Yajing MA, Yuan WANG, Zhanjie LI, Xiangpeng XIE, 2024. Event-triggered finite-time command-filtered tracking control for nonlinear time-delay cyber physical systems against cyber attacks. *Frontiers of Information Technology & Electronic Engineering*, 25(2):225-236. https://doi.org/10.1631/FITEE.2300613

Event-triggered finite-time command-filtered tracking control for nonlinear time-delay cyber physical systems against cyber attacks

Front Inform Technol Electron Eng

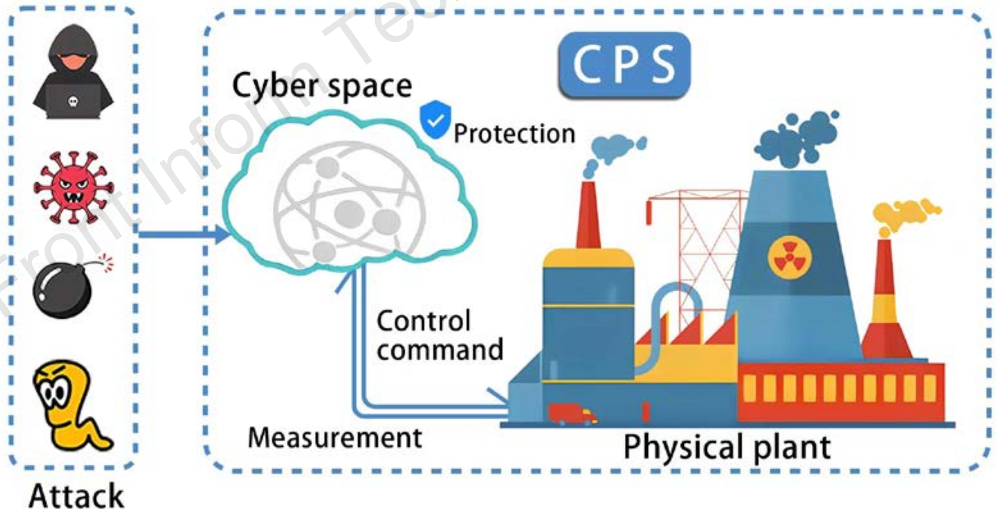
Key words: Cyber physical systems; Finite-time tracking; Event-triggered; Command-filtered control; Attacks

Corresponding author: Zhanjie LI
E-mail: zhanjie_lii@126.com
ORCID: https://orcid.org/0000-0002-3902-1453

Motivation

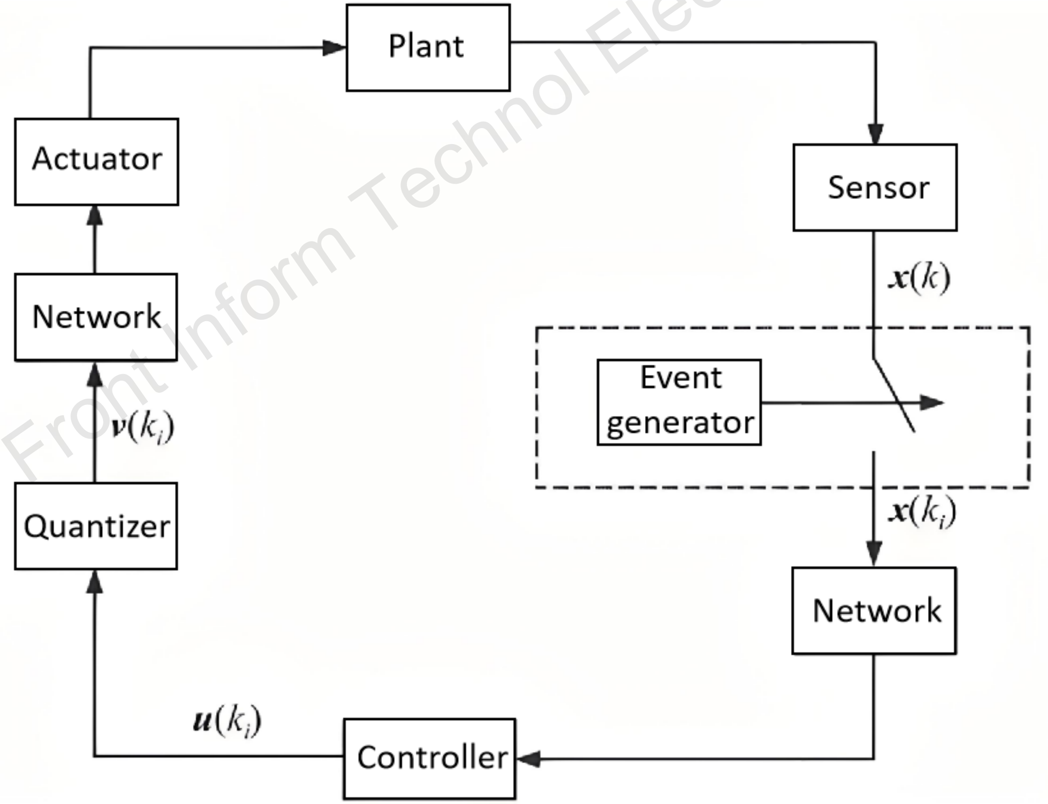
- Cyber physical systems (CPSs), where physical systems are tightly integrated with cyber components via the network communication channels, have been widely used. Considering the fact that CPSs are vulnerable to cyber attacks, security issues are one of the main concerns.

