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Stabilization of switched linear systems under asynchronous switching subject to admissible edge-dependent average dwell time

Key words: Asynchronous switching; Admissible edge-dependent average dwell time; Multi-Lyapunov function

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Motivation

- In recent decades, switched systems have been widely studied due to their extensive applications in practical systems.
- In fact, there is a lag between controller switching and system switching, because it takes some time to identify the system mode and apply the corresponding controller. Asynchronous switching may decrease control performance and lead to instability.
- It is difficult to determine the lag time between system switching and the switching of the corresponding controller. Hence, there is still significant research need for removing this restriction in switching signal design.

Contributions

- The switching signal is designed by combining the slow AED-ADT (SAED-ADT) method and fast AED-ADT (FAED-ADT) method, assuming that the maximum asynchronous switching delay is not known a priori.
- The constructed Lyapunov function is associated with both the system mode and controller mode.

Contributions (Cont’d)

- In the literature, it was generally assumed that the controller cannot stabilize the subsystems in asynchronous switching intervals. In this paper, we take a different approach and investigate whether the asynchronous switching controller may be able to stabilize the subsystem in asynchronous switching intervals.
- The stabilization criteria are obtained, and the corresponding algorithm is presented to determine the controller gains and to design the switching signal. In the simulations, two examples are provided to demonstrate the effectiveness of the proposed results.

Method

The effect of the lag time $d(t)$ is that the switching between the system and the controller is not synchronous (Fig. 1).

In synchronous switching intervals $[t_0, t_1)$ and $[t_m+d(t_m), t_{m+1})$, $\sigma(t)=\sigma'(t)$.

In asynchronous switching intervals $[t_m, t_m+d(t_m))$, $\sigma(t)\neq\sigma'(t)$.

