



Remotely Augmented Reality Intelligent Cognitive Robotics for Personally Assisted Living under Unstructured Environment

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Objectives:

- To develop remote augmented reality intelligent cognitive robotics for personally assisted living under unstructured environment.
- The main research issues are how to let the robot deal with the complex and dynamic environment and have the personal assistant ability either in remote distance or actual in-situ presence.



Research Approaches

- It is proposed to focus on innovative research in two relevant areas of application needs especially in remote augmented reality intelligent cognitive robotics for personally assisted living under unstructured environment. The research issues include:
- **A. Medical and Healthcare Robotics**
- (1). Issues in Intuitive physical human-robot Interaction between caregivers, patients, robots and sensing, perception, and action.
- (2). Issues in Multisensor fusion and integration to enable automated understanding of human behavior and real-time user interaction and assistances.
- (3). Issues in Emotion understanding, modeling, and classification for activity recognition, physiologic data processing, and multi-modal perception.

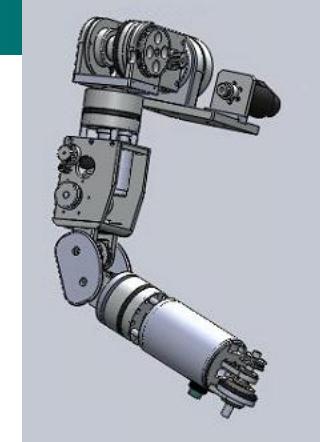
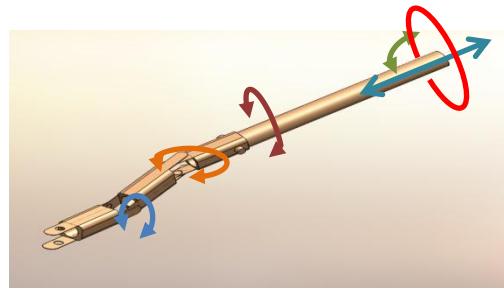


B. Intelligent Service Robotics

- (1). Issues in Dexterous hands and safe manipulators with skill learning, modeling and transfer.
- (2). Issues in real-world 3D perception, mapping and navigation to accommodate unstructured and dynamic environment.
- (3). Issues in cognition systems for smooth interaction with users and deployment in domains where there is limited opportunities for user training and ensuring system robustness
- (4). Issues in skill acquisition to solve novel tasks with continuously improving performance through advances in perception, representation, machine learning, cognition, planning, and control research.
- (5). Issues in safe robots through advances in perception and control to detect objects and persons and predict possible safety hazards as well as avoid contact damage.

- **Remote Augmented Reality Bi-directional Adaptive Force Reflection and Impedance Control Dual Arm Robot for Intelligent Service Robotics**

Structure



Motor (1 DOF)

- Impedance control (one DOF)
- compliance control (one DOF)

Multi-DOF manipulator

- Impedance control
- Compliance control
- Gravity compensation
- Auxiliary force control

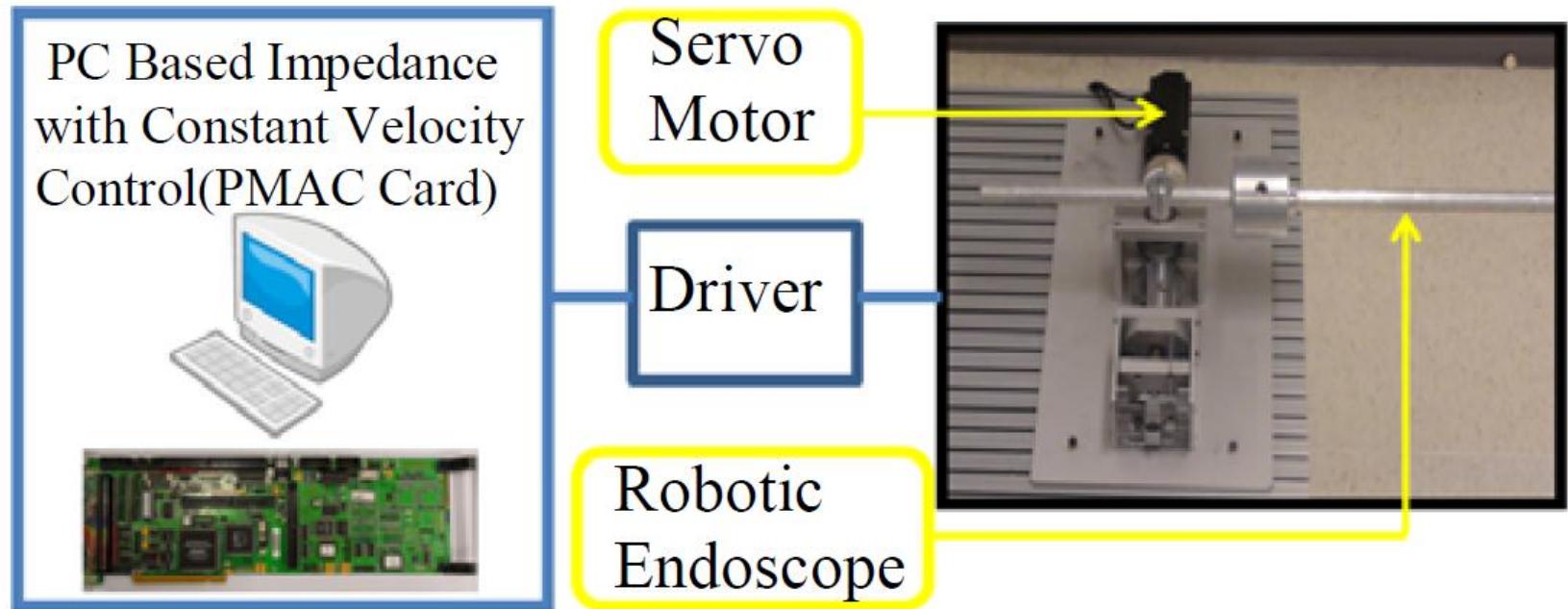
Application

- Force balance
- Learning & play
- Massage
- Endoscope



1-DOF Adaptive Impedance control

Robotic Endoscope System Experiment Setup



The PMAC card provides 1ms servo interrupt time for the routine of the control, and sends out the control command to the servo driver through the D/A converter.

From Kirchhoff's voltage law , we obtain

$$L\dot{I}_a + RI_a = V - V_b \quad (1)$$

Where I_a is the armature current, V is the applied armature voltage, V_b is the back electromotive force(back emf). R and L denotes resistance and inductance respectively. Since the current-carrying armature is rotating in a magnetic field, its voltage is proportional to speed. Thus,

$$V_b = K_b \dot{\theta} \quad (2)$$

Where V_b is the back emf , K_b is back emf constant, and $\dot{\theta}$ is the angular velocity of the motor.

The torque developed by the motor is proportional to the armature current, thus,

$$\tau = K_t I_a \quad (3)$$

Where K_t is the torque developed by the motor and I_a is the motor torque constant.

To find the transfer function of the motor, we first substitute Eq. (2) into (1) and take the Laplace transform, yielding

$$I_a(s) = \frac{V - K_b s \Theta(s)}{Ls + R} \quad (4)$$

From Newton second law and Laplace transform, we obtain

$$Js^2\theta + Cs\theta = \tau - \tau_d \quad (5)$$

Substituted Eq.(3) and (4) into Eq. (5) yields

$$\left(Js^2 + Cs + \frac{K_t K_b s}{Ls + R} \right) \Theta(s) = \frac{K_t V}{Ls + R} - \tau_d \quad (6)$$

Assume $L \ll R$ thus

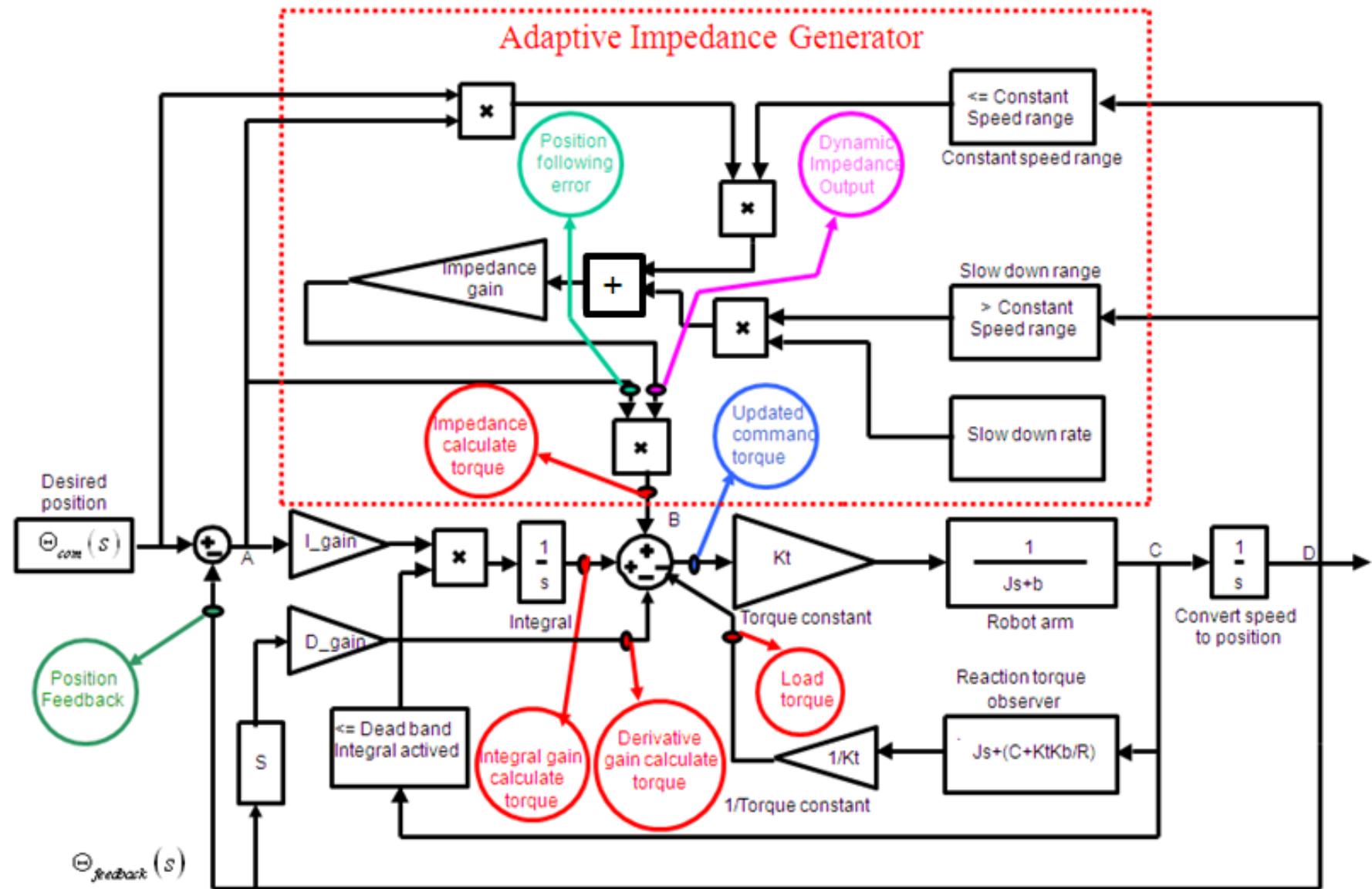
$$\Theta(s) [Js^2 + (C + K_t K_b / R)s] = \frac{K_t}{R} V(s) - \tau_d \quad (7)$$

$$[\Theta_{com}(s) - \Theta_{feedback}(s)](K_{impedance} + K_I / s) - sK_D\Theta_{com}(s) - Torque_{load} = Torque_{command} \quad (8)$$

Denote torque command.

$$Torque_{com} = [\Theta_{com}(s) - \Theta_{feedback}(s)](K_{impedance} + K_I / s) - s\Theta_{com}(s)K_D - \{\omega_{feedback}(s)[Js + (C + K_t K_b / R)] + \tau_d\} \quad (9)$$

