

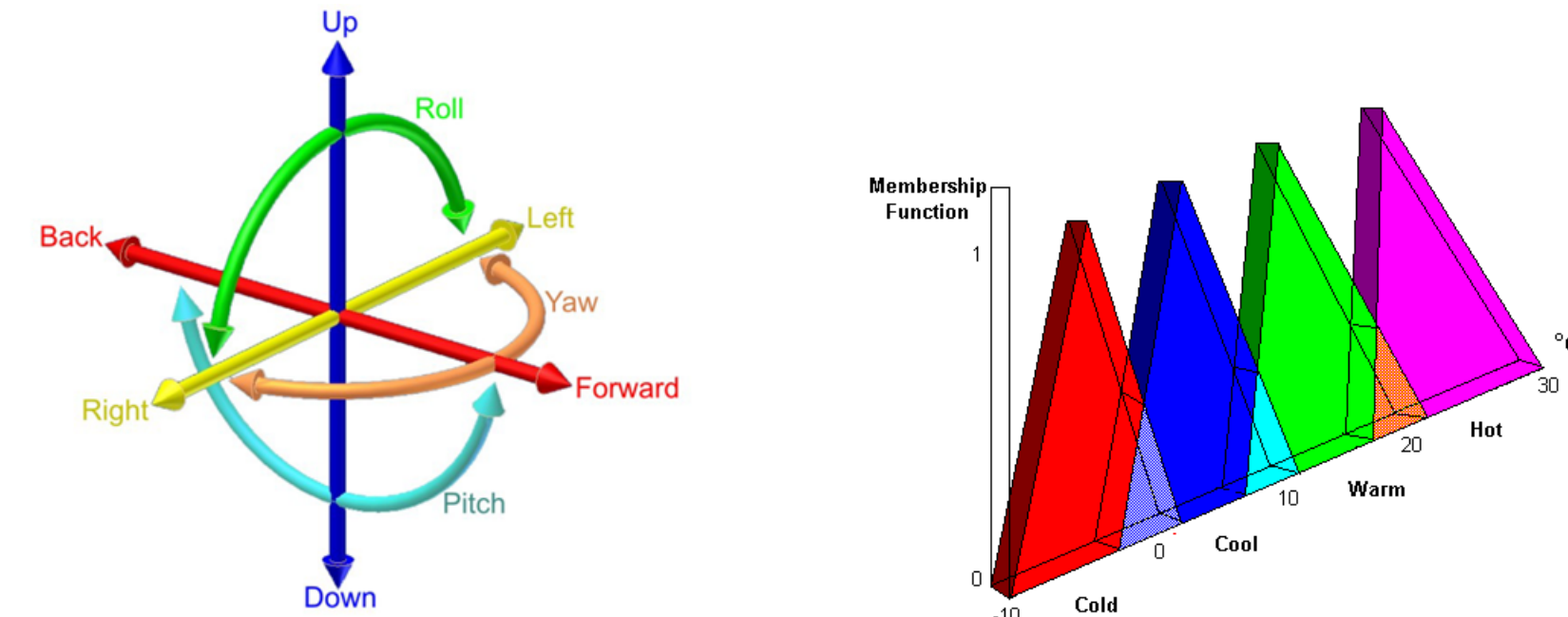
# Multi-Input Multi-Output (MIMO) Adaptive Control of 9-DOF Hyper-Redundant Robotic Arm

