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Xingsheng Xu
University of Dayton, stander@udayton.edu

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Multi-Input Multi-Output (MIMO) Adaptive Control of 9-DOF Hyper-Redundant Robotic Arm

Xingsheng Xu, Advisor: Raúl Ordóñez
School of Electrical and Computer Engineering University of Dayton

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

**Dynamic Model**
- Manipulator Jacobian Matrix: An expression to connect angular velocity \( \omega^0 \), linear velocity \( v^0 \) of the end-effector and joint velocity \( \dot{q} \) as
  \[
  \begin{align*}
  \omega^0 &= J_\omega \dot{q}, \\
  v^0 &= J_v \dot{q},
  \end{align*}
  \]
  where \( J_\omega \) and \( J_v \) are \( 3 \times n \) matrices.
- Euler-Lagrange Equation:
  \[
  \frac{d}{dt} \frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = \tau_i, \quad i = 1, \ldots, n,
  \]
  where \( \tau_i \) is input torque of each motor and the Lagrangian \( L \) is given by
  \[
  L = K - P,
  \]
  where \( K \) is the kinetic energy and \( P \) is the potential energy.

**MIMO Adaptive Control in Workspace**

**Simulation Results**
- 9-DOF Arm Tracking and Disturbance Simulation

**Objective**
- Design both the kinematic and dynamic model of a 9-DOF hyper-redundant arm;
- Apply MIMO adaptive controllers to control the end-effector of the arm in work space.

**Kinematic Model**
- (a) Joint schematic  
  (b) Frame assignment

**Extra Constraints**
- \( X \)  
  \[
  \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [\text{Jacobian}] \begin{bmatrix} \delta_1 \\ \vdots \\ \delta_n \end{bmatrix}
  \]
  More redundant!

**Conclusion**
- Take care of the system nonlinearity and uncertainty;
- Approximate the ideal controller online to the particular system;
- Adjust itself and try to track the reference again after having system disturbance.

**Real 9-DOF Arm Platform**
- (a) Home position 1  
  (b) Home position 2