Adaptive Impedance Control Block Diagram



Adaptive Impedance Control Block Parameters

$\Theta_{com}(s)$:Command position

K_t : Torque constant

$\Theta_{feedback}(s)$:Actual feedback position

K_b : Back EMF coefficient

R : Resistor of the servo motor driver

$K_{impedance}$:Impedance gain

J : Inertial of the system load

τ_d :Disturbance torque

C : Viscosity coefficient of the system load

According to the diagram, close loop transfer function between B and

C is

$$T_{C/B}(s) = \frac{\frac{K_t}{Js+b}}{1 + \frac{1}{Js+b}[Js + (C + K_t K_b / R)]} \quad (10)$$

$$Output_D(s) = Input_B(s) \left\{ \frac{\frac{K_t}{Js+b}}{1 + \frac{1}{Js+b}[Js + (C + K_t K_b / R)]} \right\}^{\frac{1}{s}} \quad (11)$$

and the relationship between B and D is

$$following_error_A(s) = Desired_position - Output_D = \Theta_{com}(s) - Input_B(s) \left\{ \frac{\frac{K_t}{Js+b}}{1 + \frac{1}{Js+b}[Js + (C + K_t K_b / R)]} \right\}^{\frac{1}{s}} \quad (12)$$

From the outer position loop to observe the inner current control loop of the system, the bandwidth of the inner current control loop of the system is wide enough. Therefore, we assume

$$T_{C/B}(s) \approx A_{tor_vel} \quad (13)$$

where A_{tor_vel} defined as the gain between impedance torque input(B) and velocity output(C)

Substituting Eq.(13) into Eq.(12) yields,

$$following_error_A(s) = \Theta_{com}(s) - \frac{Input_B(s) * A_{tor_vel}}{s} \quad (14)$$

Output velocity at C can be expressed as

$$Output_C(s) = Input_B(s)T_{C/B} = following_error_A(s)T_{B/A}(s)T_{C/B} \quad (15)$$

Substituting Eq.(13) and (14) to Eq.(15), we obtain

$$Output_C(s) \approx \left\{ \frac{\Theta_{com}(s)s - Input_B(s)A_{tor_vel}}{s} \right\} T_{B/A}(s)A_{tor_vel} \quad (16)$$

To obtain the constant speed , we design the impedance gain as

$$T_{B/A}(s) = Impedance_{gain}(s) = \frac{\frac{Q\Theta_{com}(s)}{\Theta_{com}(s)s - Input_B(s)A_{tor_vel}}}{s} \frac{1}{A_{tor_vel}} \quad (17)$$

Substituting Eq.(17) to Eq.(16) and multiplying s yield,

$$Output_C(s) \approx Q\Theta_{com}(s) \quad (18)$$

Simulation Results: Adaptive Impedance Control

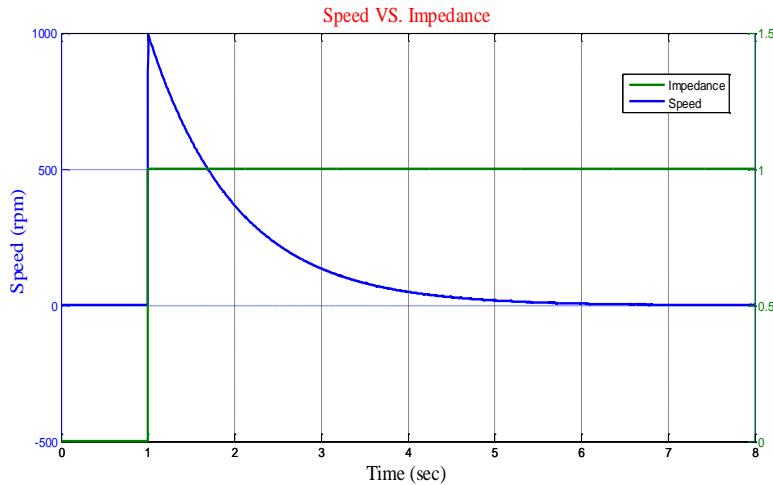


Fig A. Without constant speed portion because it uses the fixed constant value of impedance gain

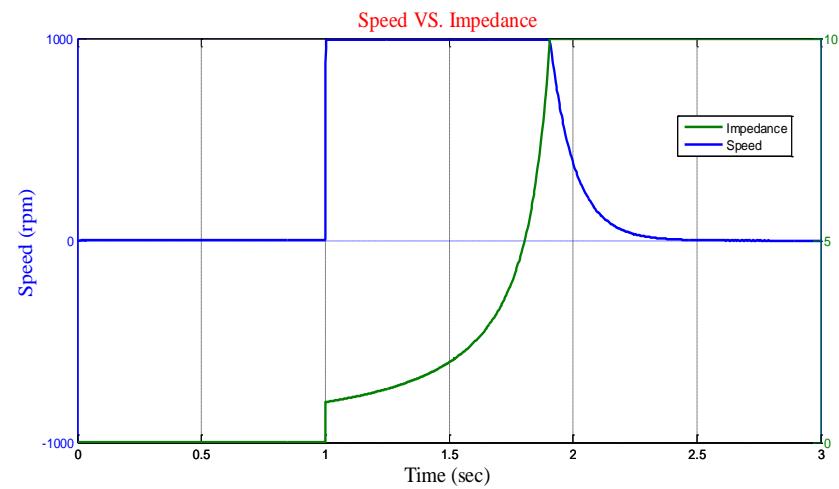


Fig B. Constant speed at 1000rpm because it uses the adaptive impedance gain

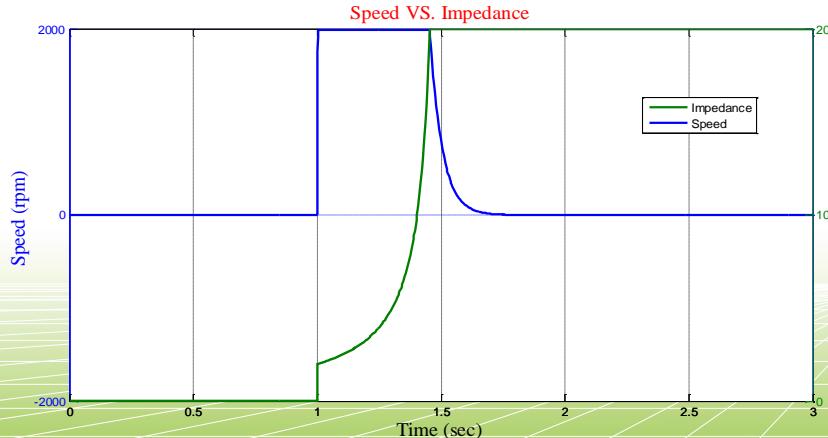


Fig C. Increase the constant speed to 2000rpm with adaptive impedance gain

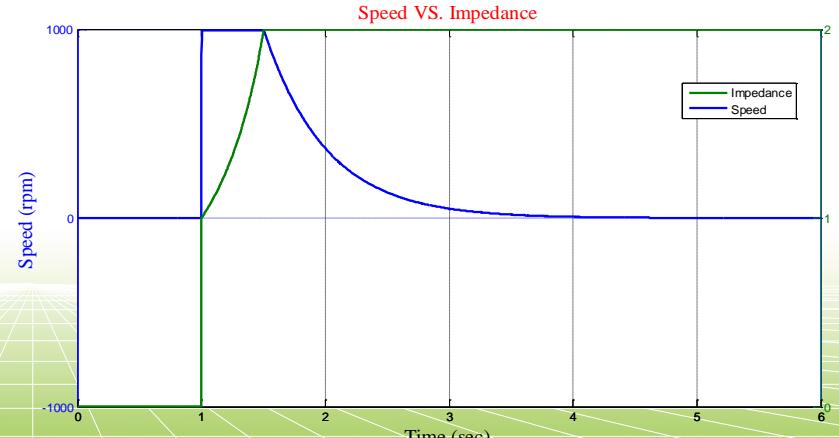
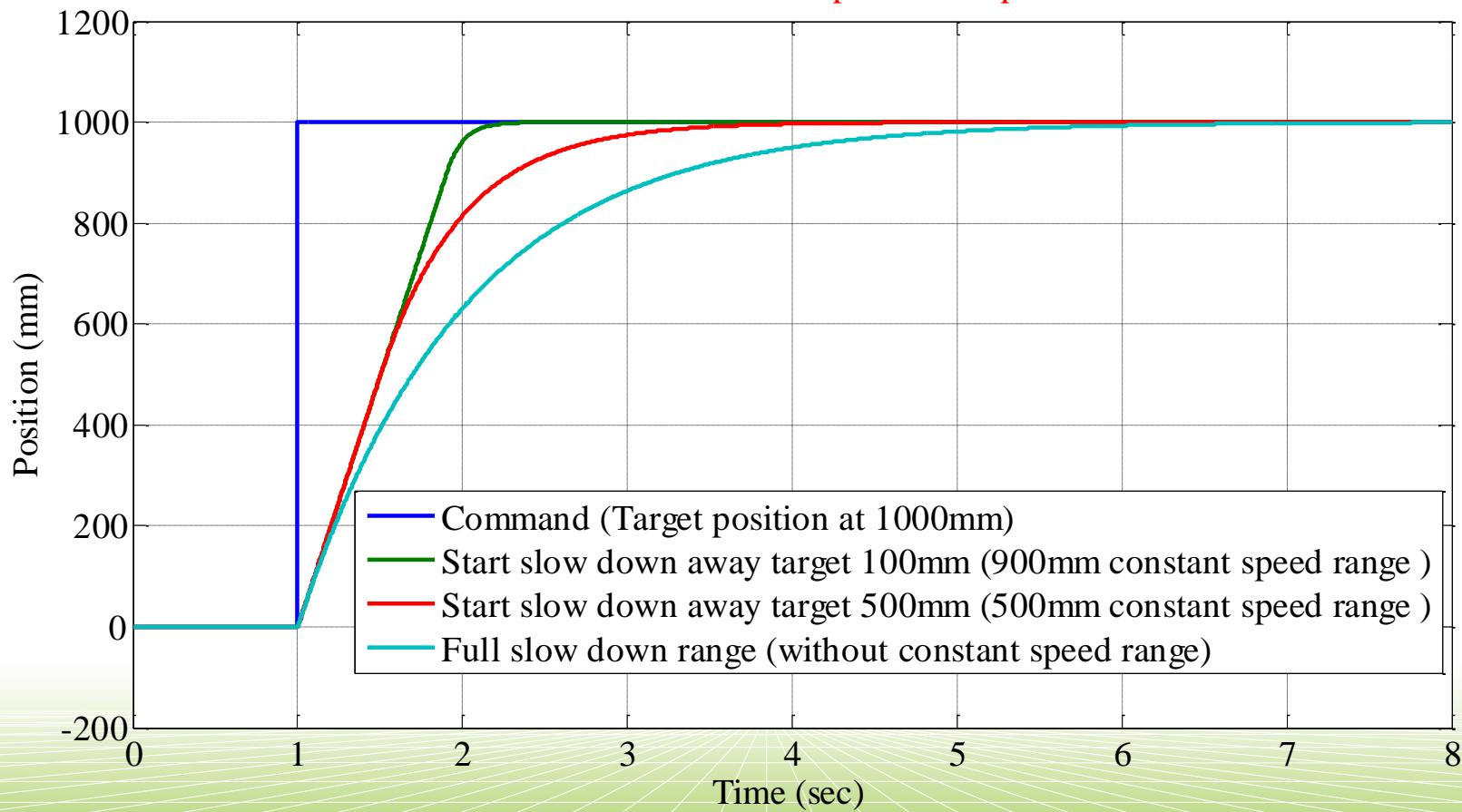


