Adaptive Tracking and Parameter Identification

Michael Malisoff

Basic Problem Formulation

Consider a system of differential equations

$$\dot{\xi} = f(\xi, P, u) \tag{1}$$

with a vector P of unknown constant parameters and functions ξ_R and u_R such that $\dot{\xi}_R(t) = f(\xi_R(t), P, u_R(t))$ for all $t \geq 0$.

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Problem: Find $u(\xi, \hat{P})$ and a system of differential equations

$$\dot{\hat{P}} = g(\xi, \hat{P}) \tag{2}$$

such that with the control choice $u(\xi, \hat{P})$ in (1), all solutions $Y = (\tilde{\xi}, \tilde{P}) = (\xi - \xi_R, P - \hat{P})$ converge to 0 as $t \to +\infty$.

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This requires finding a control function u and a vector field g.

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Lavretsky-Wise, Narendra-Annaswamy, Sastry-Bodson,...

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Basar, Cortes, Dixon, Duncan, Krstic, Morse, Ortega, Yucelen,...

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Flight control, mechanical systems, robotics,...

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ZP. Jiang, E. Justh, P. Krishnaprasad, V. Lumelsky, A. Stepanov

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Strict decay: there is a continuous positive definite α such that $\frac{d}{dt}V(Y(t)) \leq -\alpha(Y(t))$ along all solutions of system.

Gyroscopic Model (with Georgia Tech)

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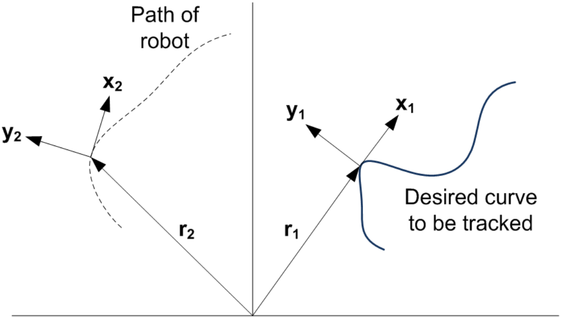
Simpler 2D case: Boundary following with gyroscopic control.



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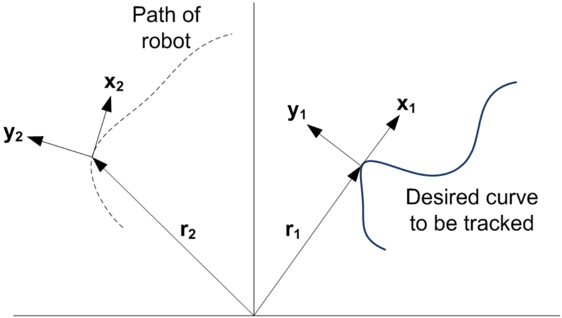

Zhang-Justh-Krishnaprasad, IEEE-CDC'04.

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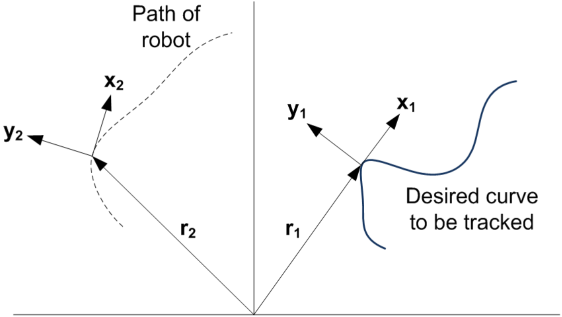

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$\rho = |\mathbf{r_2} - \mathbf{r_1}|$, $\phi =$ angle between $\mathbf{x_1}$ and $\mathbf{x_2}$, $\cos(\phi) = \mathbf{x_1} \cdot \mathbf{x_2}$

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Along all solutions of (CL) for all $t \geq 0$, we have $\frac{d}{dt}V(Y) \leq 0$.

Strict Lyapunov Function (Mazenc-M-Z, TAC)

Theorem 1: The closed loop system (CL) has the strict Lyapunov function

$$U(Y) =$$
$$-h'(\rho)\sin(\phi) + \frac{1}{\mu}\int_0^{V(Y)} \gamma(m)\mathrm{d}m + \Gamma(V(Y)) + V(Y),$$

where $\gamma(q) = \frac{2(q+2\rho_0)^3}{\rho_0^4} + 1 + 0.5\mu^2 + \mu,\ \ Y = (\rho - \rho_0, \phi),$

$\Gamma(q) = \frac{18}{\rho_0} q + 9\left(\frac{2}{\rho_0}\right)^4 q^4,$ and $V(Y) = -\ln\left(\cos(\phi)\right) + h(\rho)$

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$$U(Y) \geq V(Y) \qquad \text{(PD)}$$

$$\frac{d}{dt}U(Y) \leq -0.5[h'(\rho)\cos(\phi)]^2 - \sin^2(\phi) \qquad \text{(SD)}$$

Unknown Control Gains (M-Zhang)

$$\begin{cases} \dot{\rho} &= -\sin(\phi) \\ \dot{\phi} &= \frac{\kappa\cos(\phi)}{1+\kappa\rho} + Ku, \quad K \in (c_{\min}, c_{\max}) \subseteq (0, \infty) \\ \dot{\hat{K}} &= (\hat{K} - c_{\min})(c_{\max} - \hat{K})\frac{\partial U}{\partial \phi}u, \quad \hat{K} \in (c_{\min}, c_{\max}) \end{cases} \tag{7}$$

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i.e., the dynamics for $Y = (\tilde{q}_1, \tilde{q}_2, \tilde{K}) = (\rho - \rho_0, \phi, \hat{K} - K)$. $\xi_R = (\rho_0, 0)$. Strictness allowed a robustness analysis to satisfy performance and safety bounds under other uncertainties.

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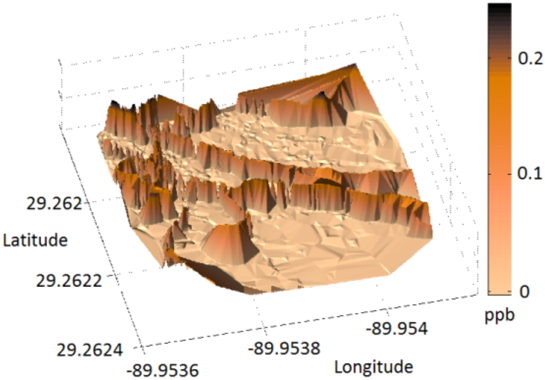

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Malisoff, M., and F. Zhang, "Robustness of adaptive control under time delays for three-dimensional curve tracking," *SIAM Journal on Control and Optimization*, 53(4):2203-2236, 2015.

Our Other Adaptive Control Applications

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Joint work with J. Muse from AFRL on model reference adaptive control to reduce oscillations, applied to hovering helicopters.

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Thanks for your interest!