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Recursive filtering of multi-rate cyber-physical systems with unknown inputs under adaptive event-triggered mechanisms

Key words: Cyber-physical systems; Multi-rate; Joint recursive filtering; Adaptive event-triggered mechanisms; Unknown inputs

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Abstract

The purpose of this paper is to develop a joint recursive filtering scheme that estimates both unknown inputs and system states for multi-rate cyber-physical systems (CPSs) with unknown inputs. In cyberspace, the information transmission between the local joint filter and the sensors is governed by an adaptive event-triggered strategy. Furthermore, the desired parameters of joint filters are determined by a set of algebraic matrix equations in a recursive way, and a sufficient condition verifying the boundedness of filtering error covariance is found by resorting to some algebraic operations. A state fusion estimation scheme that uses local state estimation is proposed based on the covariance intersection (CI) based fusion conception. Lastly, an illustrative example demonstrates the effectiveness of the proposed adaptive event-triggered recursive filtering algorithm.

Motivation

- A joint recursive filter with an adaptive event-triggered mechanism is constructed to simultaneously estimate unknown inputs and system states.
- The ideal filter gains are obtained by recursively solving two algebraic matrix equations using the lifting technique.
- A sufficient condition is derived using classical algebraic operations to verify the boundedness of the filtering error covariance.
- The filtering performance is enhanced by employing a famous state fusion scheme in the covariance intersection (CI) based fusion conception.

Main idea

- We identify a sufficient condition that guarantees the boundedness of the upper limit of the obtained filtering error covariance.

- The CI fusion estimation scheme is adopted, considering the objectives of avoiding the calculation of cross-covariance and ensuring the robustness of state estimation.