Fig D. Decrease the constant speed range with adaptive impedance gain

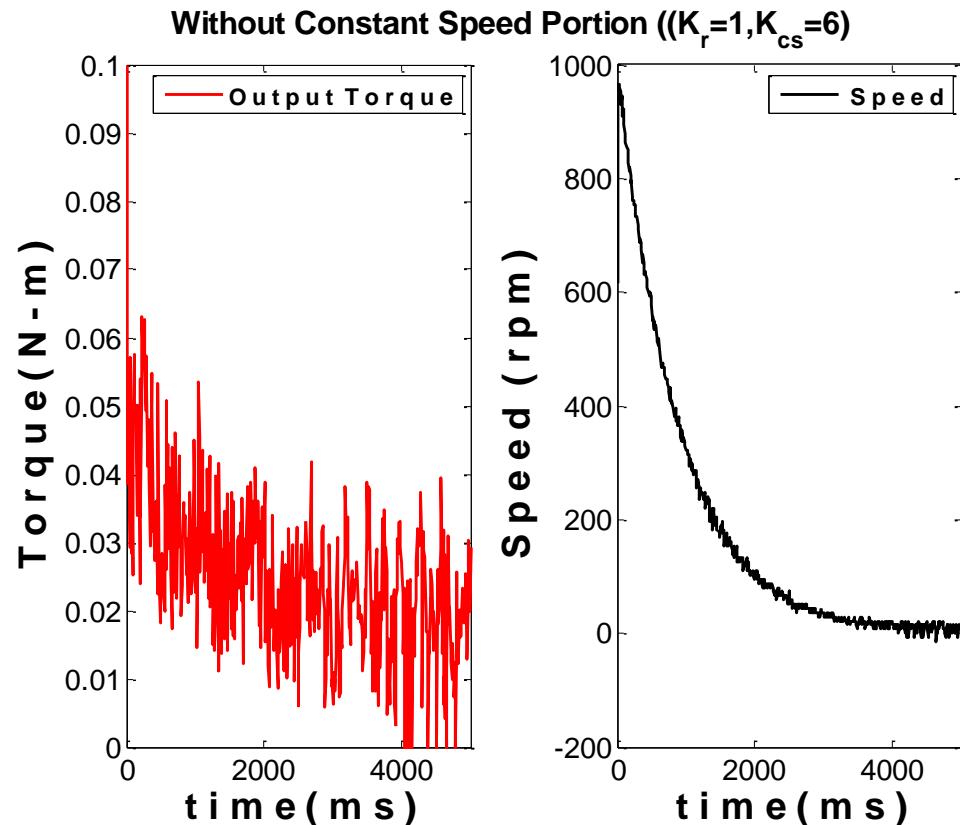
Command VS. Actual position response



Command and actual position response

Experimental Results: Adaptive Impedance Control

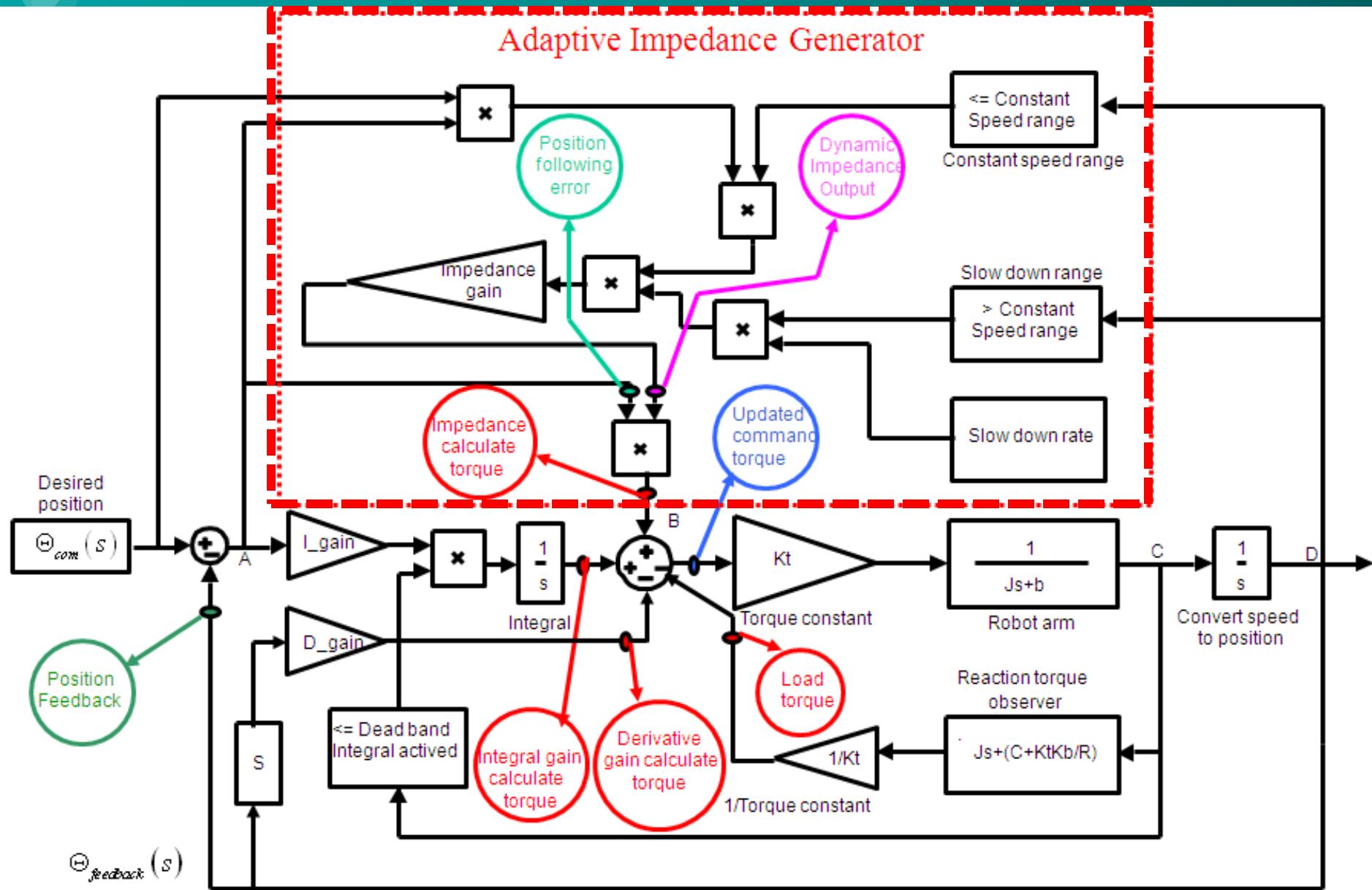
As shown in this figure, the constant impedance gain results in quick decay of speed. However, there are many applications need constant speed, such as welding robots perform the weld and service robots deliver objects to human.



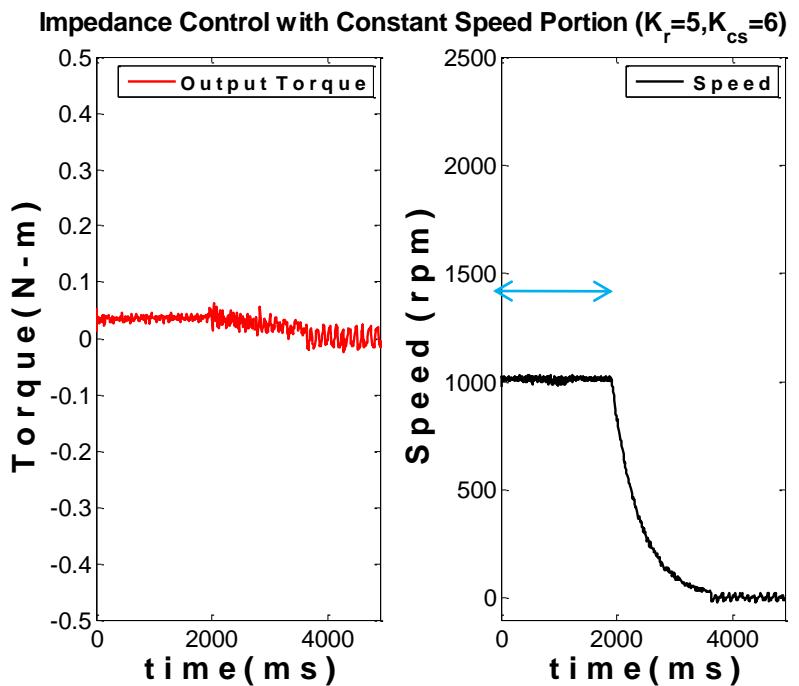
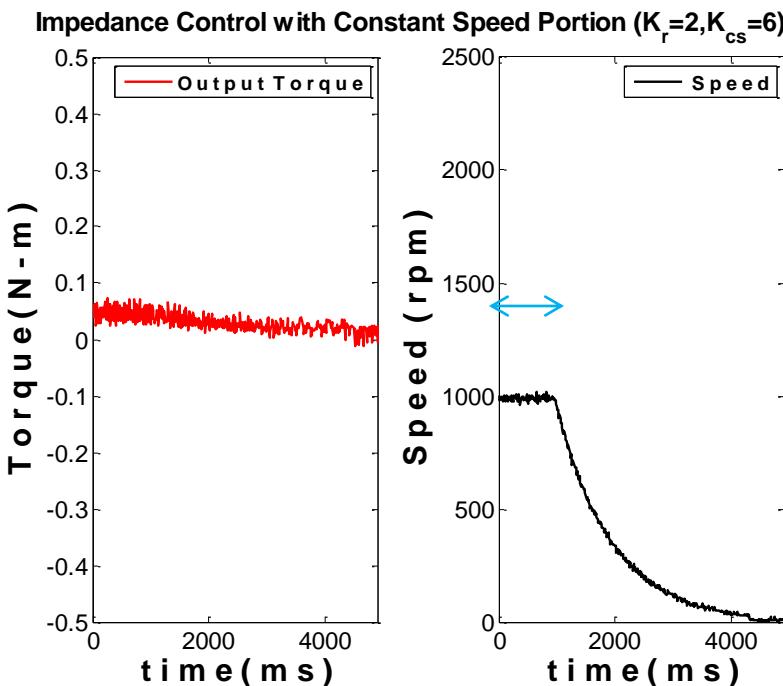
Without constant speed portion because it uses the fixed constant value of impedance gain

[Demo](#)

Adaptive Impedance Control Block Diagram



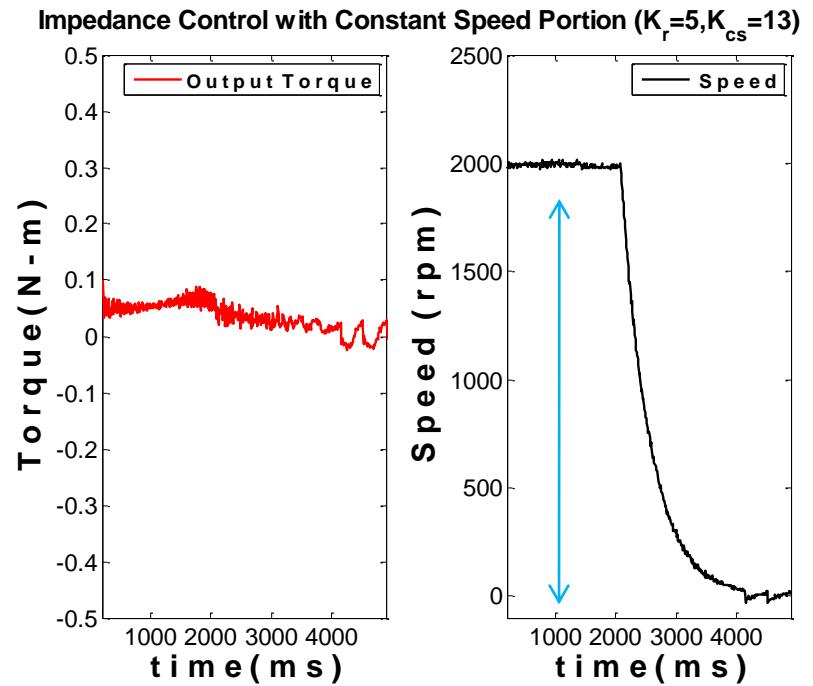
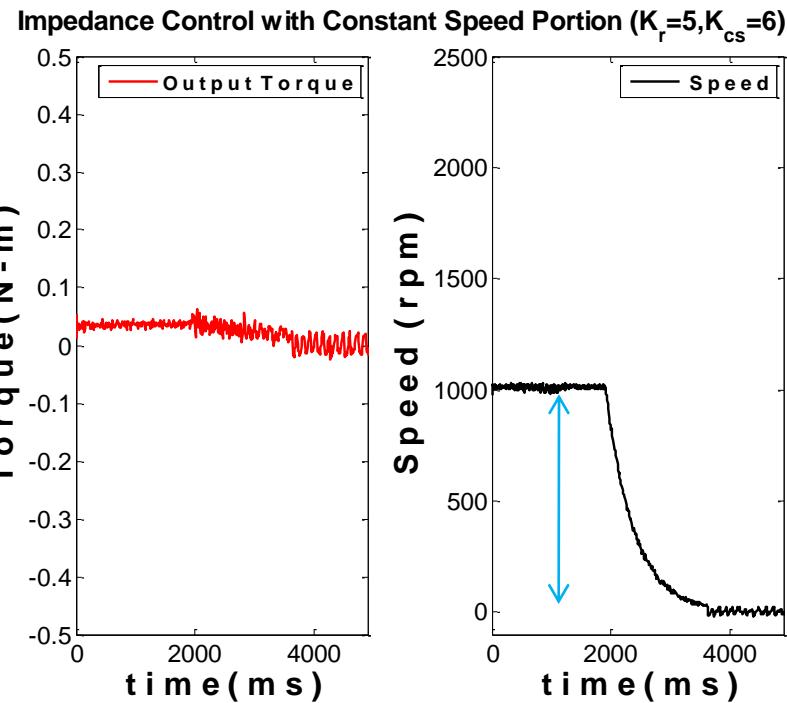
We can set range gain(K_R) to determine the constant speed range.