Xingsheng Xu, Advisor: Raúl Ordóñez

School of Electrical and Computer Engineering University of Dayton

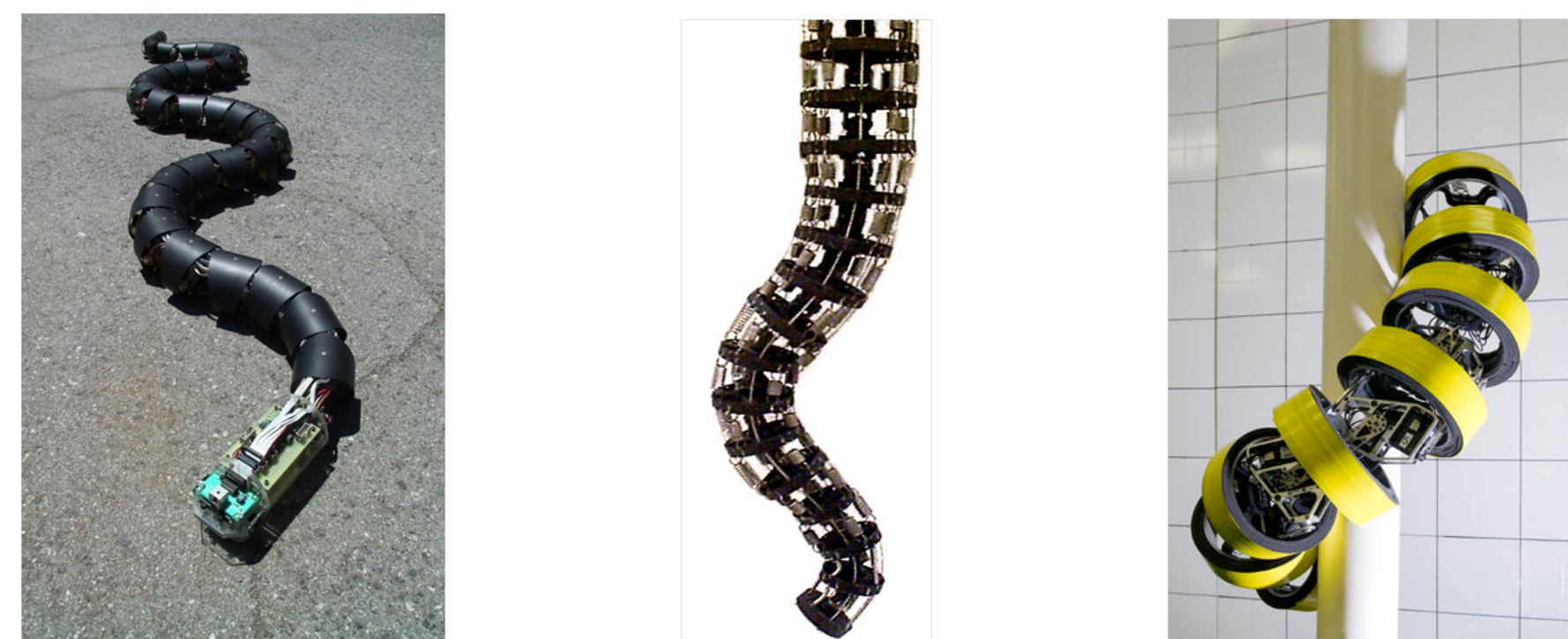
## KEY WORDS

- Degree of freedom (DOF) and Fuzzy system



(a) Degree of freedom (b) Fuzzy system

- Hyper-redundant robots (HRR)

