Control of Cyber-Robotic Systems

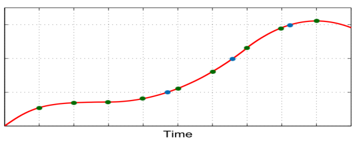
Yen-Chen Liu, Pavan Tallapragada, Nikhil Chopra

ISR@25 The Institute for Systems Research, University of Maryland, A. James Clark School of Engineering

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: $x_d(t) \in \mathbb{R}^n$
- Bounds on: $x_d(t)$ and $\dot{x}_d(t)$
- Continuous time control: $u(p, q, s) = A[p, q, s]^T$
- Lyapunov function: $V(x - x_d(t))$

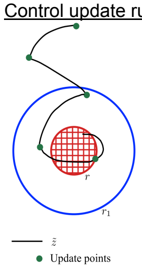
System with event based control:

$$\dot{z} = f(z) + u(z(t_i), x_d(t_i), v(t_i))$$

$$\text{for } t \in [t_i, t_{i+1}),\ i \in \{0, 1, 2, ...\}$$

- Trajectory tracking error at time t : $\tilde{z}(t)$
- Measurement error in tracking error and reference trajectory at time t : $\bar{e}(t)$
- Control update rule

Control update rule:



IF

If $\|\tilde{z}\| < r$ Control not updated

If $\|\tilde{z}\| \geq r$ Control updated when $P\|\bar{e}\| \geq \sigma g(\|\tilde{z}\|)$, where, $0 < \sigma < 1$

$P,\ g(.),\ r,$ and r_1 determined by system properties and the Lyapunov function

THEN

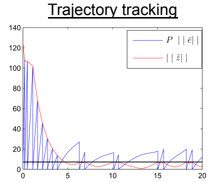
(i) Tracking error is globally uniformly ultimately bounded.
(ii) Inter-update times are lower bounded (no accumulation of update times).

Example: Double integrator: $\dot{x}_1 = x_2$, $\dot{x}_2 = u$

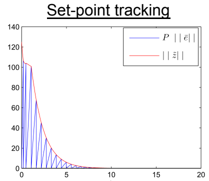
Result: Update control when:

$$P\|\bar{e}\| \geq \sigma\|\tilde{z}\|,\ \text{where, } 0 < \sigma < 1,\ \text{for any } r > 0$$

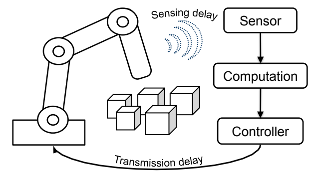
Trajectory tracking



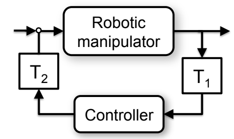
Set-point tracking



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*.



Controller dynamics

$$\begin{cases} \dot{x}_c = u_c = \dot{q} \\ y_c = K_P u_c + K_I(x_c - q_d) \end{cases}$$

Dynamics of the robotic manipulator

$$M(q)\ddot{q} + C(q, \dot{q})\dot{q} = -\tau_s + \tau_e = \tau_t$$

Constant delays

Scattering representation

$$v_1 = \frac{1}{\sqrt{2b}}(\tau_s + b\dot{q})\ ;\ z_1 = \frac{1}{\sqrt{2b}}(\tau_s - b\dot{q})$$

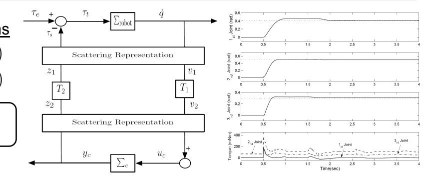
$$v_2 = \frac{1}{\sqrt{2b}}(y_c + bu_c);\ z_2 = \frac{1}{\sqrt{2b}}(y_c - bu_c)$$

Transmission equations

$$z_1(t) = z_2(t - T_2)$$

$$v_2(t) = v_1(t - T_1)$$

System with constant delays + Scattering Transformation ⇒ Stable System



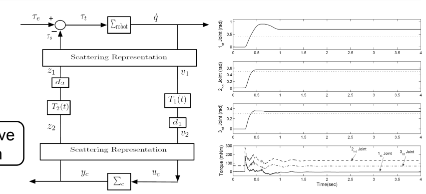
Time-varying delays

Assumption $0 < T_i(t) \leq T_{Mi} < \infty$ with $\dot{T}_i(t) \leq \bar{T}_i < 1,\quad i = 1, 2$

Define gains dependent on the maximum rate of change of delay $d_1^2 < (1 - \bar{T}_1)$ and $d_2^2 < (1 - \bar{T}_2)$

Using Scattering Transformation

System with time-varying delays + Scattering Transformation ⇒ Not able to achieve desired position



Two Loop Architecture

Assume there exists innate dissipation in the system.