Demo

Demo

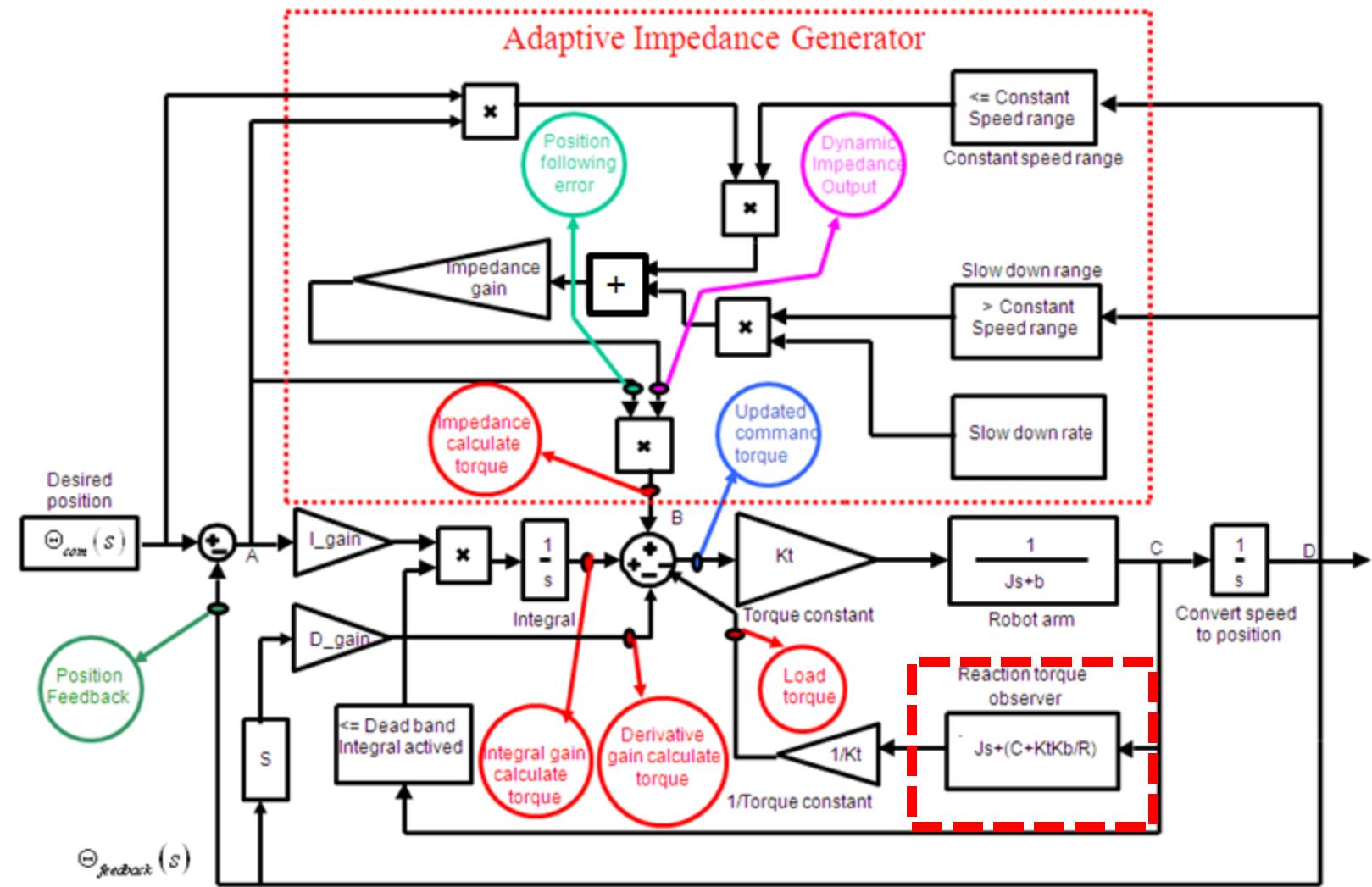
We can set constant speed gain ($K_{C.S}$) to determine the constant speed magnitude.



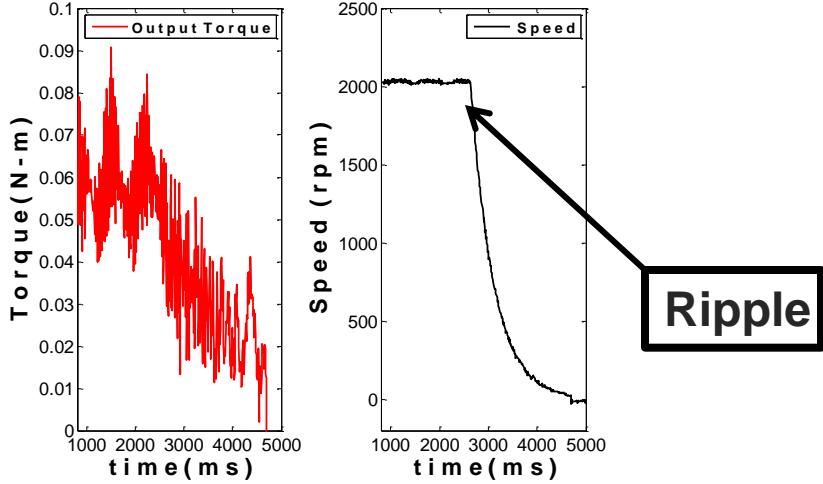
[Demo](#)

[Demo](#)

Adaptive Impedance Control Block Diagram

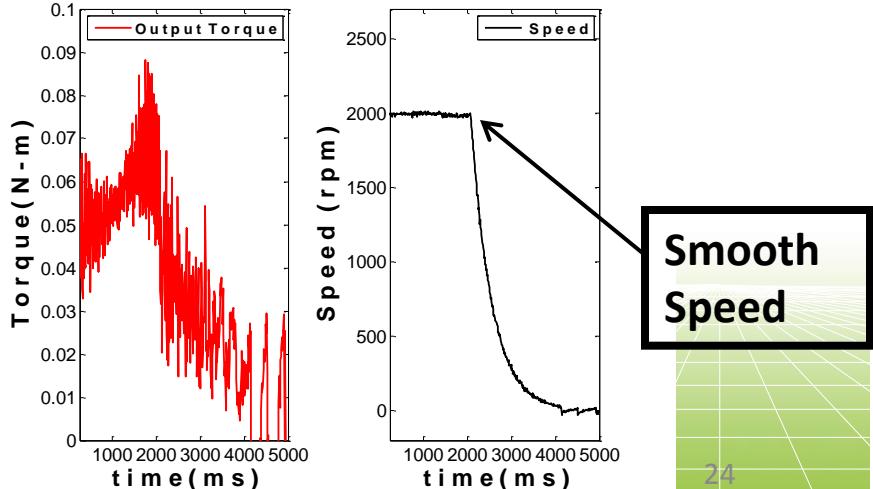


Adaptive Impedance Control without Observer ($K_{cs}=5, K_{de}=13$)

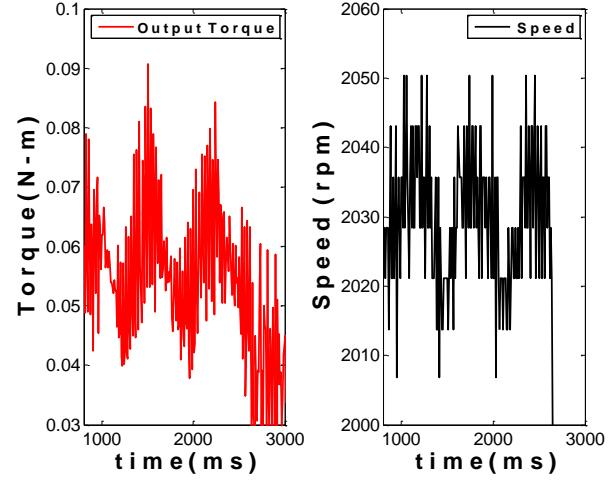


The ripple torque causes the speed output with ripple

Adaptive Impedance Control with Observer ($K_{cs}=5, K_{de}=13$)

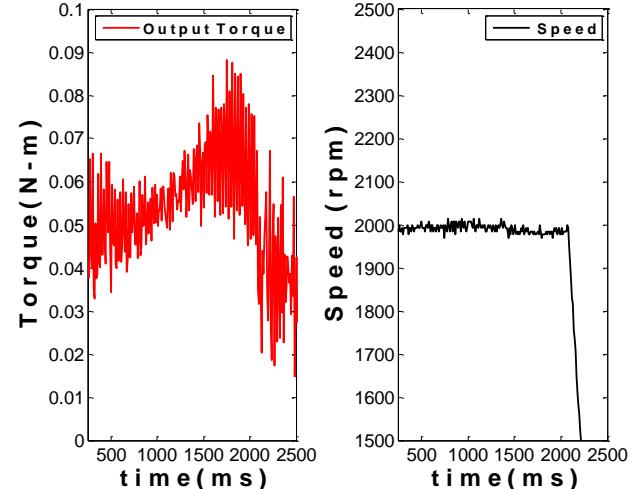


Adaptive Impedance Control without Observer (Zoom In) ($K_{cs}=5, K_{de}=13$)