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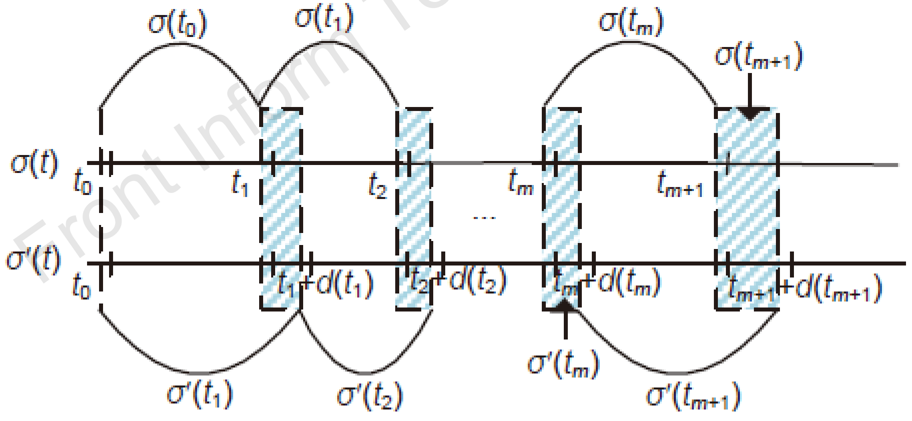
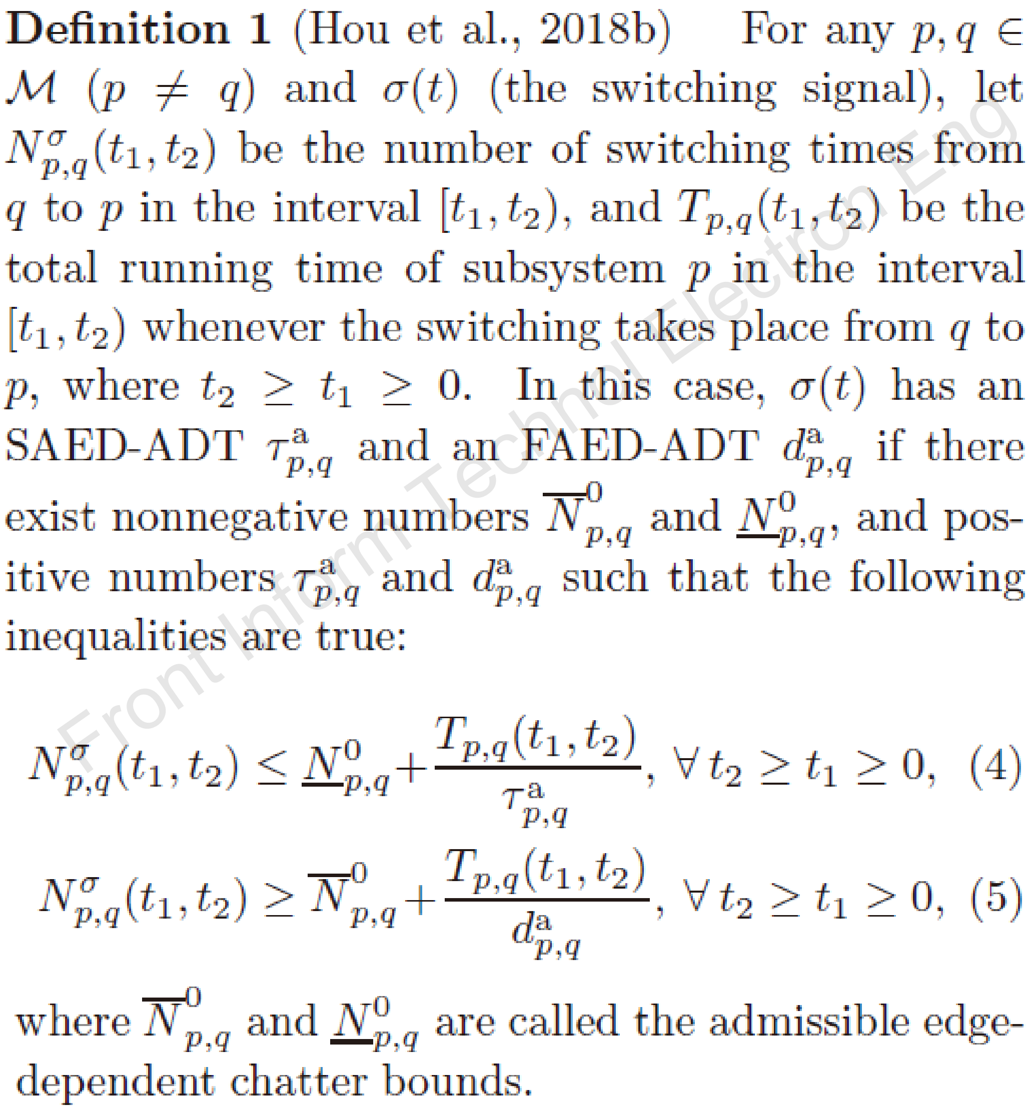


Fig. 1 Switching signals $\sigma(t)$ and $\sigma'(t)$

Method (AED-ADT, Cont’d)



Definition 1 (Hou et al., 2018b) For any $p, q \in \mathcal{M}$ $(p \neq q)$ and $\sigma(t)$ (the switching signal), let $N^{\sigma}_{p,q}(t_1, t_2)$ be the number of switching times from q to p in the interval $[t_1, t_2)$, and $T_{p,q}(t_1, t_2)$ be the total running time of subsystem p in the interval $[t_1, t_2)$ whenever the switching takes place from q to p, where $t_2 \geq t_1 \geq 0$. In this case, $\sigma(t)$ has an SAED-ADT $\tau^{\mathrm{a}}_{p,q}$ and an FAED-ADT $d^{\mathrm{a}}_{p,q}$ if there exist nonnegative numbers $\overline{N}^{0}_{p,q}$ and $\underline{N}^{0}_{p,q}$, and positive numbers $\tau^{\mathrm{a}}_{p,q}$ and $d^{\mathrm{a}}_{p,q}$ such that the following inequalities are true:

$$N^{\sigma}_{p,q}(t_1, t_2) \leq \underline{N}^{0}_{p,q} + \frac{T_{p,q}(t_1, t_2)}{\tau^{\mathrm{a}}_{p,q}}, \ \forall\, t_2 \geq t_1 \geq 0, \quad (4)$$

$$N^{\sigma}_{p,q}(t_1, t_2) \geq \overline{N}^{0}_{p,q} + \frac{T_{p,q}(t_1, t_2)}{d^{\mathrm{a}}_{p,q}}, \ \forall\, t_2 \geq t_1 \geq 0, \quad (5)$$

where $\overline{N}^{0}_{p,q}$ and $\underline{N}^{0}_{p,q}$ are called the admissible edge-dependent chatter bounds.

