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# Reply to 'Comments on the examples in "Dynamic output feedback compensation for linear systems with independent amplitude and rate saturations"'

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## Correspondence

# Reply to 'Comments on the examples in "Dynamic output feedback compensation for linear systems with independent amplitude and rate saturations"'

FENG TYAN† and DENNIS S. BERNSTEIN‡

Hui (1998) discussed the steady state error occurring in the examples given in Tyan and Bernstein (1997). As was pointed out in Hui (1998), the steady state error was due to the under capacity of control amplitude due to the saturation non-linearity. In this responding letter, we increase the saturation level and demonstrate that even though the requirement of saturation capacity is satisfied, the given LQG controller still gives totally unsatisfactory response compared to that of the controller derived in Tyan and Bernstein (1997).



## 1. Introduction

In example 6.1 of Tyan and Bernstein (1997), we increase both saturation levels to 10.1 to satisfy the requirement given by equation (14) of Hui (1998). As we can see from figures 1–4, the response of both the LQG controller and the controller provided by Proposition 3.1 are similar to those given in Tyan and Bernstein (1997) except that the saturation non-linearity is not activated by the latter. Note that in this case, the LQG controller gains are

$$A_c = \begin{bmatrix} 1.4031e0 & -8.5595e-1 & 4.773e-1 & -8.6660e0 & -1.8339e1 \\ -2.4149e3 & -2.8768e2 & -1.4021e2 & 9.1114e3 & 3.3617e4 \\ -4.3197e4 & -4.4009e2 & -2.4217e3 & 1.6856e5 & 1.1117e5 \\ -1.0000e0 & 0 & 0 & -7.0711e1 & -7.3561e-6 \\ 0 & -1.0000e0 & 0 & -7.3651e-6 & -2.2361e2 \end{bmatrix}$$

$$B_c = \begin{bmatrix} -2.0077e-3 & 2.28903e-4 \\ -2.3967e-3 & -7.7655e-3 \\ 8.8935e-2 & 1.5503e-1 \\ 7.0711e1 & 7.3651e-6 \\ 7.3651e6 & 2.2361e2 \end{bmatrix}$$

$$C_c = \begin{bmatrix} 1.4433e1 & 1.1226e0 & 8.2991e-1 & -5.5376e1 & -1.3905e2 \\ 8.2860e0 & -1.8310e0 & 5.6151e-1 & -4.3971e1 & 1.7512e2 \end{bmatrix}$$

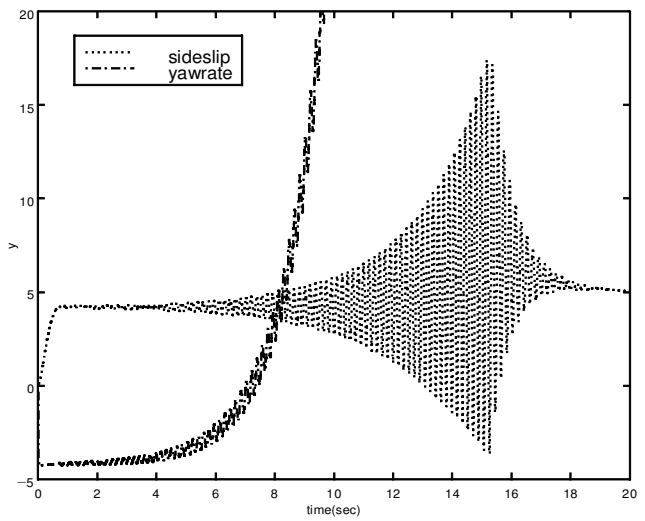


Figure 1. Output of system (6.1), (6.2) using the LQG controller for Example 6.1 of Tyan and Bernstein (1997) with amplitude saturation present.

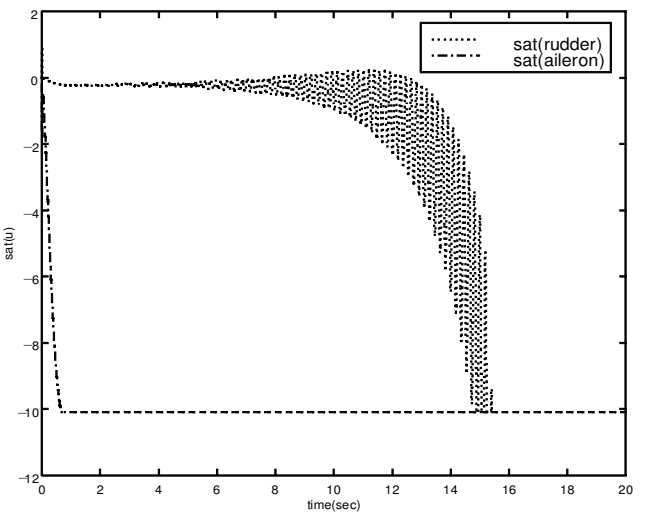


Figure 2. Saturated input $\sigma(u)$ of the LQG controller for Example 6.1 of Tyan and Bernstein (1997) with amplitude saturation present.