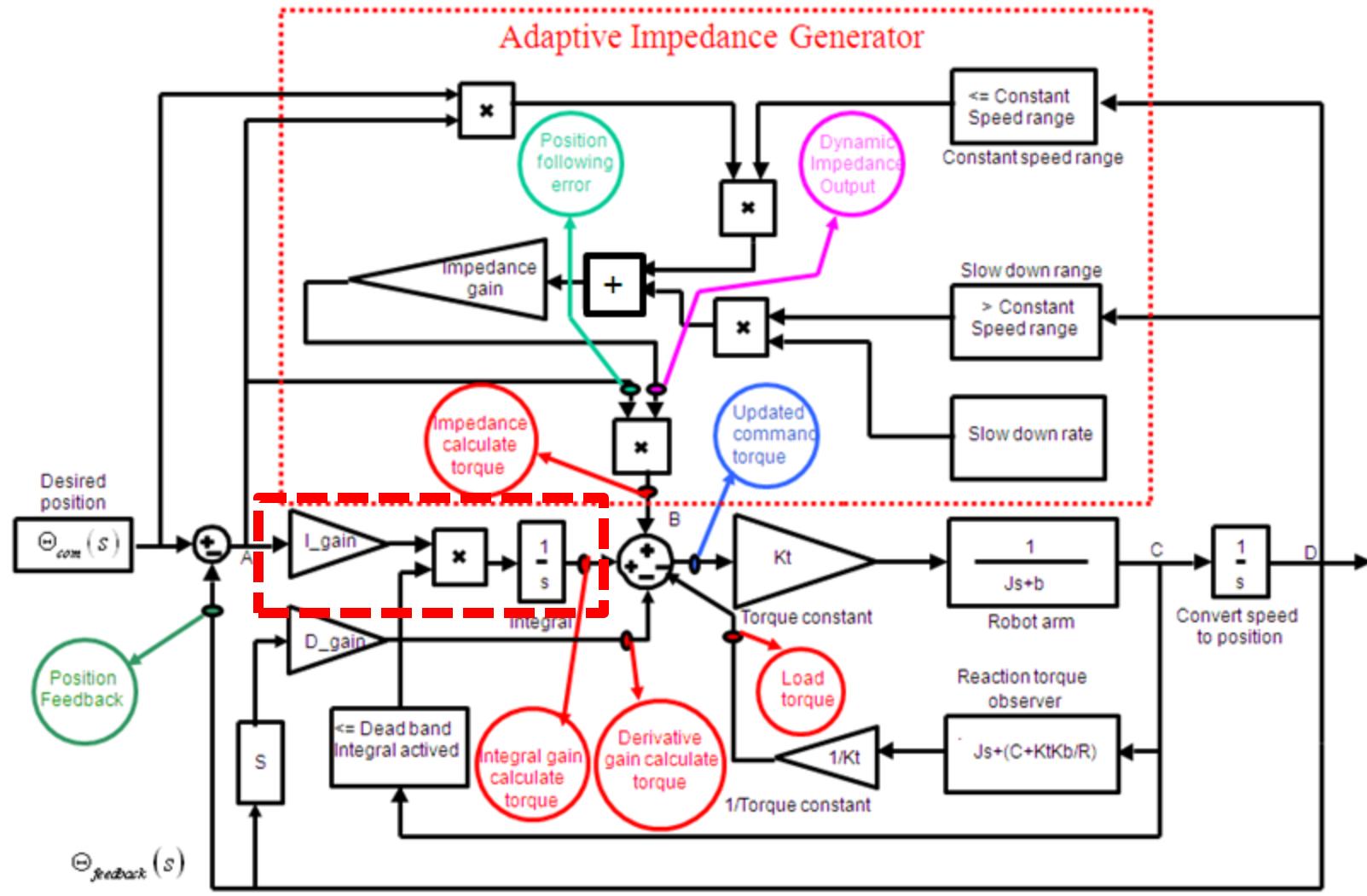


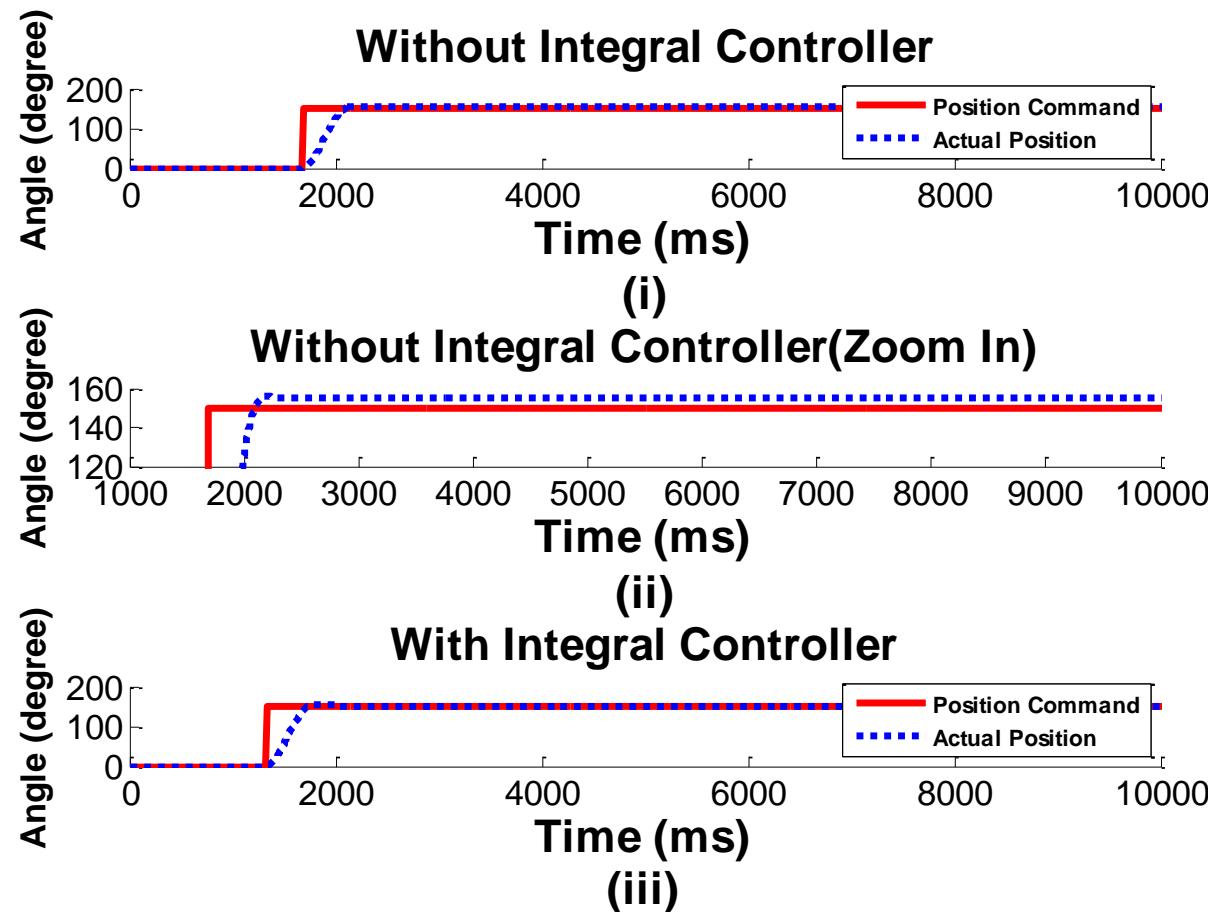
Zoom in right side speed result of above figure

Adaptive Impedance Control with Observer (Zoom In) ($K_{cs}=5, K_{de}=13$)



Adaptive Impedance Control Block Diagram

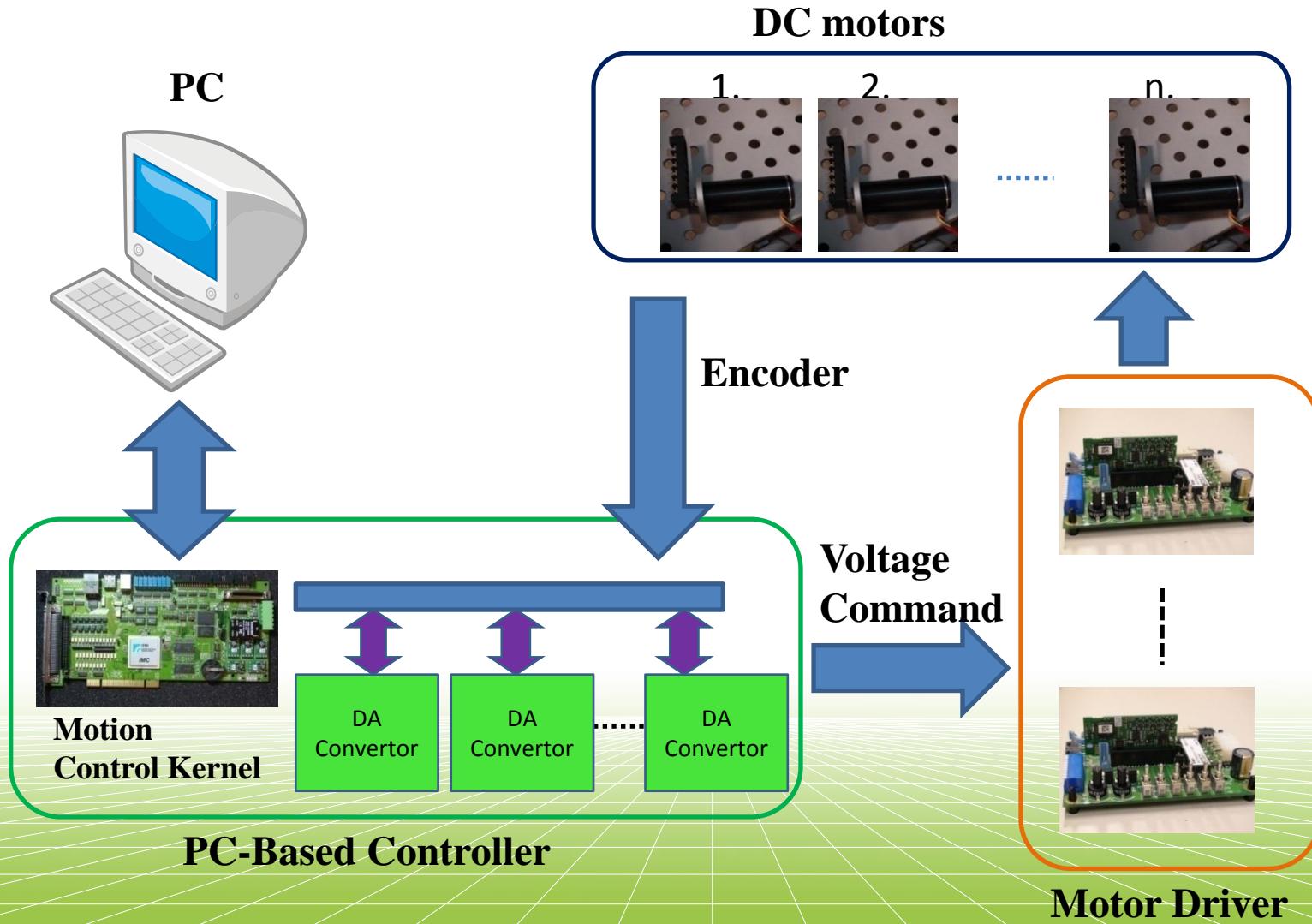




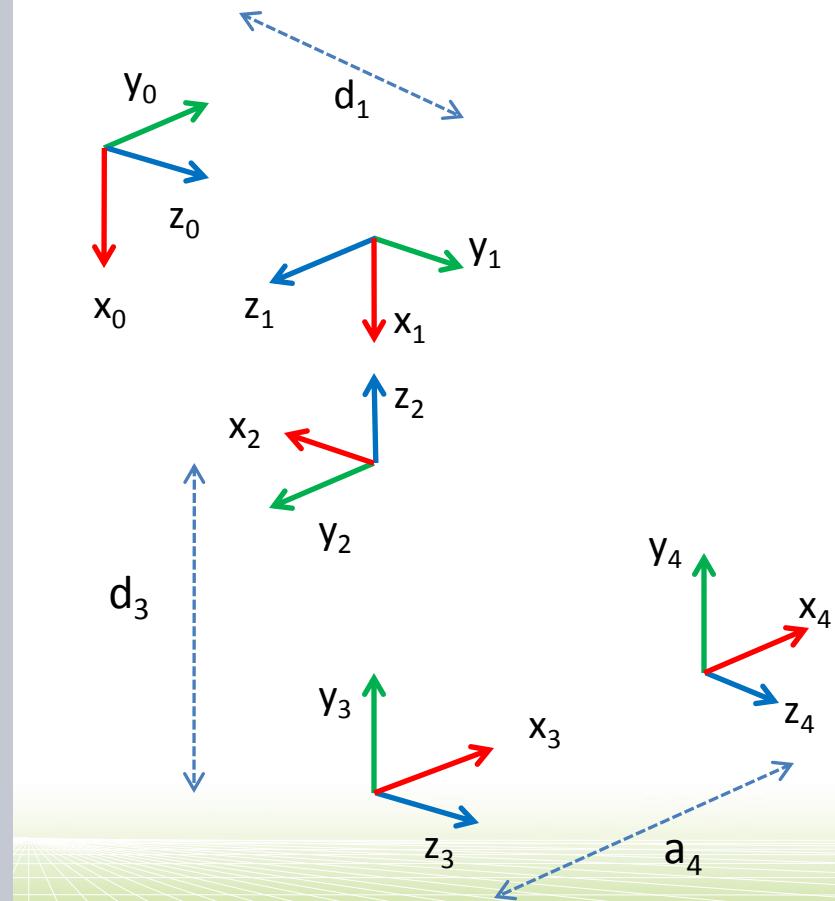
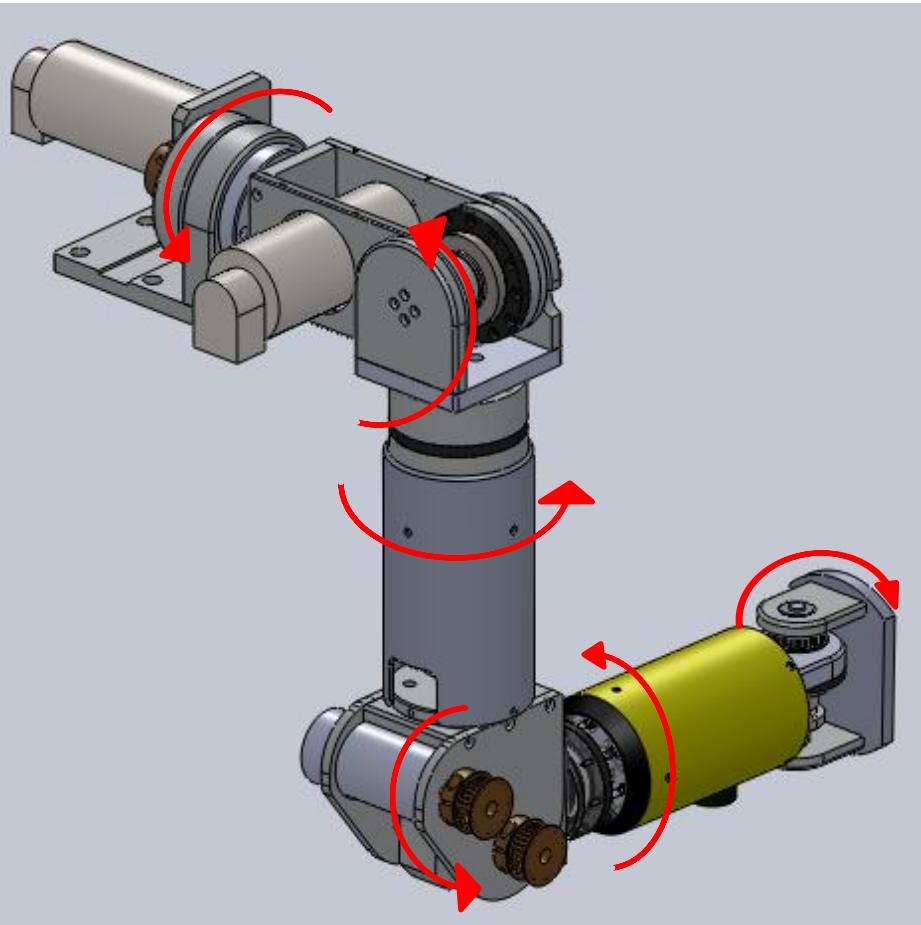