An illustrative example

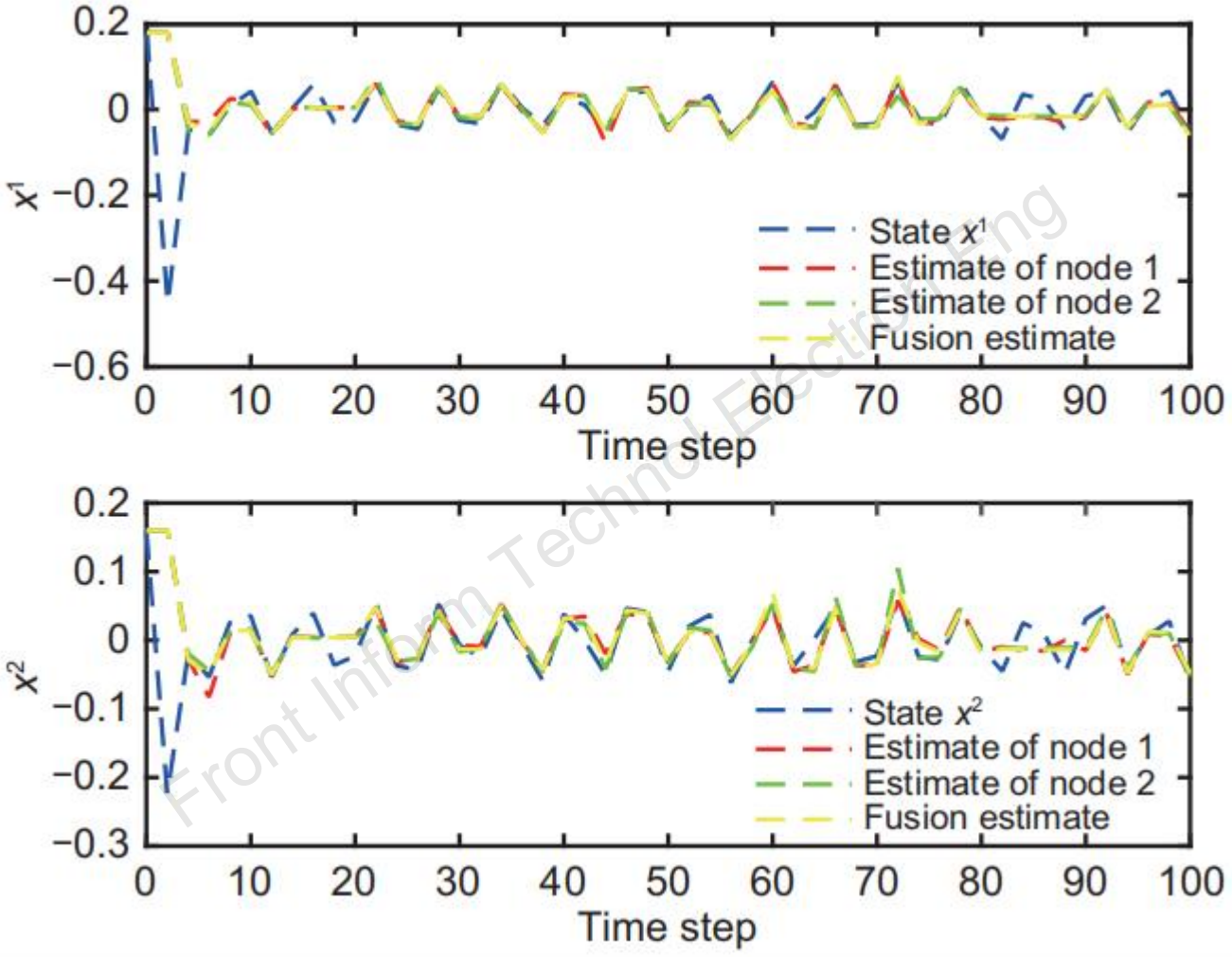

Fig. 1 State estimates of x^1 and x^2 and their fusion estimates

An illustrative example

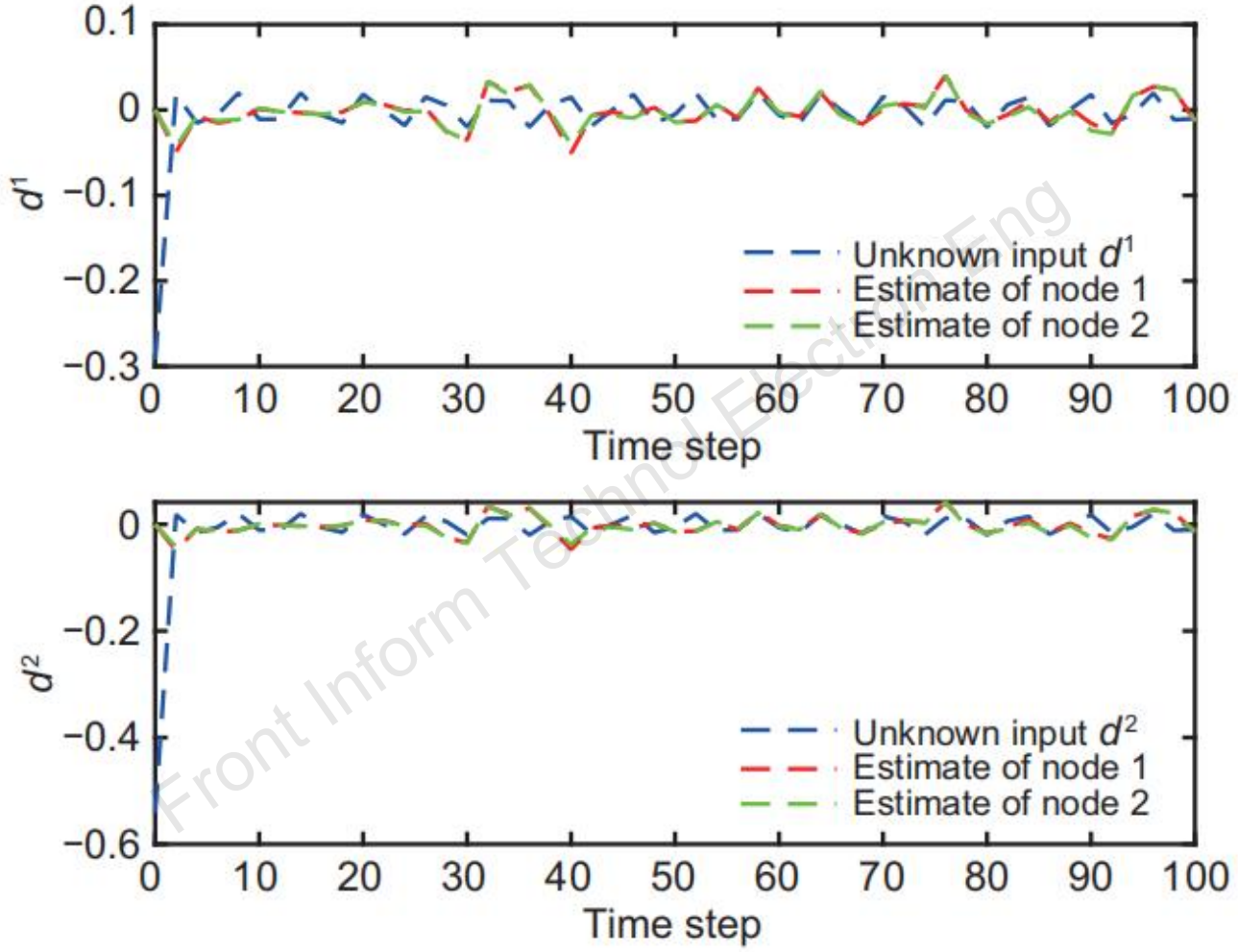

