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

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

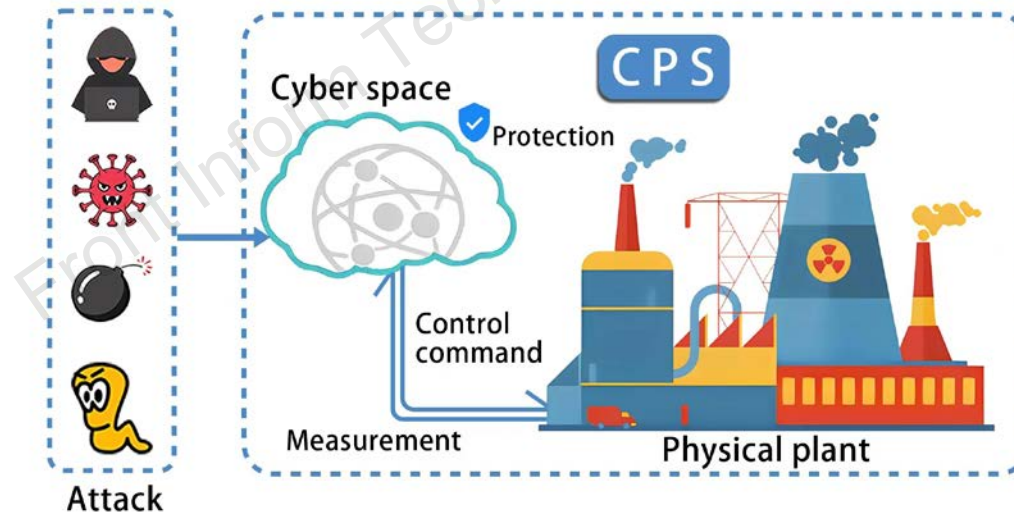
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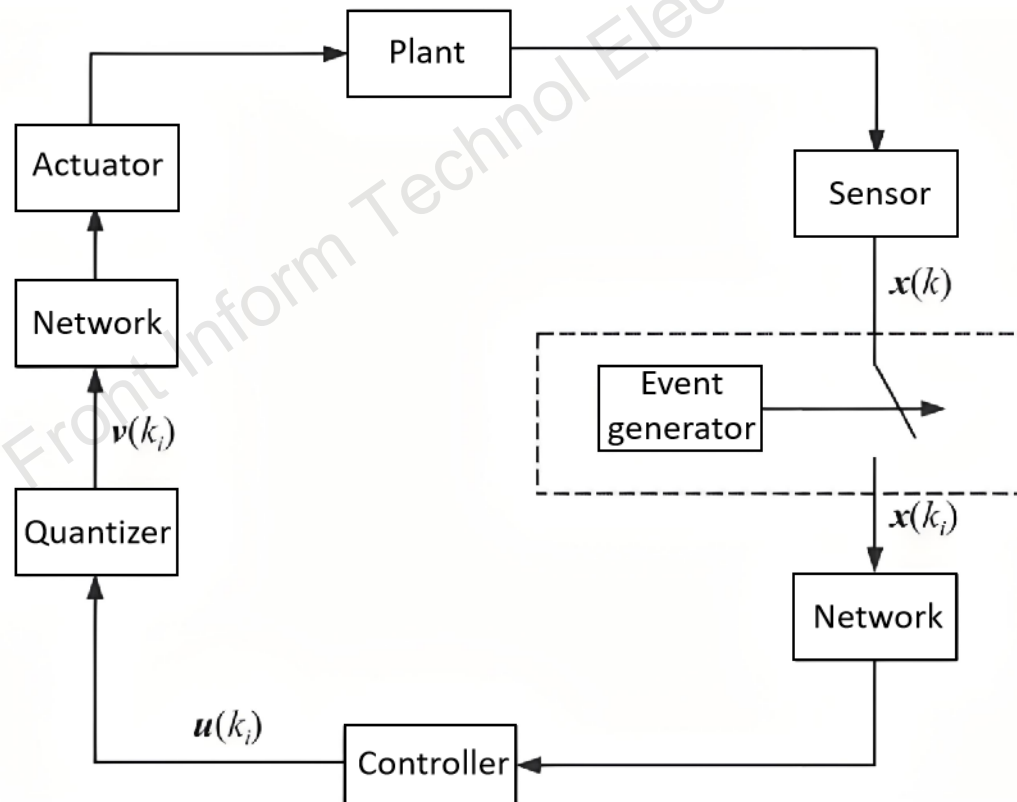
Motivation

- 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.