Multi-DOF Manipulator

System Architecture



Denavit-Hartenberg' (DH) form



Denavit-Hartenberg' (DH) form

	θ_i	d_i	α_i	a_i
1	$\theta_1 + 0^0$	$d_1 = 7.5\text{cm}$	90^0	0
2	$\theta_2 - 90^0$	0	90^0	0
3	$\theta_3 - 90^0$	$d_3 = -30\text{cm}$	90^0	0
4	$\theta_4 + 0^0$	0	0^0	$a_4 = 30\text{cm}$

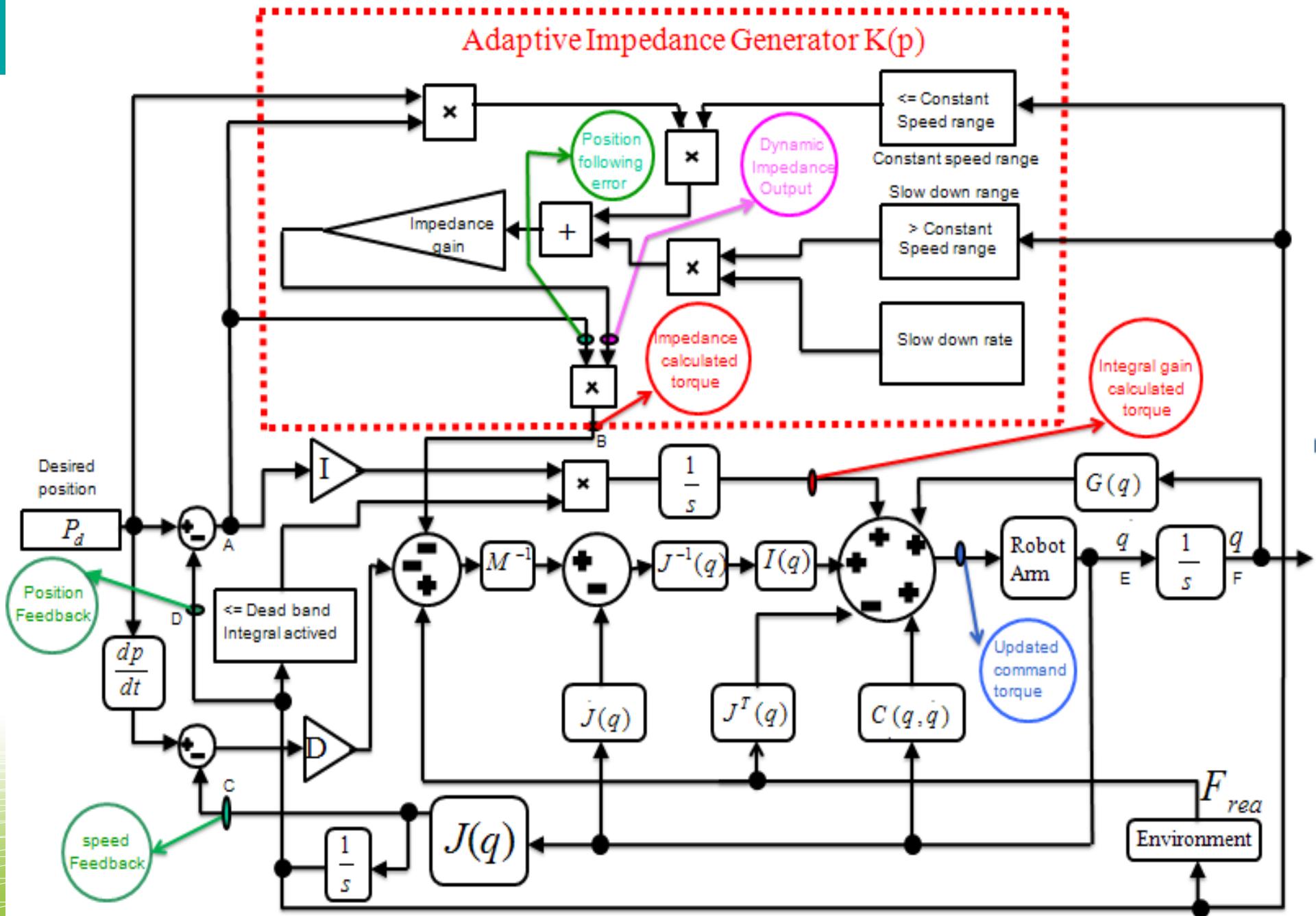
$$T_i^{i-1} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \cos \alpha_i & \sin \theta_i \sin \alpha_i & a_i \cos \theta_i \\ \sin \theta_i & \cos \theta_i \cos \alpha_i & -\cos \theta_i \sin \alpha_i & a_i \sin \theta_i \\ 0 & \sin \alpha_i & \cos \alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_4^0 = T_1^0 \cdot T_2^1 \cdot T_3^2 \cdot T_4^3 = \begin{bmatrix} R_{4 \times 3}^0 & P_{4 \times 3}^0 \\ 0 & 1 \end{bmatrix}$$



