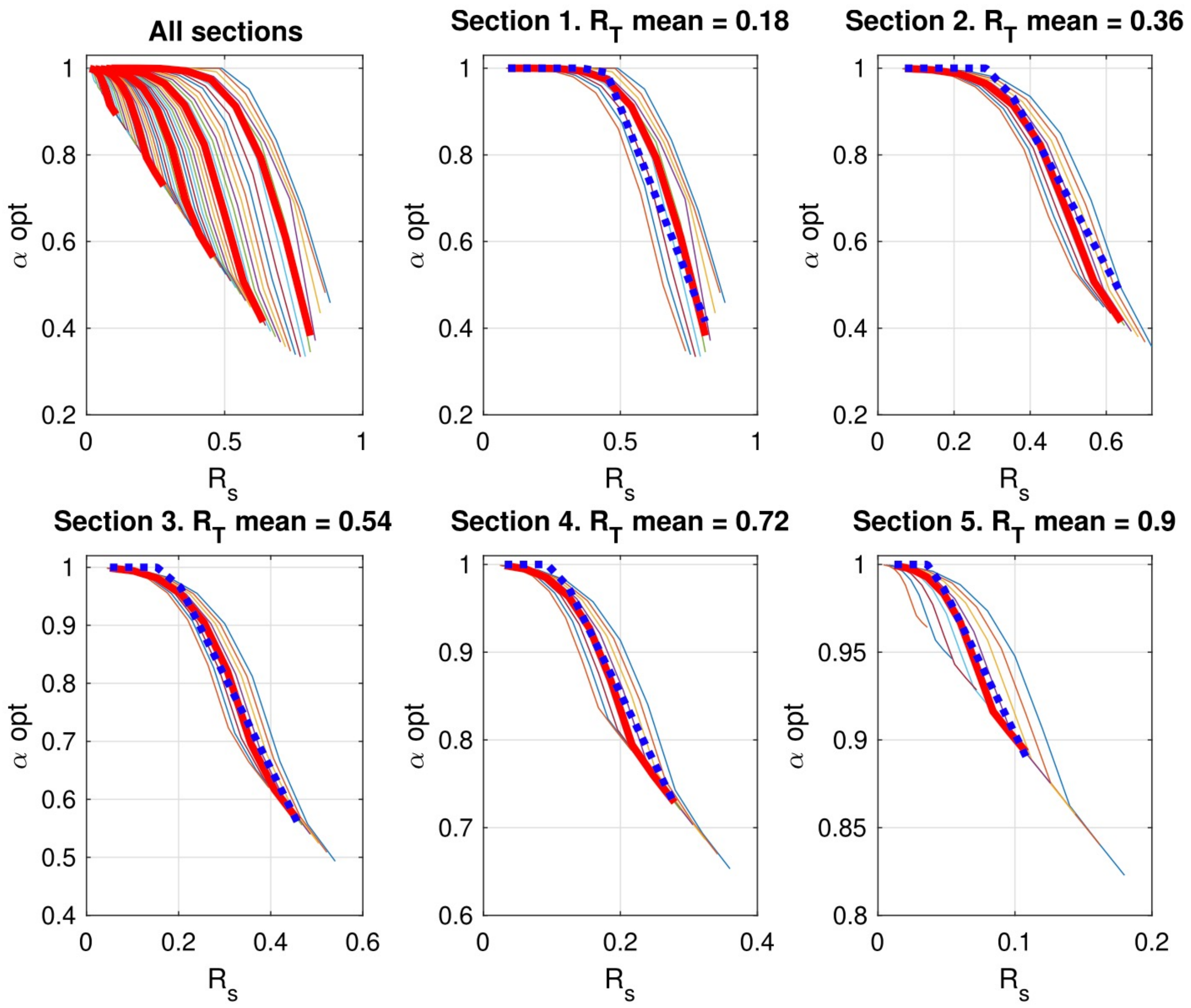
$$\min_{\alpha} \int_0^{T^*} |e(t)|\, dt \quad \text{such that :} \quad 0 < \alpha \leq 1$$