Fig. 2 Unknown inputs and their estimates

An illustrative example

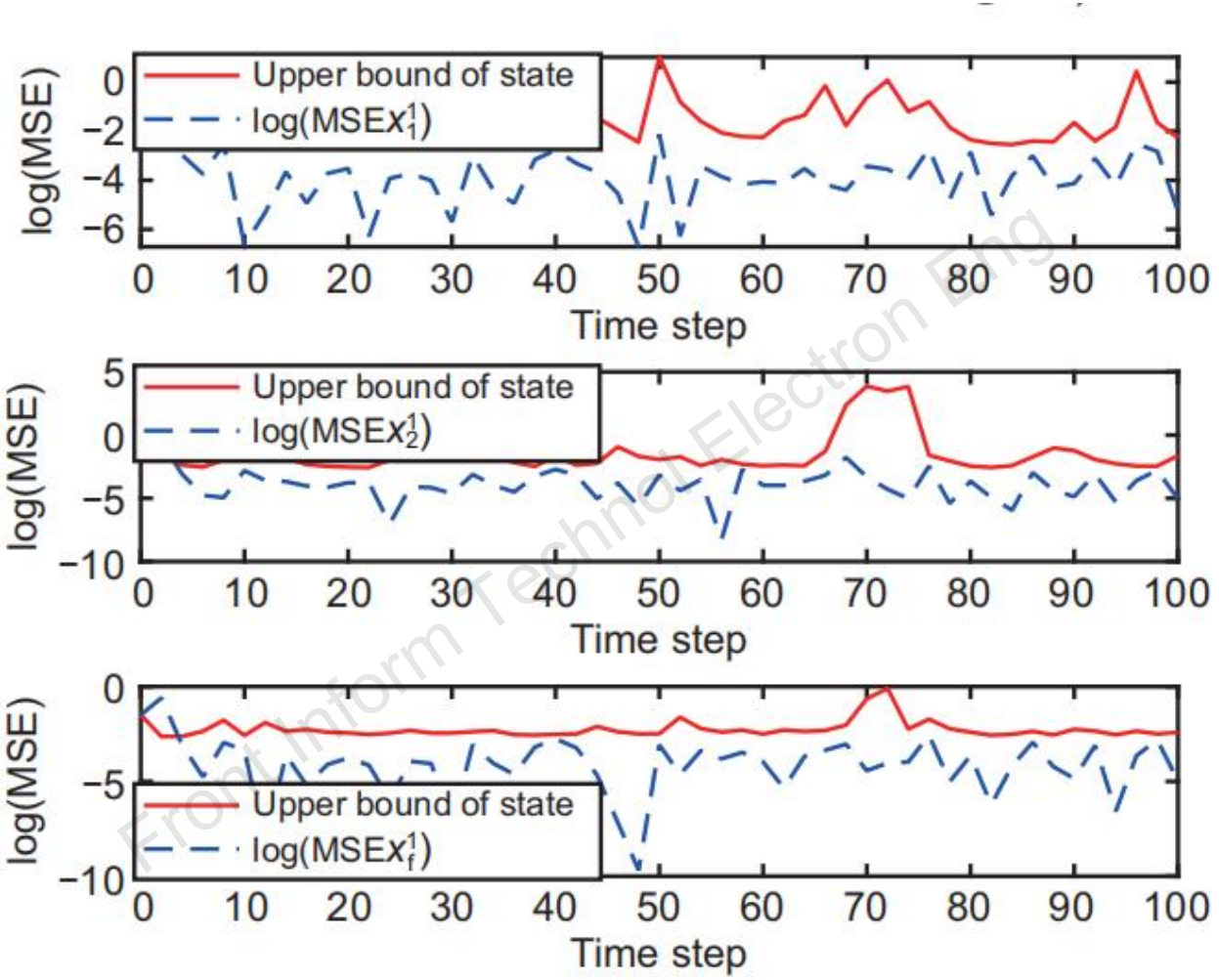

Fig. 3 Upper bound of the trace of filtering error covariance of system state x^1