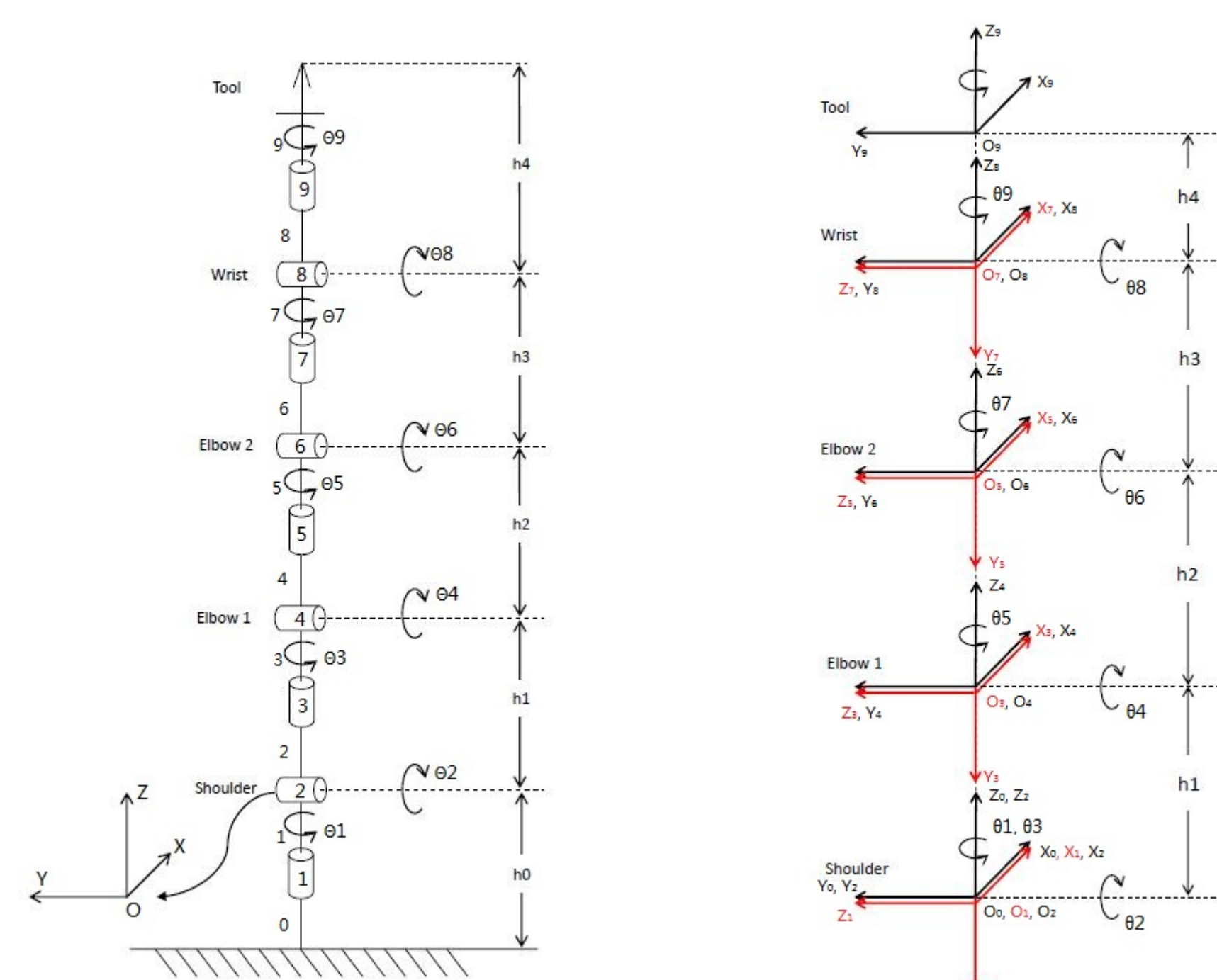


(a) Snake (b) Elephant trunk (c) Tentacle

## 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

## DYNAMIC MODEL

- Manipulator Jacobian Matrix: An expression to connect angular velocity  $\omega_n^0$ , linear velocity  $v_n^0$  of the end-effector and joint velocity  $\dot{q}$  as

$$\omega_n^0 = J_\omega \dot{q},$$

$$v_n^0 = J_v \dot{q},$$

where  $J_\omega$  and  $J_v$  are  $3 \times n$  matrices.

- Euler-Lagrange Equation:

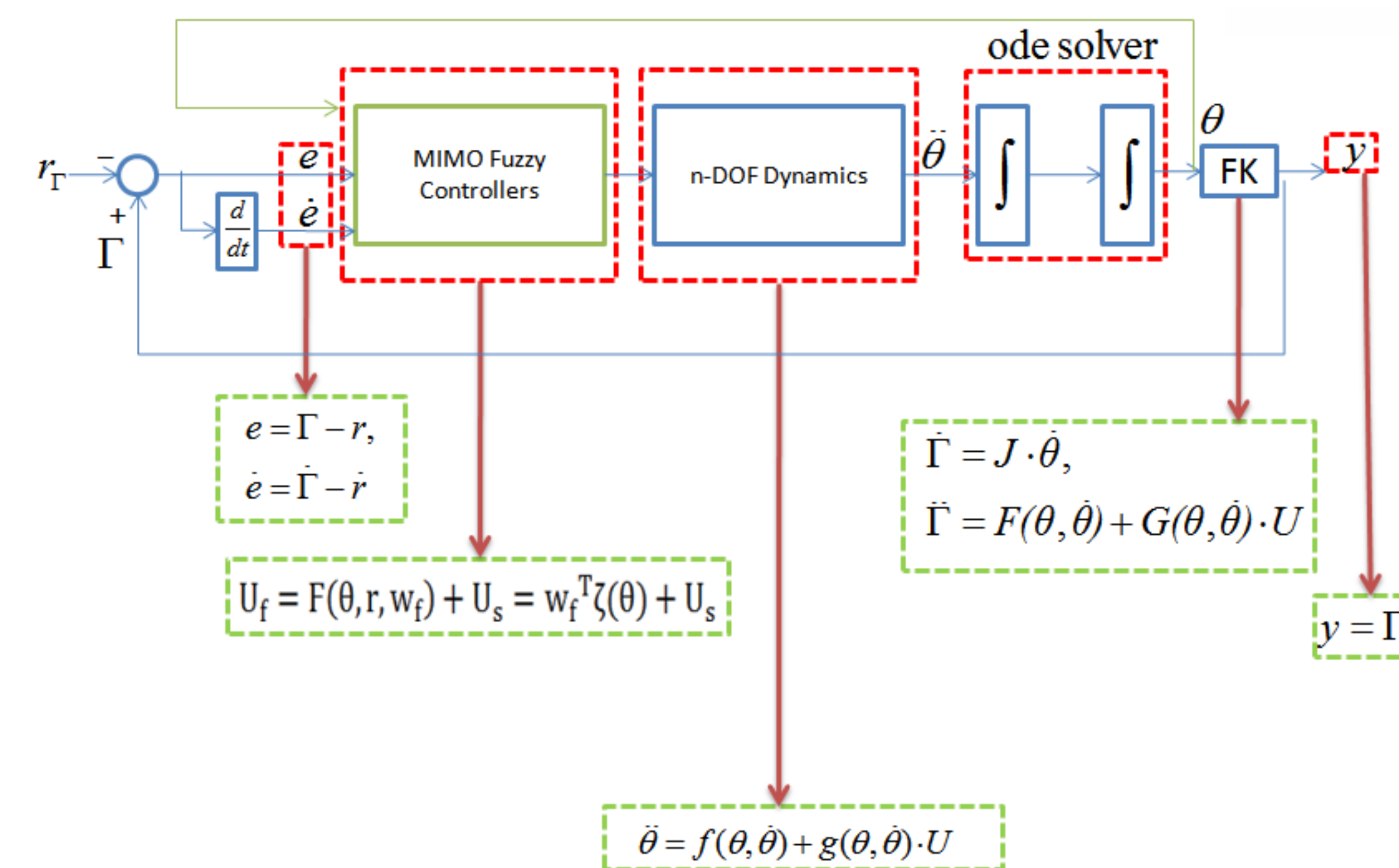
$$\frac{d}{dt} \frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = \tau_i, i = 1, \dots, n,$$