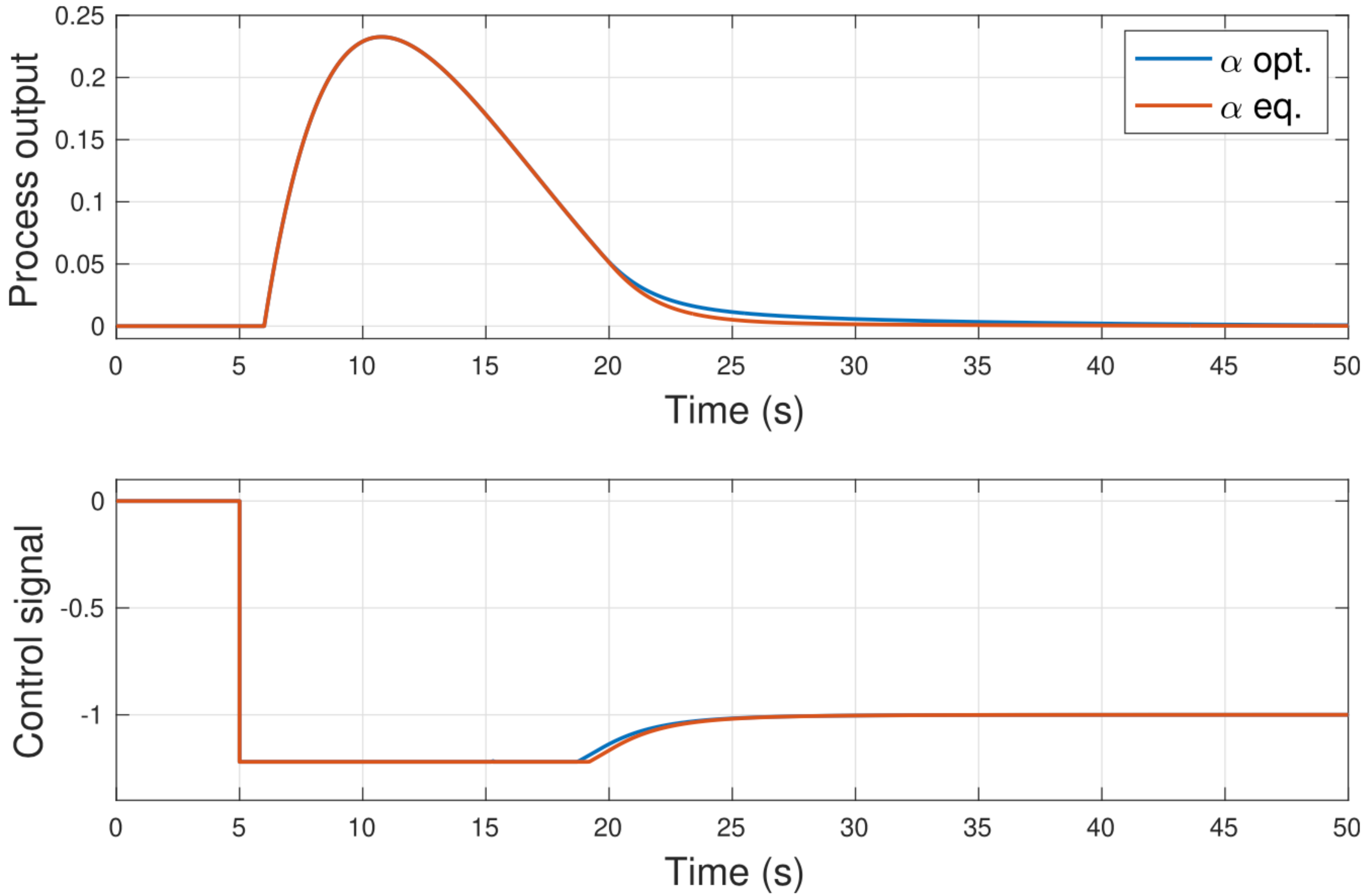
Proposed method

$$\alpha = \begin{cases} f & 0 < f < 1 \\ 1 & \text{else} \end{cases}$$

$$f(R_S, R_T) = -1.6 \cdot R_S - R_T + 1.9$$



Proposed method



3 Examples

Examples

Example 1. $K_u = K_d$, $L_u = L_d$, small R_T and large R_S.

Example 2. $K_u \neq K_d$, $L_u = L_d$, small R_T and medium R_S.

Example 3. $K_u = K_d$, $L_u < L_d$ (no inversion problem), small R_T and medium R_S.