Experimental Results of Adaptive Impedance Control with 4-D.O.F Robot Arm

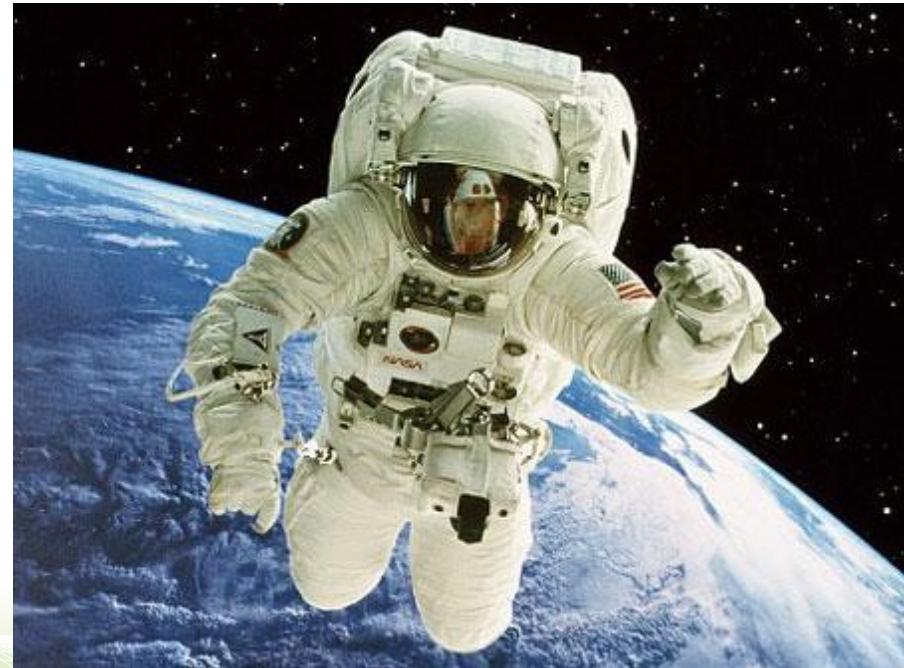
Multi-DOF Impedance Control Structure



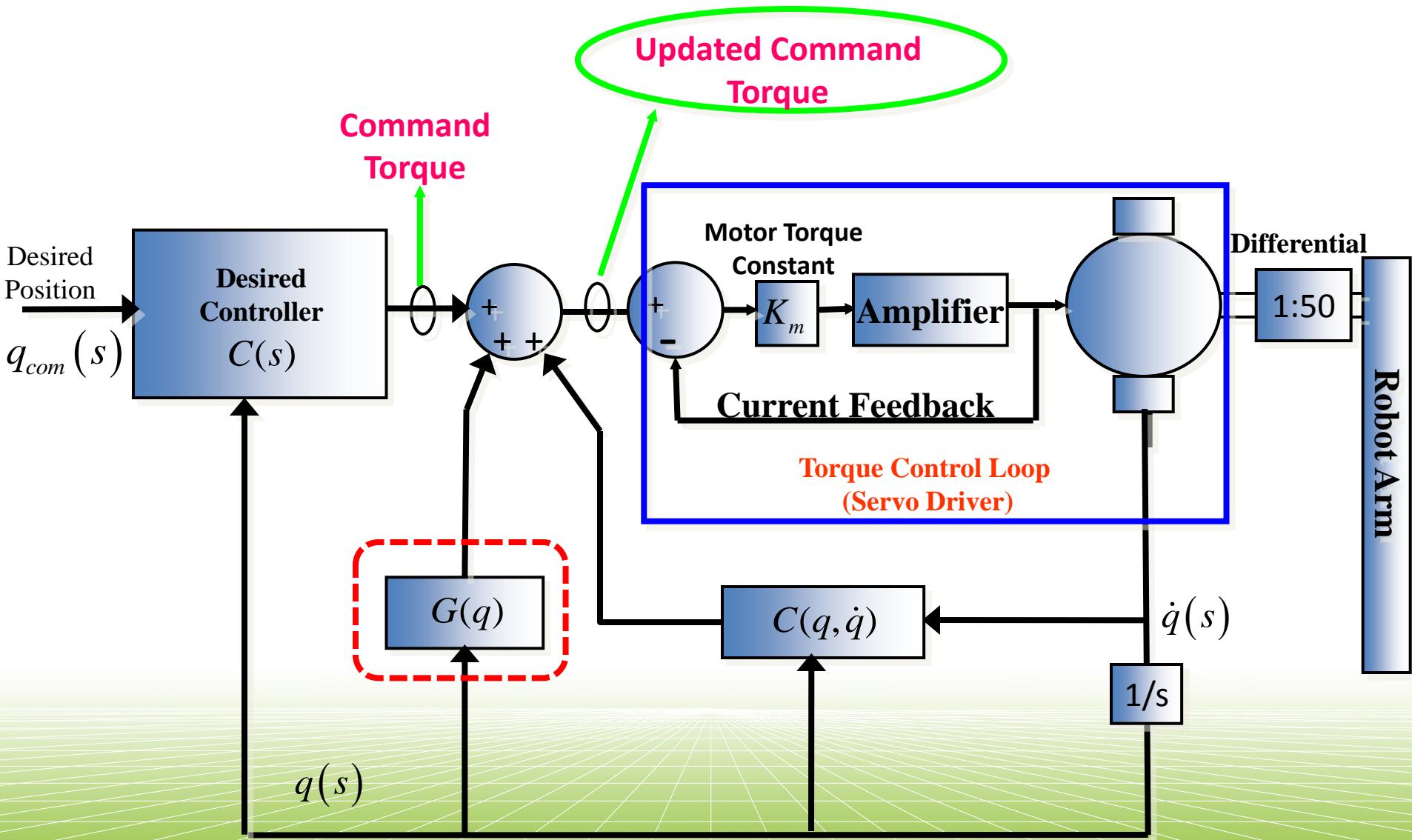


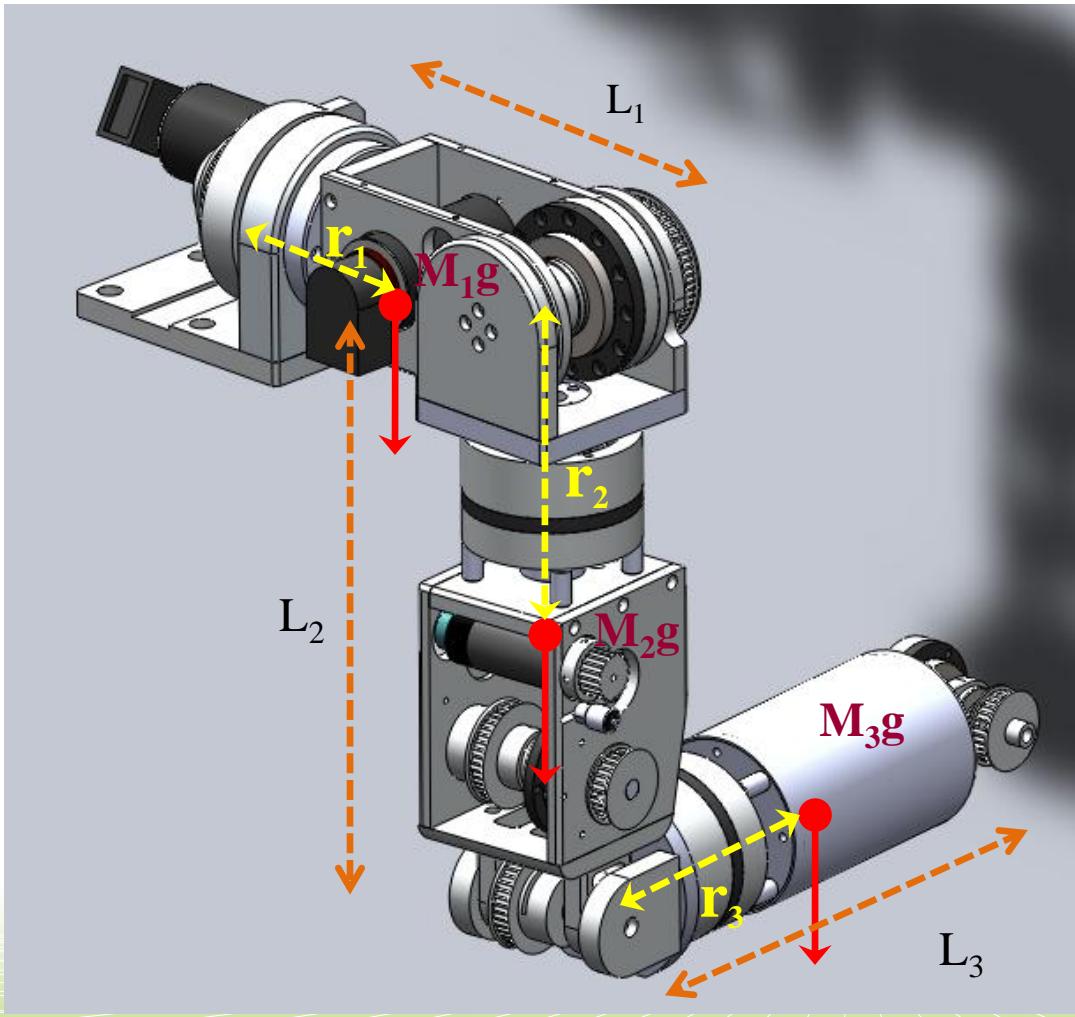
Gravity Compensator

Gravity Compensator



General Control Block Diagram





L_1 : Link₁

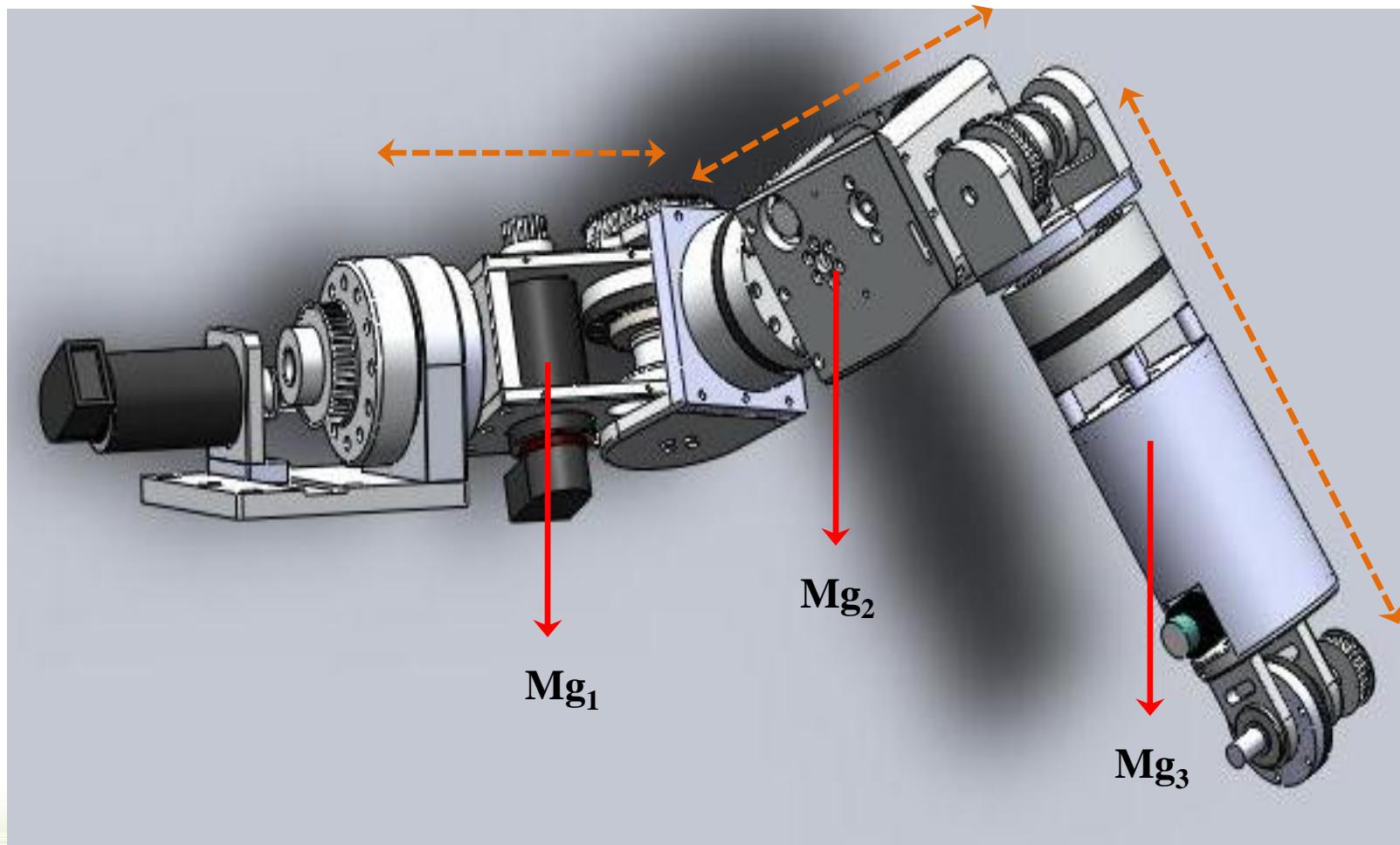
r_1 : distance of CoM1

L_2 : Link₂

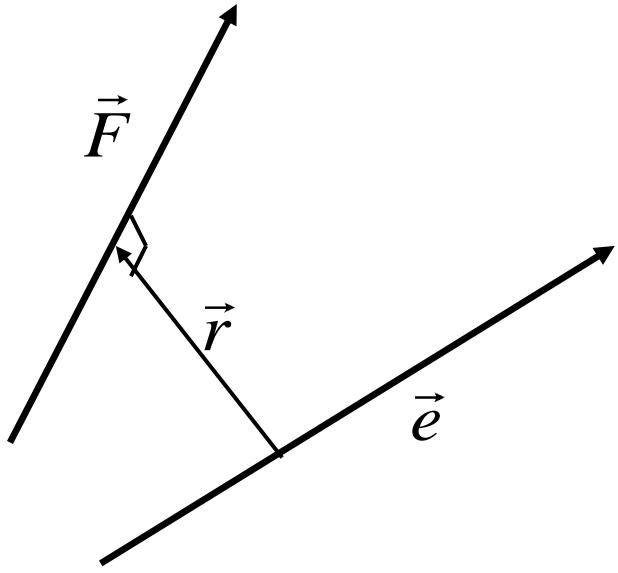
r_2 : distance of CoM2

L_3 : Link₃

r_3 : distance of CoM3



Vector Projection in 3 Dimension



$$\vec{M} = \vec{r} \times \vec{F}$$

$$\tau = \vec{M} \cdot \vec{e} = [\vec{r} \times \vec{F}] \cdot \vec{e}$$

$$\vec{\tau} = \{[\vec{r} \times \vec{F}] \cdot \vec{e}\} \vec{e}$$

\vec{F} : force vector in 3D space

\vec{r} : position vector in 3D space

\vec{e} : unit vector in 3D space

Vector Projection in Multi-DOF

$$\vec{F}_i = \sum m_i g \vec{i}$$

$$T_{r_i}^{0 \times 4} = T_1^0 \cdot T_2^1 \cdots T_{r_i}^{i-1}, \quad \vec{r}_i = \begin{bmatrix} T_{r_i}^0(1,4) \\ T_{r_i}^0(2,4) \\ T_{r_i}^0(3,4) \end{bmatrix}$$

$$R_{\theta_i} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i & 0 \\ \sin \theta_i & \cos \theta_i & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_{\alpha_i} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha_i & -\sin \alpha_i \\ 0 & \sin \alpha_i & \cos \alpha_i \end{bmatrix}$$

$$e_i^0 = R_{\theta_1} \cdot R_{\alpha_1} \cdot R_{\theta_2} \cdot R_{\alpha_2} \cdots R_{\theta_{i-1}} \cdot R_{\alpha_{i-1}} \cdot \vec{R}, \quad R = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

Result and Demo(Cont.)

$$\tau_1 = [\vec{r}_1 \times \vec{F}_1] \cdot \vec{e}_1^0$$

$$\begin{aligned} &= M_2 g * (r_2) * \cos(\theta_2) * \sin(\theta_1) + M_3 g * (L_2) * \cos(\theta_2) * \sin(\theta_1) \\ &+ M_3 g * (r_3) * (\cos(\theta_2) * \sin(\theta_4) * \sin(\theta_1) + \cos(\theta_1) * \cos(\theta_3) * \cos(\theta_4) + \sin(\theta_1) \\ &* \sin(\theta_2) * \sin(\theta_3) * \cos(\theta_4)) \end{aligned}$$

$$\tau_2 = [\vec{r}_2 \times \vec{F}_2] \cdot \vec{e}_2^0$$

$$\begin{aligned} &= \cos(\theta_1) * (M_2 g * (r_2) * \sin(\theta_2) + M_3 g * (L_2) * \sin(\theta_2) + M_3 g * (r_3) * \sin(\theta_4) * \sin(\theta_2) \\ &- M_3 g * (r_3) * \cos(\theta_2) * \sin(\theta_3) * \cos(\theta_4)) \end{aligned}$$