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



## EXTRA CONSTRAINTS

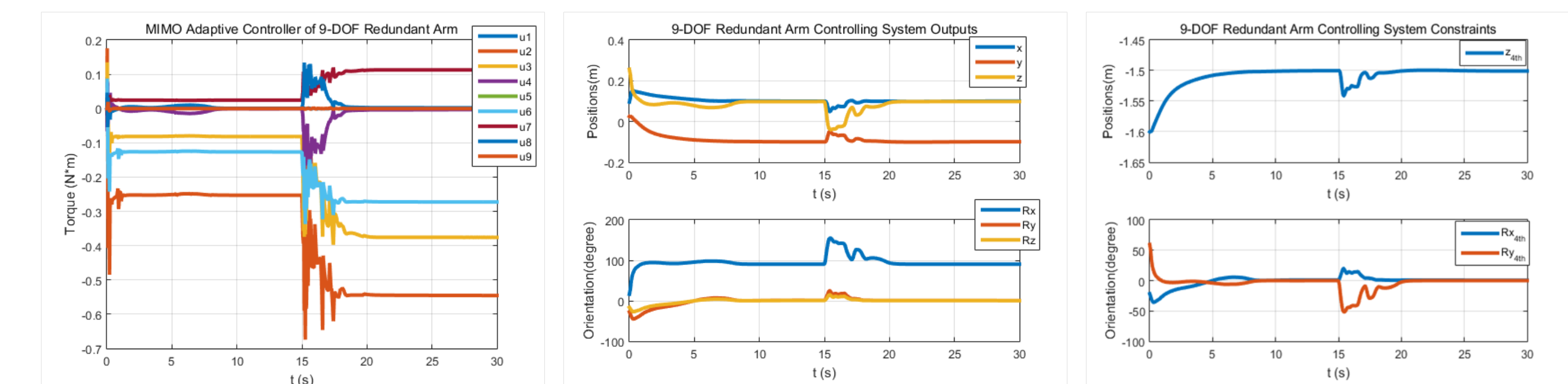
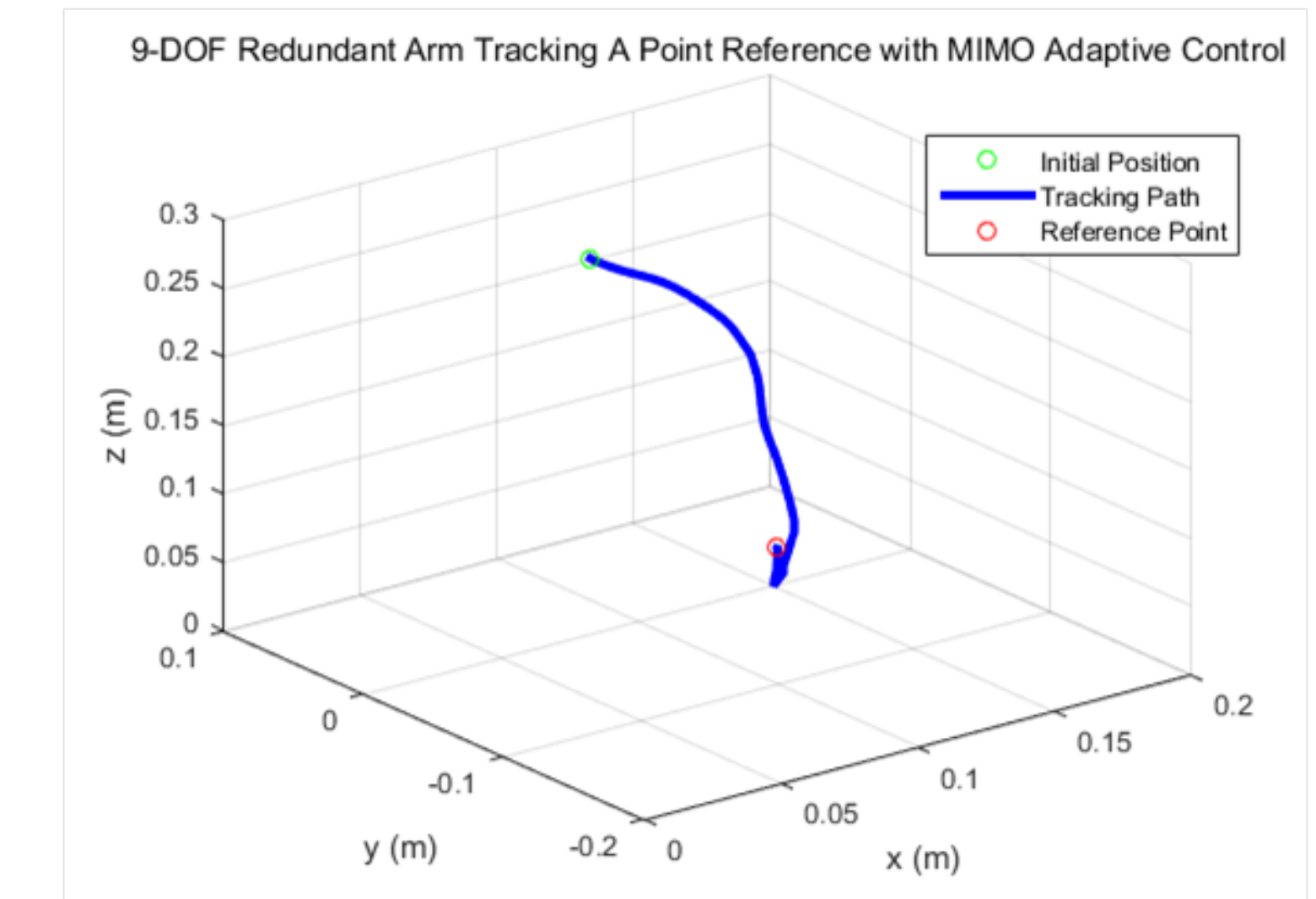
$$\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ \dot{R}_x \\ \dot{R}_y \\ \dot{R}_z \end{bmatrix} = \begin{bmatrix} \text{Jacobian} \\ 6 \times n \end{bmatrix} \cdot \begin{bmatrix} \dot{\theta}_1 \\ \vdots \\ \dot{\theta}_n \end{bmatrix} + \begin{bmatrix} \text{Constraint Jacobian} \end{bmatrix} \cdot \begin{bmatrix} \dot{\theta}_1 \\ \vdots \\ \dot{\theta}_n \end{bmatrix}$$