Example 4. $K_u = K_d$, $L_u > L_d$ (inversion problem), small R_T and medium R_S.

Example 5. $K_u = K_d$, $L_u = L_d$, small R_T and medium R_S. P_1 and P_2 are second-order transfers function with two real poles.

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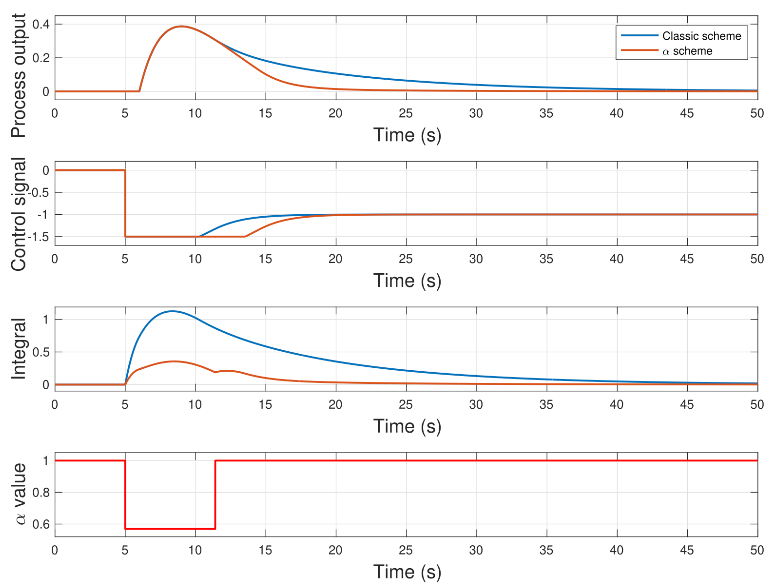
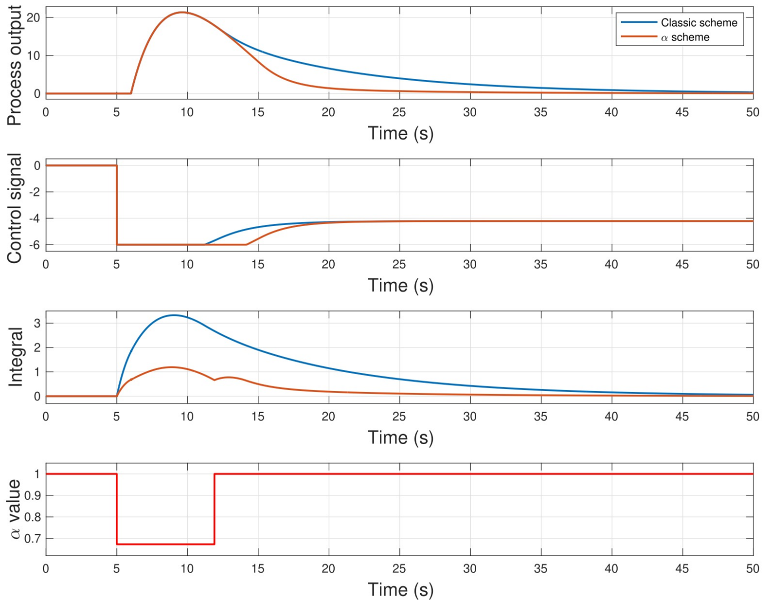
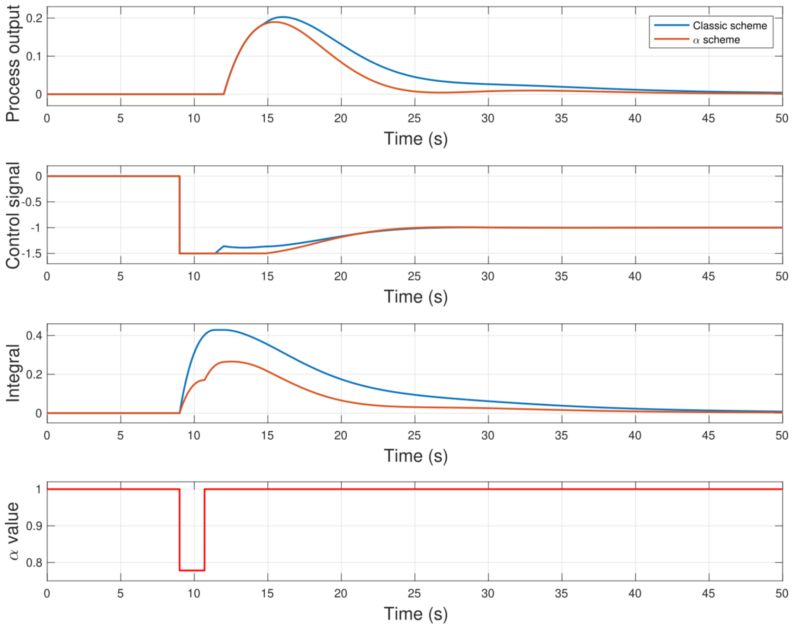
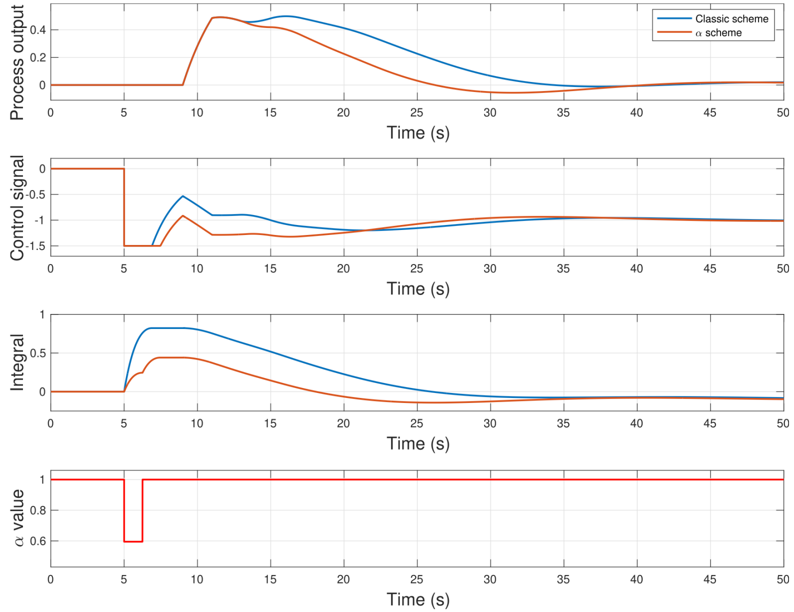
Examples