Major results (Example 1)

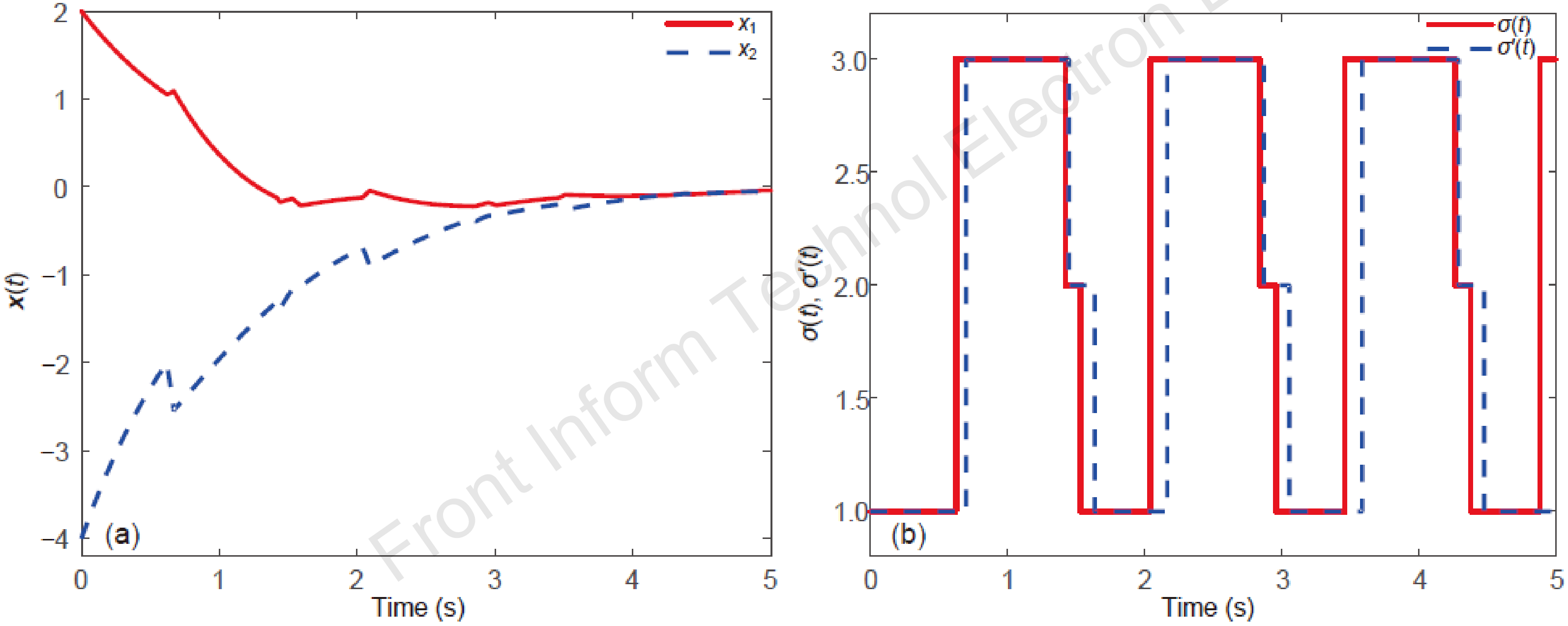


Fig. 3 Response curves of $x(t)$ (a) and switching signals $\sigma(t)$ and $\sigma'(t)$ (b) for Example 1

Major results (Example 1, Cont’d)

