Control of Cyber-Robotic Systems
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Event-triggered trajectory tracking for nonlinear systems

Objective: Design event-triggered control for trajectory tracking, based on a continuous time control.

Event based sampling and control as an alternative to Time based sampling and control:

Advantages of event-based control:
- Reduced costs and energy consumption.
- Reduced use of computational resources.
- More tasks can be performed.
- Better utilization of communication resources.

Given:
- Nonlinear system: \( \dot{x} = f(x) + u(x, x_d(t), v(t)) \), \( x \in \mathbb{R}^n \)
- Reference trajectory: \( x_d(t) \)
- Continuous time control: \( u(x, q, t) = A(p, q, t) \)
- Lyapunov function: \( V(x - x_d(t)) \)

System with event based control:
\[ \dot{x} = f(z) + u(z(t), x_d(t), v(t)) \]
for \( t \in [t_i, t_{i+1}) \), \( i \in \{0, 1, 2, \ldots \} \)
- Trajectory tracking error at time \( t \): \( e(t) \)
- Control update rule

Control update rule:
- If \( ||e|| < \tau \) Control not updated
- If \( ||e|| \geq \tau \) Control updated when \( P||e|| \geq \sigma(||e||) \)

where, \( 0 < \sigma < 1 \)

Example: \( \dot{x}_1 = x_2 \)
Double integrator: \( \dot{x}_2 = u \)

Result:
Update control when:
\( P||e|| \geq \sigma(||e||) \), where, \( 0 < \sigma < 1 \), for any \( r > 0 \)

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Control of Robotic Manipulators under Input / Output Delays

Objective: Design algorithms to stabilize a robotic manipulator system with input/output (constant or time-varying) delays.

System with constant delays:
\[ \dot{q}(t) = \frac{1}{\tau_1}(q(t) - \hat{q}(t)) \]
\[ \dot{\dot{q}}(t) = \frac{1}{\tau_2}(\dot{q}(t) - \hat{\dot{q}}(t)) \]

Dynamics of the robotic manipulator:
\[ \dot{q}(t) + C(q, \dot{q}, \ddot{q}) = -\tau_1 + \tau_2 \]

Using Scattering Transformation

System with time-varying delays:
\[ \dot{q}(t) = \frac{1}{\tau_1}(q(t) - \hat{q}(t)) \]
\[ \dot{\dot{q}}(t) = \frac{1}{\tau_2}(\dot{q}(t) - \hat{\dot{q}}(t)) \]

Controller dynamics:
\[ \dot{q}(t) = u(t) = \dot{q}(t) - K(q(t) - \hat{q}(t)) \]

Estimation of unknown parameters

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