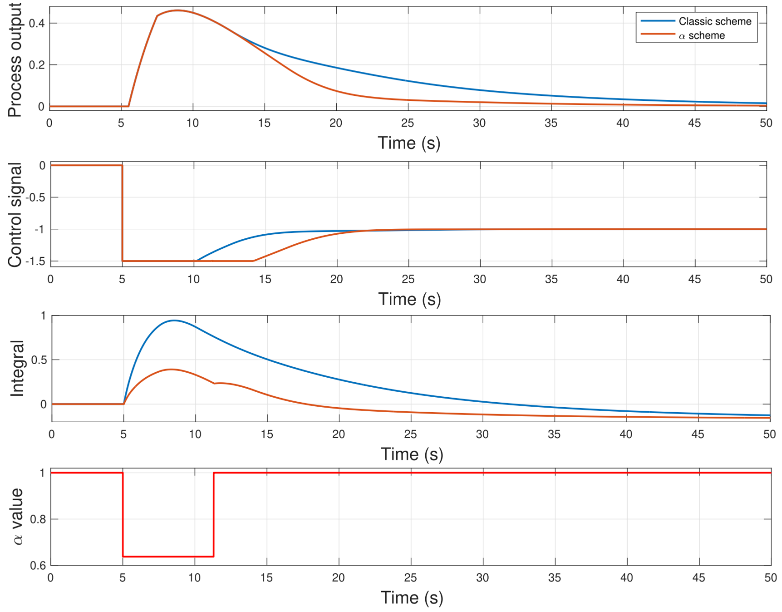
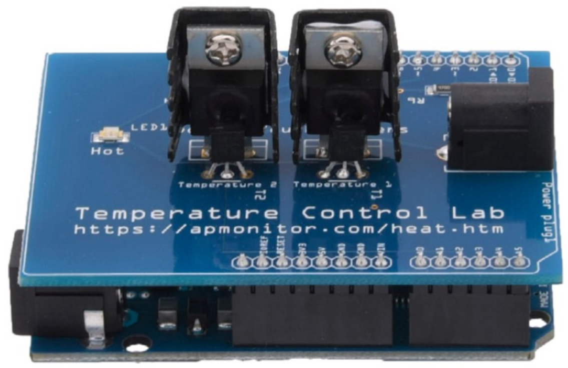
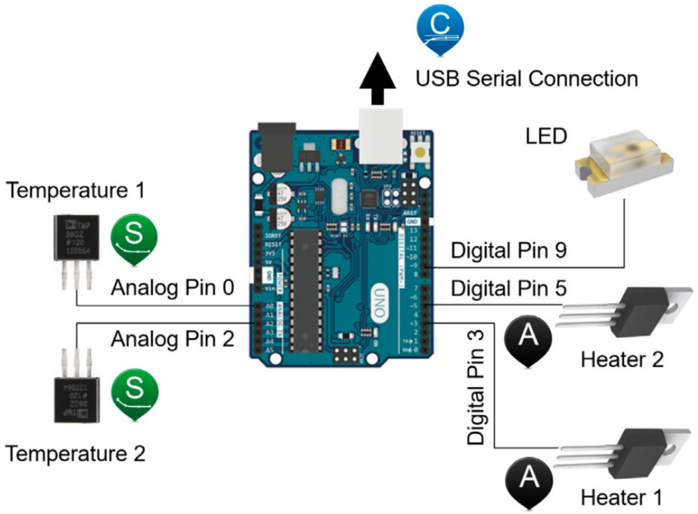