Front Inform Technol Electron Eng



Motivation

- In the network environment, a large amount of redundant data generated by continuous data transmission will bring unnecessary load to network communication. How to reduce the waste of communication resources is another issue worthy of attention.



Front Inform Technol Electron Eng

Method

Time-delay CPSs

$$\begin{cases} \dot{x}_i(t) = x_{i+1}(t) + f_i(X(t)) + g_i(\bar{x}_{i,\tau(t)}(t)) + d_i(t), \\ \dot{x}_n(t) = u(t) + f_n(X(t)) + g_n(\bar{x}_{n,\tau(t)}(t)) + d_n(t), \end{cases}$$

↓

Deception attack

$$\begin{cases} \breve{x}_1(t) = x_1(t) + \lambda_1(t), \\ \breve{x}_i(t) = x_i(t) + \lambda_i(t), \end{cases}$$

↓

Coordinate conversion

$$\begin{cases} \breve{z}_1 = \breve{x}_1 - \frac{1}{\gamma_1} y_{\mathrm{d}}, \\ \breve{z}_i = \breve{x}_i - \theta_{i-1}, \end{cases}$$

↓

Filtered signal

$$\begin{cases} D^\alpha \lambda_{1,i-1} = \Gamma_{1,i-1}, \\ \quad \Gamma_{1,i-1} = -\alpha_{1,i-1}(\lambda_{1,i-1} - \hbar_{i-1})^{\beta_1} \\ \qquad\qquad - \alpha_{2,i-1}(\lambda_{1,i-1} - \hbar_{i-1})^{\beta_2} + \lambda_{2,i-1}, \\ D^\alpha \lambda_{2,i-1} = -\alpha_{3,i-1}(\lambda_{1,i-1} - \hbar_{i-1})^{\beta_3}, \end{cases}$$

↓

Compensator

$$\begin{cases} \dot{\psi}_i = -a_{1,i}\psi_i - a_{2,i}\psi_i^{2q-1} - H\psi_i + \epsilon_i, \\ \dot{\psi}_n = -a_{1,n}\psi_n - a_{2,n}\psi_n^{2q-1}, \end{cases}$$

Front Inform Technol Electron Eng

Method

Virtual controller

$$
\left\{
\begin{aligned}
\hbar_n &= -k_n \check{z}_n + N(\xi_n)\bar{\hbar}_n + \psi_n, \\
\bar{\hbar}_n &= \frac{\check{z}_n \hat{\eta}_n \mathit{\Pi}_n^{\mathrm{T}}(\check{\Delta}_n^*)\mathit{\Pi}_n(\check{\Delta}_n^*)}{2\delta_n^2} + c_n \check{z}_n + \frac{\hat{\Lambda}_n \check{z}_n}{\sqrt{\check{z}_n^2 + \varpi_n^2}}, \\
\dot{\hat{\eta}}_n &= \frac{\check{z}_n^2 \mathit{\Pi}_n^{\mathrm{T}}(\check{\Delta}_n^*)\mathit{\Pi}_n(\check{\Delta}_n^*)}{2\delta_n^2} - \rho_{n1}\hat{\eta}_n, \\
\dot{\hat{\Lambda}}_n &= \frac{\check{z}_n^2}{\sqrt{\check{z}_n^2 + \varpi_n^2}} - \rho_{n2}\hat{\Lambda}_n,
\end{aligned}
\right.
$$

Actual controller

$$
\left\{
\begin{aligned}
v &= N(\xi_{n+1})\bar{\hbar}_{n+1}, \\
\bar{\hbar}_{n+1} &= \check{z}_n \hat{\chi} \hbar_n^2, \\
\dot{\hat{\chi}} &= \check{z}_n^2 \hbar_n^2 - \rho_{(n+1)1}\hat{\chi},
\end{aligned}
\right.
$$

Triggering condition

$$
\left\{
\begin{aligned}
& u(t) = v(t_k), \forall t \in [t_k, t_{k+1}), \\
& t_{k+1} = \inf\{t \in \mathbb{R} \mid |e(t)| \geq \bar{k}|u(t)| + m\},
\end{aligned}
\right.
$$