Constraints

More redundant!

## SIMULATION RESULTS

- 9-DOF Arm Tracking and Disturbance Simulation



(a) Controllers

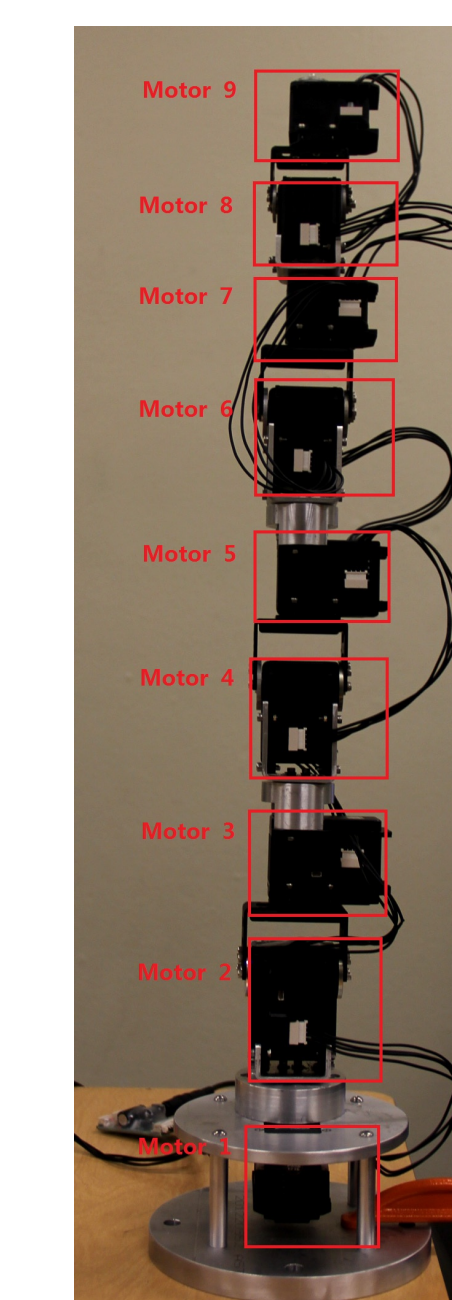
(b) Outputs

(c) Constraints

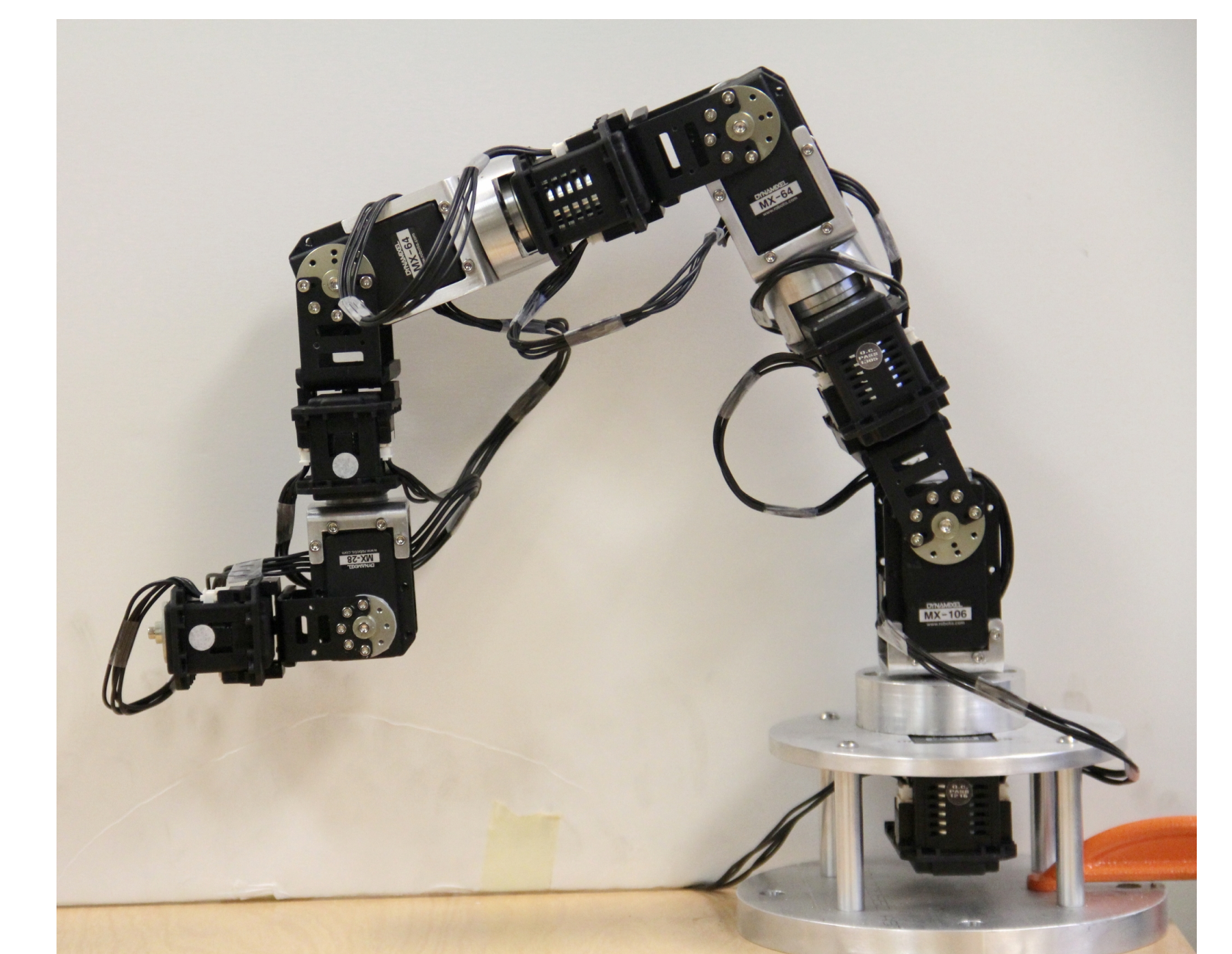
## CONCLUSION

- 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