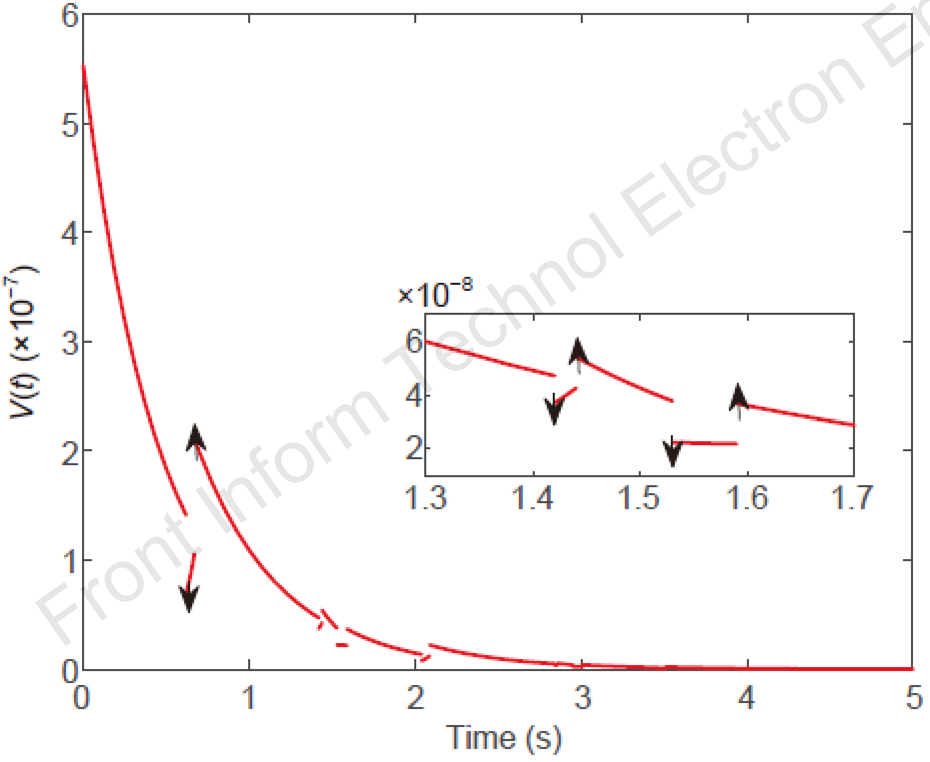


Fig. 4 Response curve of $V(t)$ for Example 1

Major results (Example 2)