Front Inform Technol Electron Eng

Major results

Filtered signal
Compensator

➕

Actual controller
Triggering condition

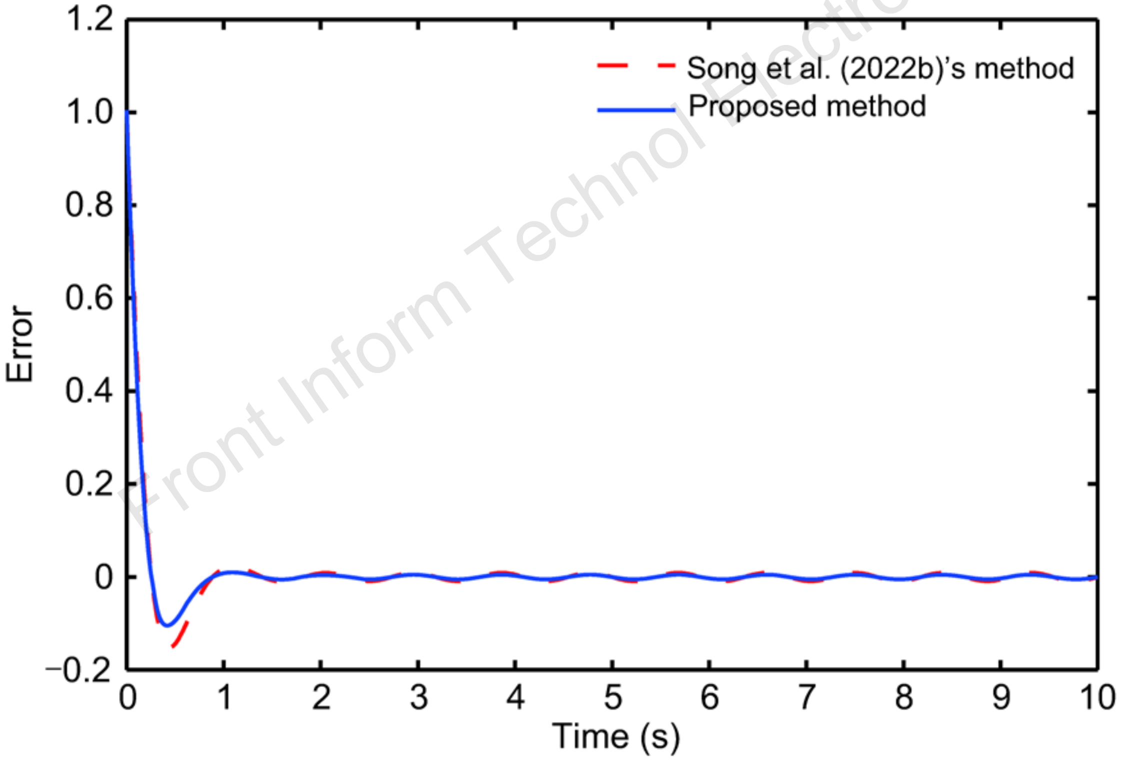
$$T_f \le \max\left\{\frac{1}{a\mu_1(1-q)}\ln\frac{a\mu_1 V_n^{1-q}(0)+\mu_2}{\mu_2}, \frac{1}{\mu_1(1-q)}\ln\frac{\mu_1 V_n^{1-q}(0)+a\mu_2}{a\mu_2}\right\}.$$

Finite-time tracking of CPSs
Reducing communication resources

Front Inform Technol Electron Eng

Major results

The proposed method guarantees a good finite-time tracking behavior with a smaller tracking error.



Front Inform Technol Electron Eng

Tracking error

Conclusions

- The problem of finite-time tracking control is addressed for the event-triggered nonlinear CPSs with deception attacks.
- A new coordinate conversion technique is proposed to deal with the influence of attack gain.
- The modified fractional-order command filtering (FOCF) recursive process is introduced to address the complexity explosion issue.
- The future research focuses on the extension to a class of CPSs with mismatched disturbance and a stochastic phenomenon.

Front Inform Technol Electron Eng

References

[1] Song S, Park JH, Zhang B, et al. Adaptive NN finite-time resilient control for nonlinear time-delay systems with unknown false data injection and actuator faults. IEEE Transactions on Neural Networks and Learning Systems, 2021, 33(10): 5416-5428.

[2] Chen WD, Li YX, Liu L, et al. Nussbaum-based adaptive fault-tolerant control for nonlinear CPSs with deception attacks: a new coordinate transformation technology. IEEE Transactions on Cybernetics, 2024, 54(2): 1212-1222.

[3] Li Z, Zhao J. Resilient adaptive control of switched nonlinear cyber-physical systems under uncertain deception attacks. Information Sciences, 2021, 543: 398-409.

[4] Wei Y, Luo J, Yan H, et al. Event-triggered adaptive finite-time control for nonlinear systems under asymmetric time-varying state constraints. Frontiers of Information Technology & Electronic Engineering, 2021, 22(12): 1610-1624.

[5] Li M, Li S, Ahn CK, et al. Adaptive fuzzy event-triggered command-filtered control for nonlinear time-delay systems. IEEE Transactions on Fuzzy Systems, 2021, 30(4): 1025-1035.

Front Inform Technol Electron Eng