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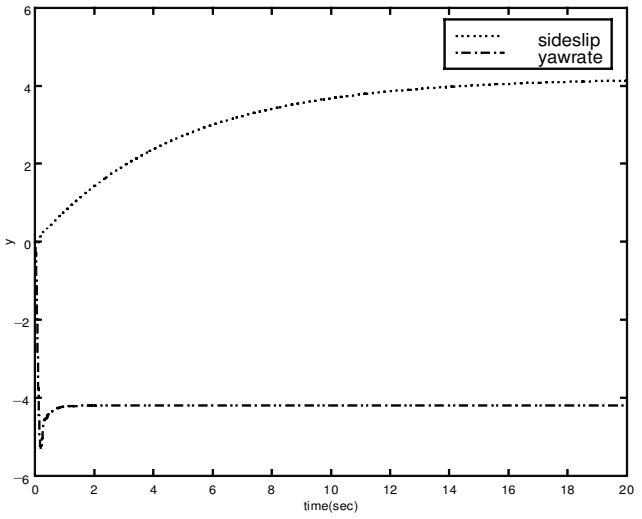


Figure 3. Response of system (6.1), (6.2) using the controller given by Proposition 3.1 for Example 6.1 of Tyan and Bernstein (1997) with amplitude saturation present.

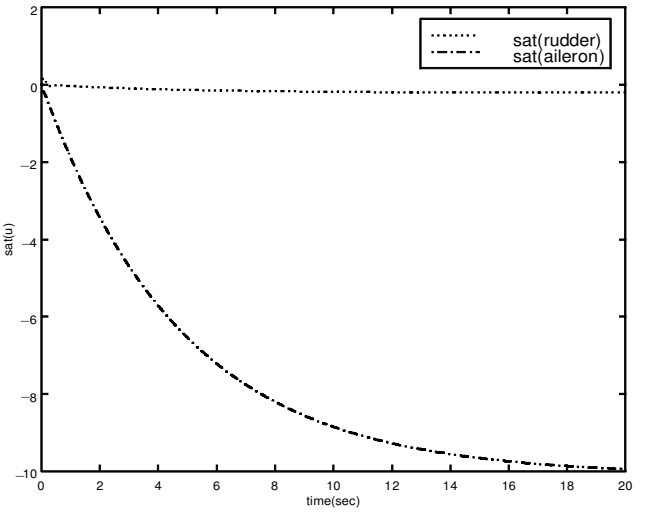


Figure 4. Saturated input $\sigma(u)$ of the controller given by Proposition 3.1 for Example 6.2 of Tyan and Bernstein (1997) with amplitude saturation present.



For Example 6.2 of Tyan and Bernstein (1997), we increase both amplitude saturation levels from 10 to 10.5, and reduce both rate saturation levels from 4 to 2.5, so that the rate saturation can be activated by the controller given by Proposition 5.1 of Tyan and Bernstein (1997), which was criticized by Hui (1998). Again, the response shown in figures 5–8 is similar to the response shown in Tyan and Bernstein (1997).

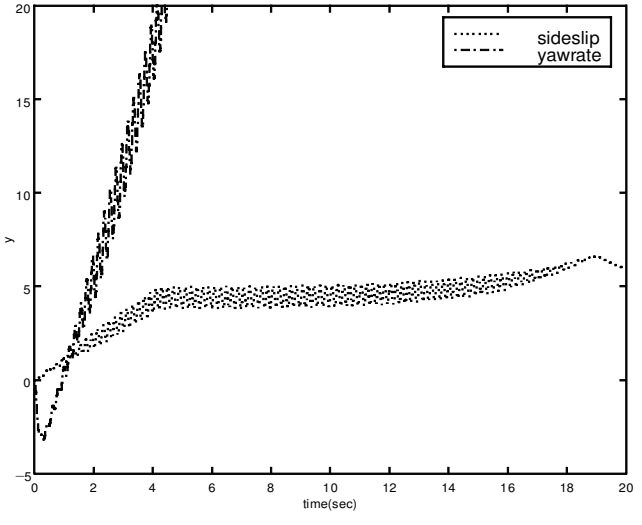


Figure 5. Output of system (6.1), (6.2) using the LQG controller for Example 6.2 of Tyan and Bernstein (1997) with amplitude saturation present.