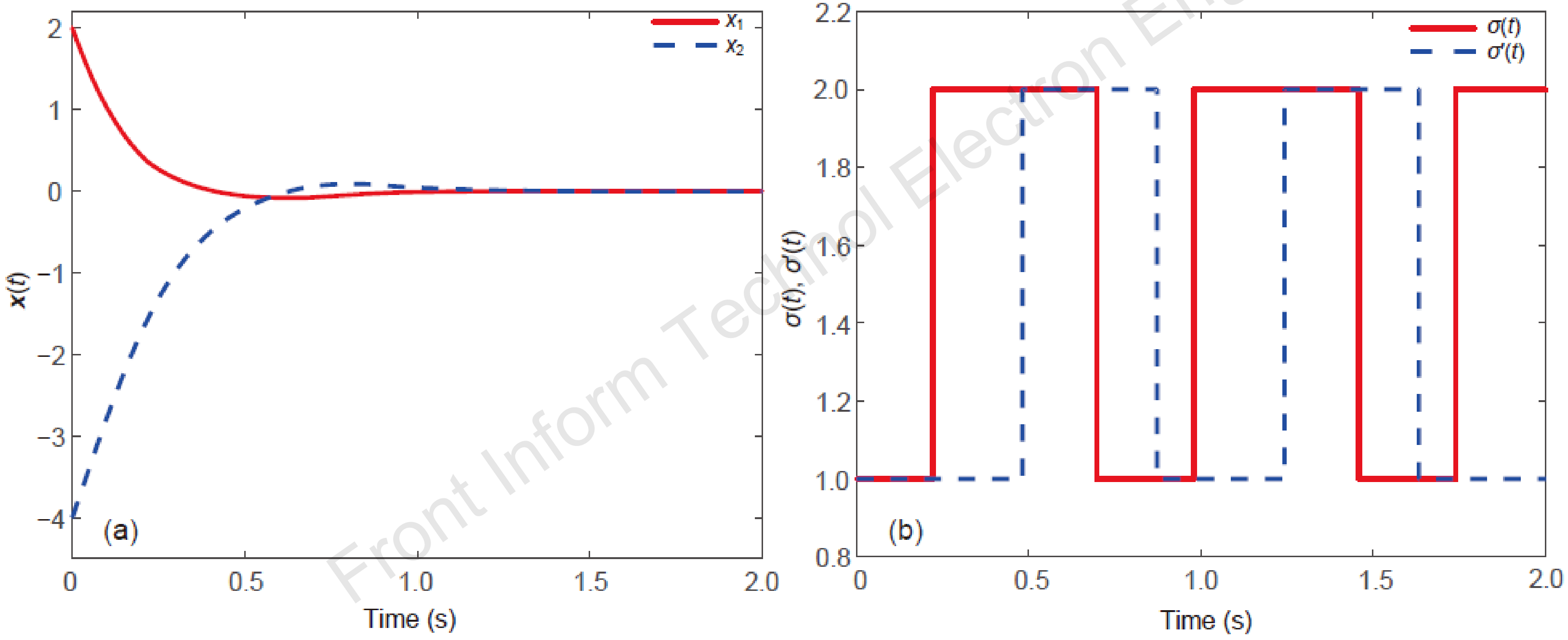


Fig. 6 Response curves of $x(t)$ (a) and switching signals $\sigma(t)$ and $\sigma'(t)$ (b) for Example 2

Major results (Example 2, Cont'd)

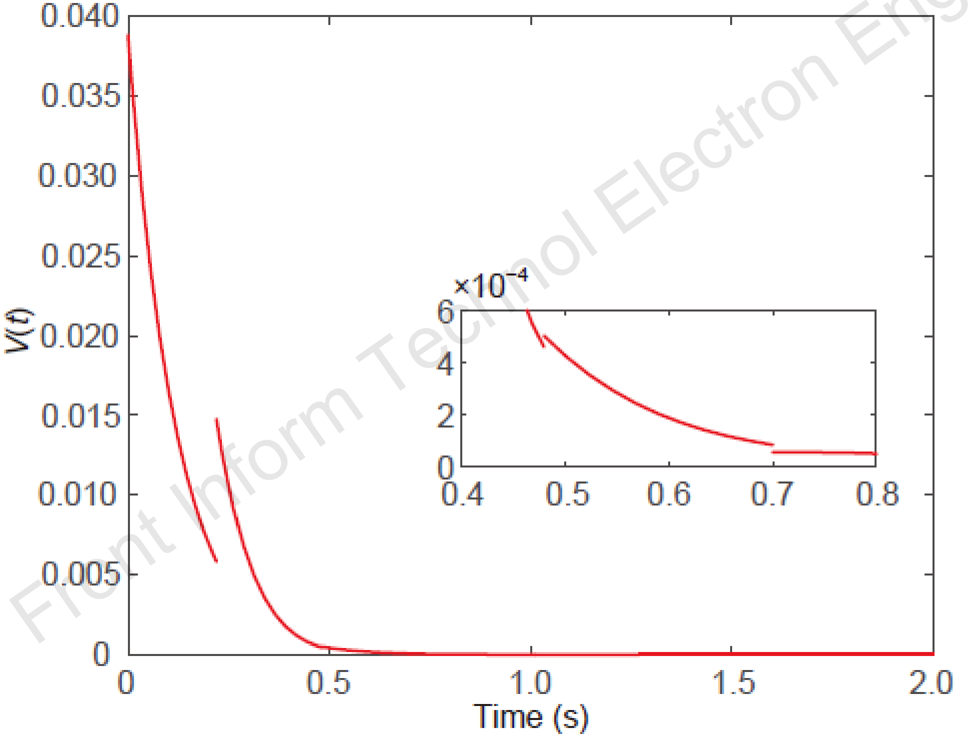


Fig. 7 Response curves of $V(t)$ for Example 2

Conclusions

- This study presents the research on the problem of stabilizing switched linear systems under asynchronous switching.
- SAED-ADT switching and FAED-ADT switching have been applied in designing the switching signal.
- Using the multi-Lyapunov function method, stabilization conditions have been given for switched linear systems.
- An algorithm has been provided to determine the controller gains and to design the switching signals.
- Finally, two examples have been given to show the effectiveness of the proposed results.

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