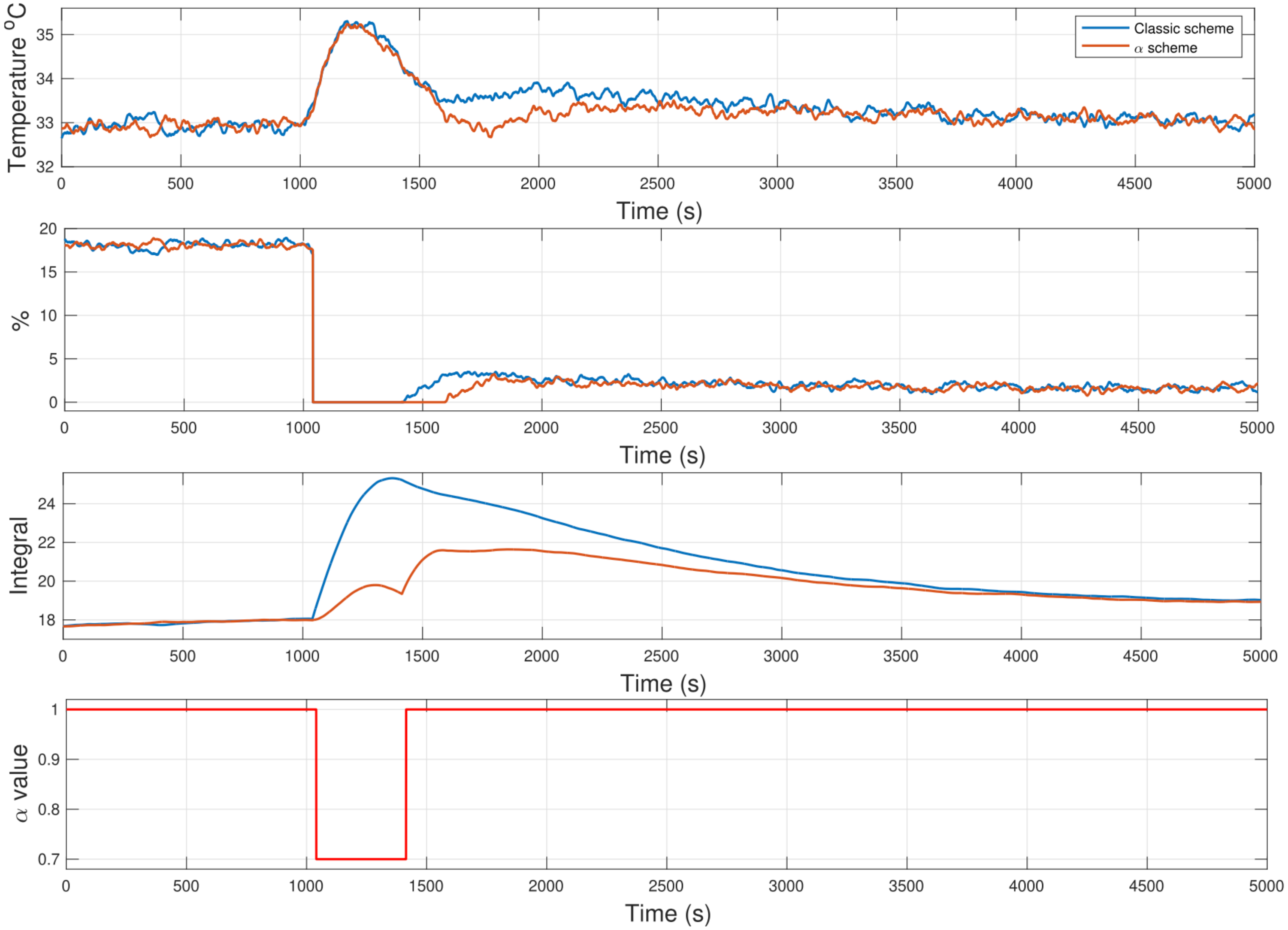
Table 1
Normalized IAE and maximum integral values in the five examples.

