MIMO Adaptive Control with $\epsilon$-modification and On-line Singularity Avoidance Method for Hyper-Redundant Robotic Arm

Follow this and additional works at: https://ecommons.udayton.edu/stander_posters

Recommended Citation
https://ecommons.udayton.edu/stander_posters/925

This Book is brought to you for free and open access by the Stander Symposium at eCommons. It has been accepted for inclusion in Stander Symposium Posters by an authorized administrator of eCommons. For more information, please contact frice1@udayton.edu, mschlangen1@udayton.edu.
MIMO Adaptive Control with $\epsilon$-Modification and On-line Singularity Avoidance Method for Hyper-Redundant Robotic Arm

Xingsheng Xu, Advisor: Raúl Ordóñez

Department of Electrical and Computer Engineering University of Dayton

---

**INTRODUCTION**

- Degree of freedom (DOF) and Fuzzy system
- Hyper-redundant robots (HRR)

(a) Degree of freedom (b) Fuzzy system

(a) Snake (b) Elephant trunk (c) Tentacle

---

**Objective**

- Design a MIMO adaptive controller that uses a fuzzy system with $\epsilon$-modification for a 9-DOF HRR.
- Apply an on-line task modification method (OTMM) to achieve singularity avoidance for HRR at the velocity level.

---

**MIMO Adaptive Control in Workspace**

---

**Error Boundaries with $\epsilon$-modification**

We represent each ideal controller as

$$\tau' = \mathcal{F}(x, r, \theta) + W_0 = \theta^T \mathcal{Z}(x, r) + W_0,$$

The fuzzy system approximation of $\tau'$ is given by

$$\hat{\tau} = \mathcal{F}(x, r, \hat{\theta}) + U_0 = \hat{\theta}^T \mathcal{Z}(x, r) + U_0,$$

where $U_0 = -(W_0 + B_0/2\sigma_0^2) \text{sat}(\epsilon/\epsilon)$ is a stabilizing control term.

In the practical case, we replace the sliding mode stabilizing control term with $U_0 = -(\hat{W}_0 + B_0/2\sigma_0^2) \text{sat}(\epsilon/\epsilon)$, and the adaptation laws

$$\dot{W}_0 = \gamma_w|\epsilon|,$$

$$\dot{\hat{B}} = \gamma_b|\epsilon|^2/2\sigma_0^2,$$

yield asymptotic convergence of error to zero.

Then, we replace the adaptation laws as

$$\dot{W}_0 = \gamma_w|\epsilon - \epsilon_0(\epsilon)|(|\hat{W}_0 - W_{\min}|),$$

$$\dot{\hat{B}} = \gamma_b|\epsilon|^2/2\sigma_0^2 - \epsilon_0(\epsilon)(\hat{B} - B_0),$$

where $\epsilon_0(\epsilon) = \sigma_u|\epsilon|$ and $\epsilon_0(\epsilon) = \sigma_v|\epsilon$, $\sigma_u > 0$, $\sigma_v > 0$, $W_{\min}$ and $B_0$ are the best guesses of the ideal parameters.

---

**OTMM for Singularity Avoidance**

The OTMM equation is formed as

$$\dot{X}_u = X - k \times \rho(\sigma_{\min}) \times U_0 \times U_0^T X, k = \begin{cases} 0, & \sigma_{\min} > \sigma_e, \\ 1, & \sigma_{\min} < \sigma_e. \end{cases}$$

where $X_u$ is the modified task velocity, $U_0$ is the singular direction vector, $\sigma_{\min} \in \mathbb{R}$ is the minimum singular value of the matrix $f$, $\sigma_e \in \mathbb{R}$ is the low limit of the minimum singular value, $\rho(\sigma_{\min})$ is a monotone function, where $\rho(\sigma_{\min}) = 1$ when $\sigma_{\min} = 0$ and $\rho(\sigma_{\min}) = 0$ when $\sigma_{\min} = \sigma_e$.

---

**Simulation Results**

- $\epsilon$-modification Method Implementation
- Singularity Avoidance by OTMM

(a) $\sigma_{\min} = 0.1$ (b) $\sigma_{\min} = 0.06$ (c) $\sigma_{\min} = 0.02$

---

**Conclusion**

- $\epsilon$-modification help keep the boundary estimator of adaptive controller robust with dynamic uncertainty.
- OTMM eliminates the need to differentiate the escapability of the singularities for HRR.

---

**Real 9-DOF Arm Platform**

(a) Home position 1 (b) Home position 2