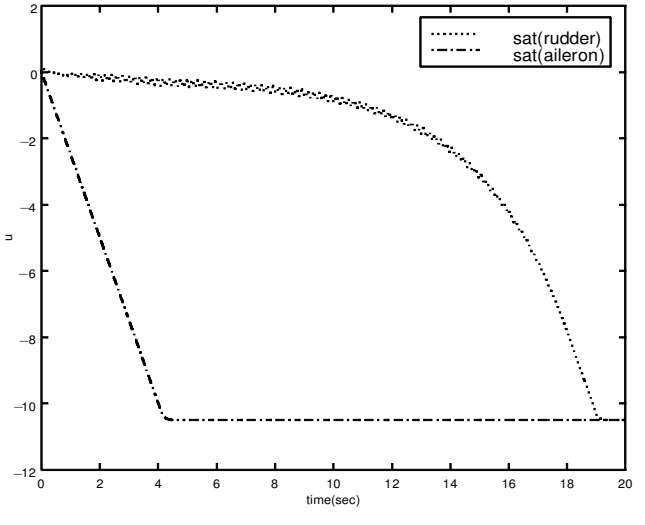


Figure 6. Saturated input $\sigma(u)$ of the LQG controller for Example 6.2 of Tyan and Bernstein (1997) with amplitude saturation present.

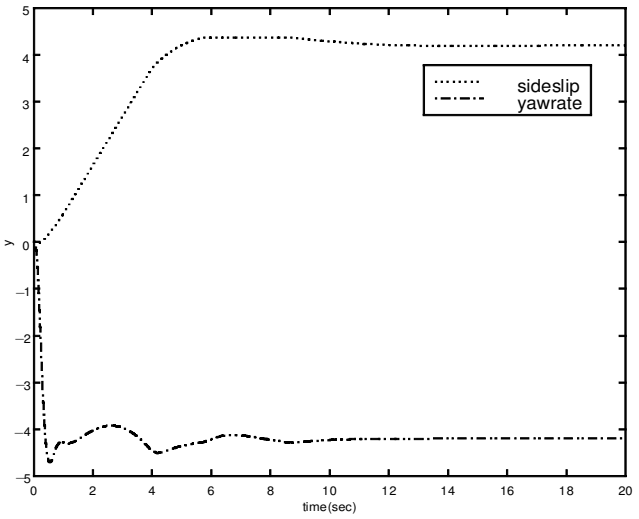


Figure 7. Response of system (6.1), (6.2) using the controller given by Proposition 5.1 for Example 6.2 of Tyan and Bernstein (1997) with amplitude saturation present.

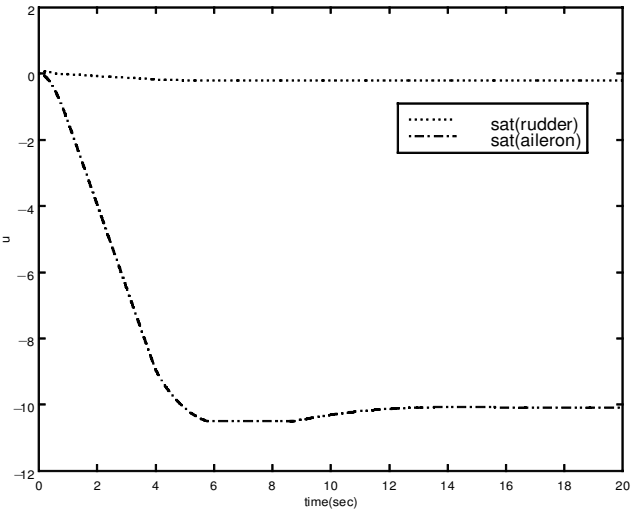


Figure 8. Saturated input $\sigma(u)$ of the controller given by Proposition 5.1 for Example 6.2 of Tyan and Bernstein (1997) with amplitude saturation present.

## 2. Conclusion

As mentioned in Tyan and Bernstein (1997) and pointed out in Hui (1998), if the saturation non-linearity and integrator are interchangeable then there will be no steady state errors. In the examples of Tyan and Bernstein (1997), a smaller saturation level was used to activate the saturation non-linearity in order to demonstrate the ability of the new controllers. Nevertheless, we thank the author of Hui (1998) for giving us the opportunity to clarify the phenomena appearing in those figures of Tyan and Bernstein (1997).

## References

HUI, K., 1998, Comments on the examples in 'Dynamic output feedback compensation for linear systems with independent amplitude and rate saturations'. *International Journal of Control,* **72**, 1227–1230.

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