	IAE_{norm}	$Imax_{norm}$
Example 1	0.63	0.31
Example 2	0.66	0.26
Example 3	0.68	0.62
Example 4	0.73	0.53
Example 5	0.26	0.53

Examples


Temperature Control Lab
https://apmonitor.com/heat.htm


USB Serial Connection
LED
Temperature 1
Analog Pin 0
Analog Pin 2
Temperature 2
Digital Pin 9
Digital Pin 5
Digital Pin 3
Heater 2
Heater 1


Temperature °C
Classic scheme
α scheme
Time (s)
%
Time (s)
Integral
Time (s)
α value
Time (s)

4 Conclusions

Conclusions

- The saturation problem on the feedforward control scheme was analyzed.
- The negative influence anti-windup functions on feedforward control actions was studied.
- A novel modification on the feedforward control scheme to deal with saturation problems was proposed.
- A general tuning rule was derived for the α parameter.
- The new scheme was evaluated in simulation under different scenarios and experimentally on a temperature control problem.

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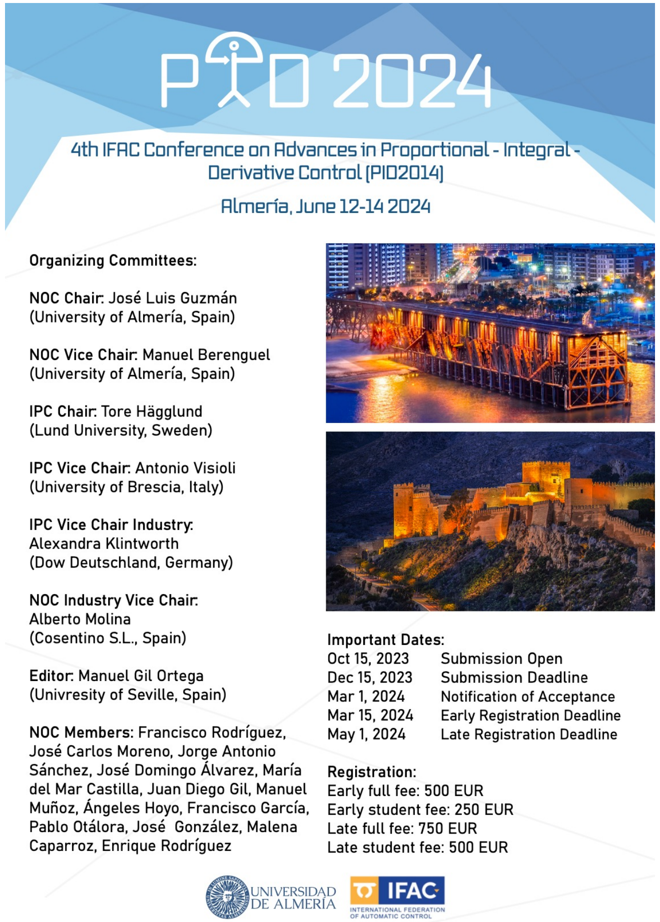

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Thank you very much for your attention!

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