An illustrative example

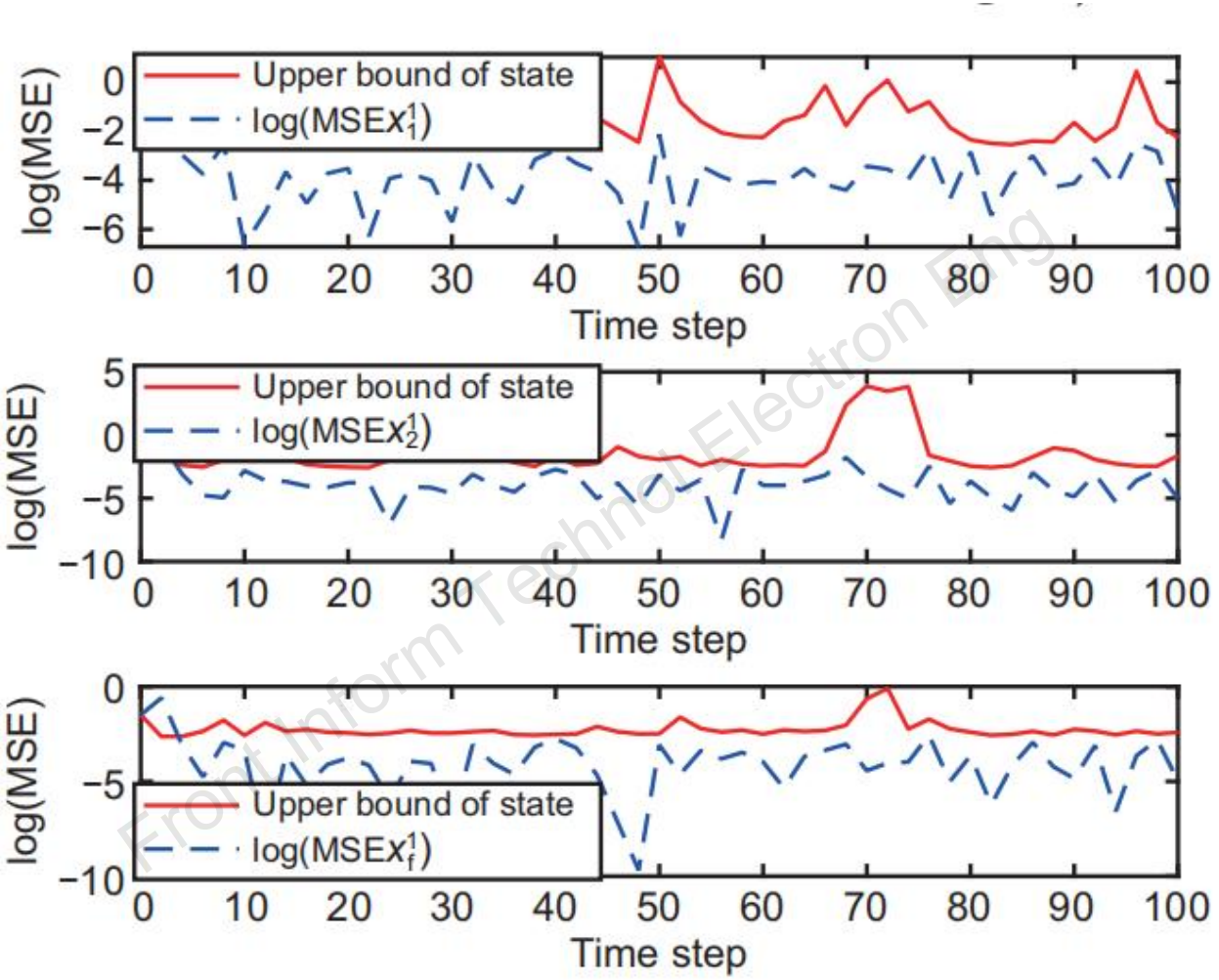

Fig. 6 Upper bound of the trace of filtering error covariance of unknown inputs

An illustrative example

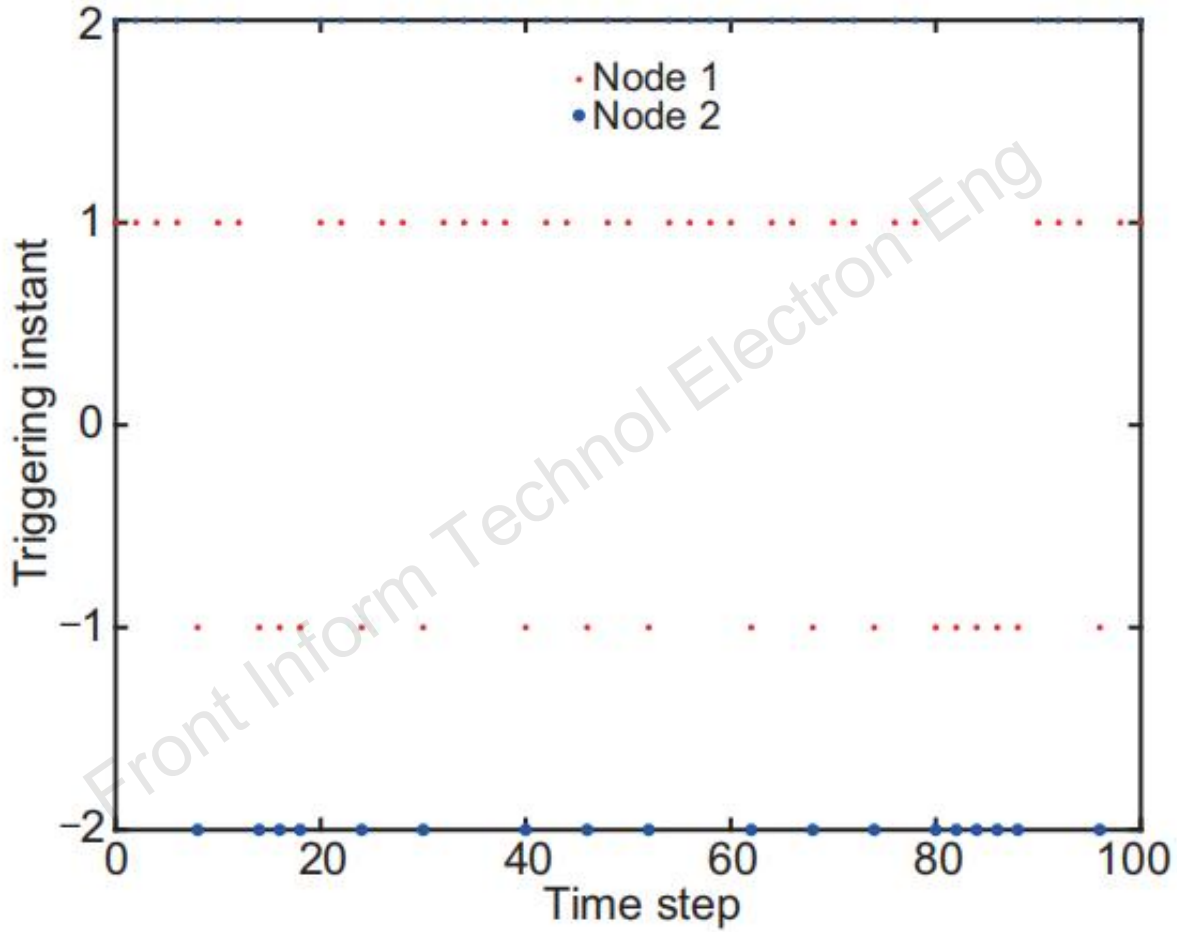

Fig. 7 Triggering instants

Conclusions

To reduce communication costs, we use a dynamic-event-based strategy to determine when a sensor node sends its measurements to neighbors. The system operation consists of two rates, namely the system state update rate (i.e., the measured sampling rate) and the measuring transmission rate (i.e., the estimated output rate). Our goal is to set enough conditions to guarantee an upper bound on the filter error covariance. We use a specific set of recursions to obtain the parameters of the desired filter. On this basis, a state fusion estimation scheme based on the CI-fusion method is proposed using local state estimation. Finally, we verify the effectiveness of the proposed adaptive event-triggered recursive filtering algorithm through an example.

Future outlook

Further research topics include extending this algorithm to other control or filtering mechanisms with time-varying topologies. Additionally, the exploration of alternative communication protocols such as the Round-Robin protocol, the weighted Try-Once-Discard protocol, and the random communication protocol is being investigated, with these being anticipated to serve as possible replacements for dynamic event-triggered mechanisms.