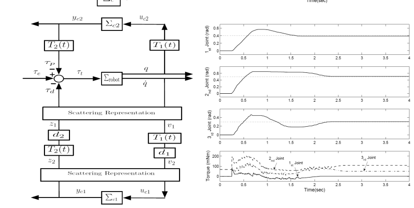
$$M(q)\ddot{q} + C(q, \dot{q})\dot{q} + B_n\dot{q} = -\tau_s + \tau_e = \tau_t$$

Given the controllers as

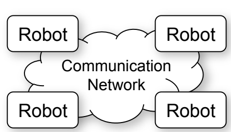
$$y_{c1} = K_d u_{c1} \qquad y_{c2} = K(q(t - T_1(t)) - q_d))$$

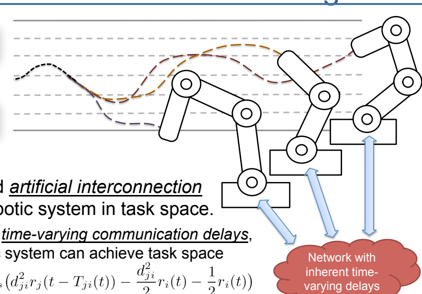
If the controller gains satisfy the condition $(B_n + K_d) \geq KT_M$ then $\dot{q}$ and $(q(t - T_1(t) - T_2(t)) - q_d)$ are asymptotically stable.

Experimental results show that the system with time-varying delays is stable with **good tracking performance.**



Task Space Synchronization of Heterogeneous Robots





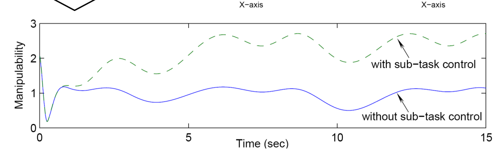
Objective

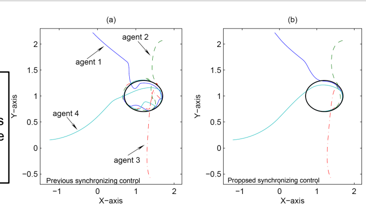
Design a *control scheme* and *artificial interconnection* to synchronize a group of robotic system in task space.

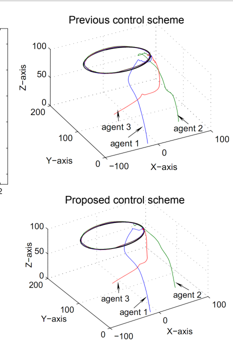
Under *dynamic uncertainties* and *time-varying communication delays*, networked heterogeneous robotic system can achieve task space synchronization on balanced graphs.

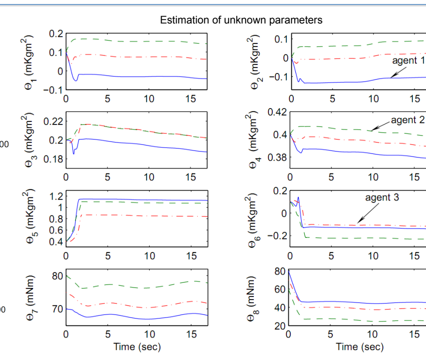
$$\tau_i(t) = \sum_{j \in \mathcal{N}_i} K_s(d_{ji}^2 r_j(t - T_{ji}(t)) - \frac{d_{ji}^2}{2} r_i(t) - \frac{1}{2} r_i(t))$$

Convergence of sub-task control for redundant manipulators is guaranteed under the proposed control scheme.









This work was supported by the NSF Grant 0931661 and the Minta Martin Fund.