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.



Method

Time-delay CPSs



Deception attack



Coordinate conversion



Filtered signal



Compensator

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

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

$$\begin{cases} \check{z}_1 = \check{x}_1 - \frac{1}{\gamma_1} y_d, \\ \check{z}_i = \check{x}_i - \theta_{i-1}, \end{cases}$$

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

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

Method

Virtual controller



Actual controller



Triggering condition

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

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

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

Major results

Filtered signal
Compensator

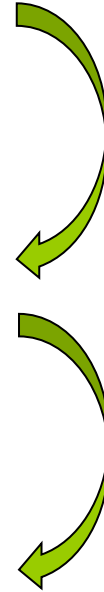


Actual controller
Triggering condition

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

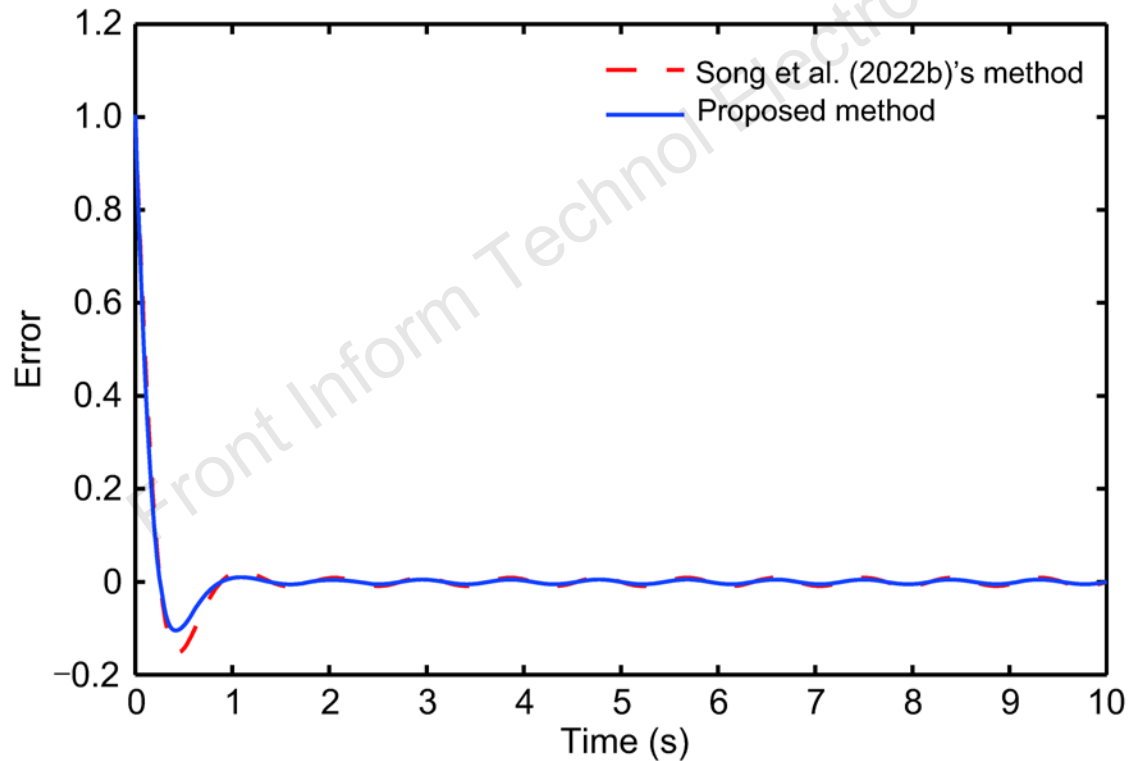
Finite-time tracking of CPSs

Reducing communication resources



Major results

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



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.

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