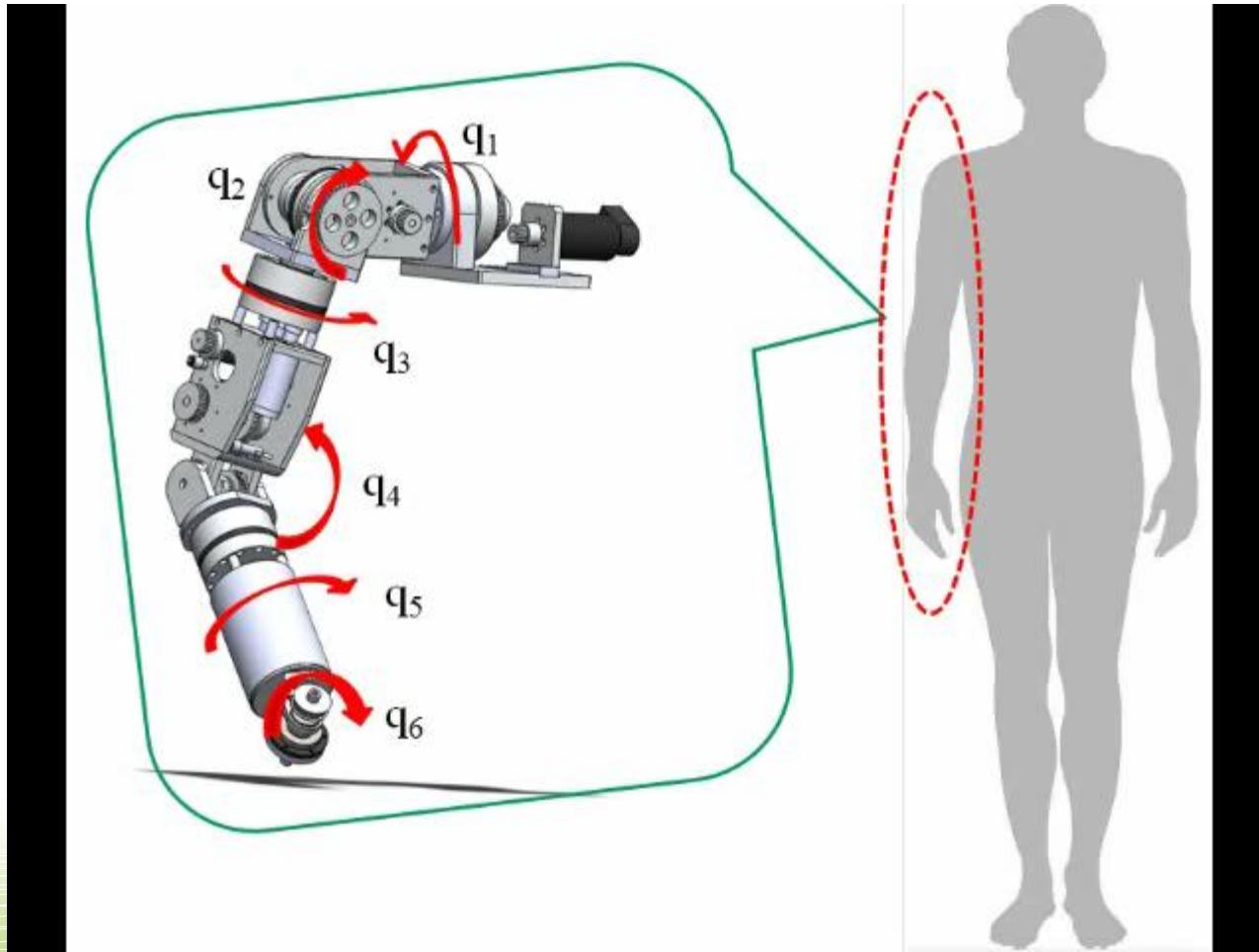
$$\tau_3 = [\vec{r}_3 \times \vec{F}_3] \cdot \vec{e}_3^0$$

$$= M_3 g * (r_3) * \cos(\theta_4) * (\sin(\theta_1) * \sin(\theta_3) + \cos(\theta_1) * \cos(\theta_3) * \sin(\theta_2))$$

$$\tau_4 = [\vec{r}_4 \times \vec{F}_4] \cdot \vec{e}_4^0$$

$$\begin{aligned} &= M_3 g * (r_3) * (\cos(\theta_1) * \cos(\theta_2) * \cos(\theta_4) + \cos(\theta_3) * \sin(\theta_4) * \sin(\theta_1) - \\ &\cos(\theta_1) * \sin(\theta_4) * \sin(\theta_2) * \sin(\theta_3)) \end{aligned}$$

Result and Demo(Gravity)





New Arm_Gravity compensator & auxiliary force.avi



Auxiliary Force/Torque Control

Auxiliary Force/Torque Control

Gravity compensation :

$$G_i = \sum_{i=1}^n \{ (\vec{r} \times \vec{F}) \bullet \vec{e} \}$$

$$\vec{e} = T_i^{Base}[Rot] * T_i[Joint_Dir]$$

Angular momentum and angular impulse principle :

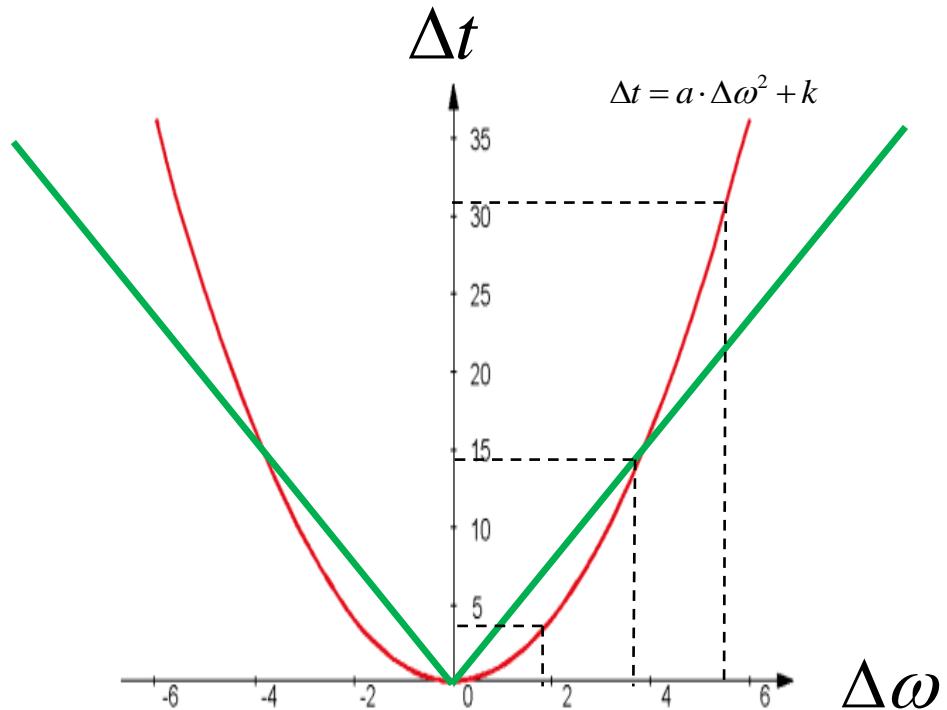
$$M_{auxiliary} \Delta t = I \Delta \omega$$

$$M_{auxiliary} = I \frac{\Delta \omega}{\Delta t}$$


The diagram shows the formula for auxiliary torque. Two red arrows point from the terms $\Delta \omega / \Delta t$ and I towards an orange oval containing the text "Adjustment Gain".

$$I = \frac{1}{12} m r^2$$

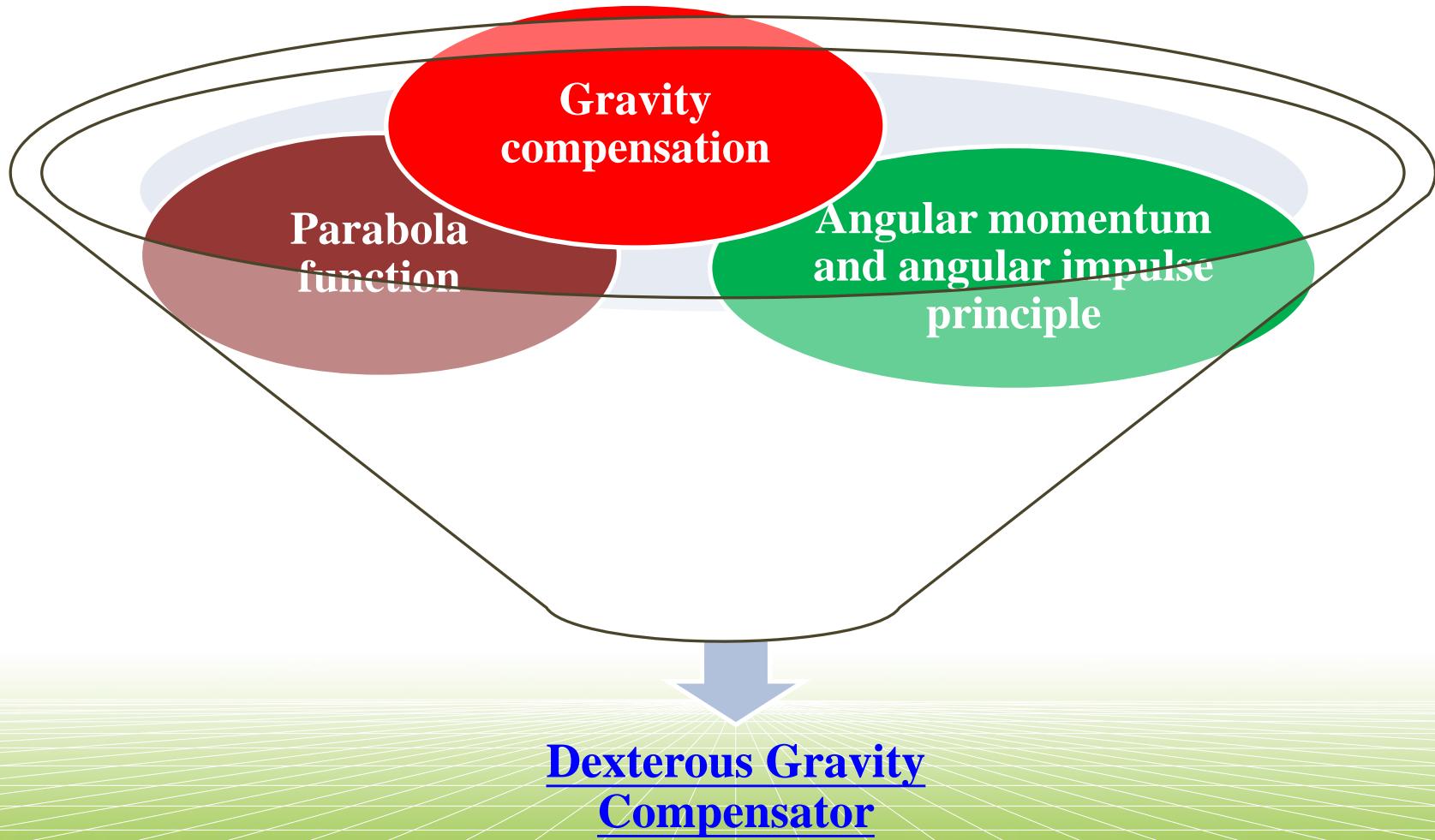
Parabolic Curve



$$\Delta t = a \cdot \Delta \omega^2 + k$$

$$M_{\text{auxiliary}} = I \frac{\Delta \omega}{a \cdot \Delta \omega^2 + k}$$

Result and Demo





gravity_compensator_compare(small_x2).avi



Arm-flip-P1070459.MOV



ArmflipA-P1070460.MOV

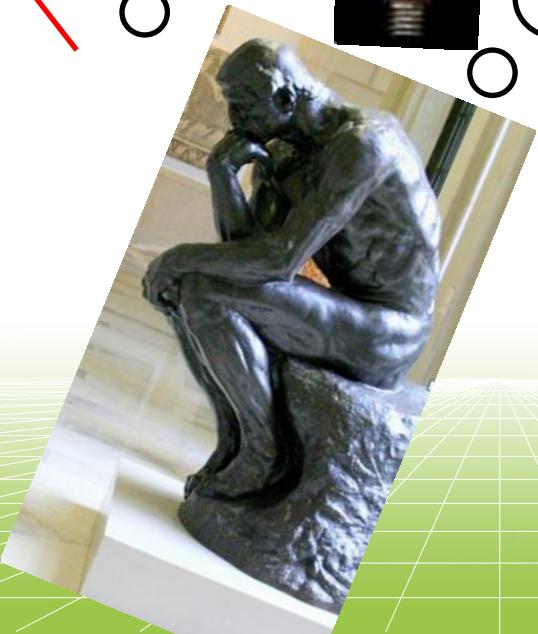


New Arm_teach&play.avi

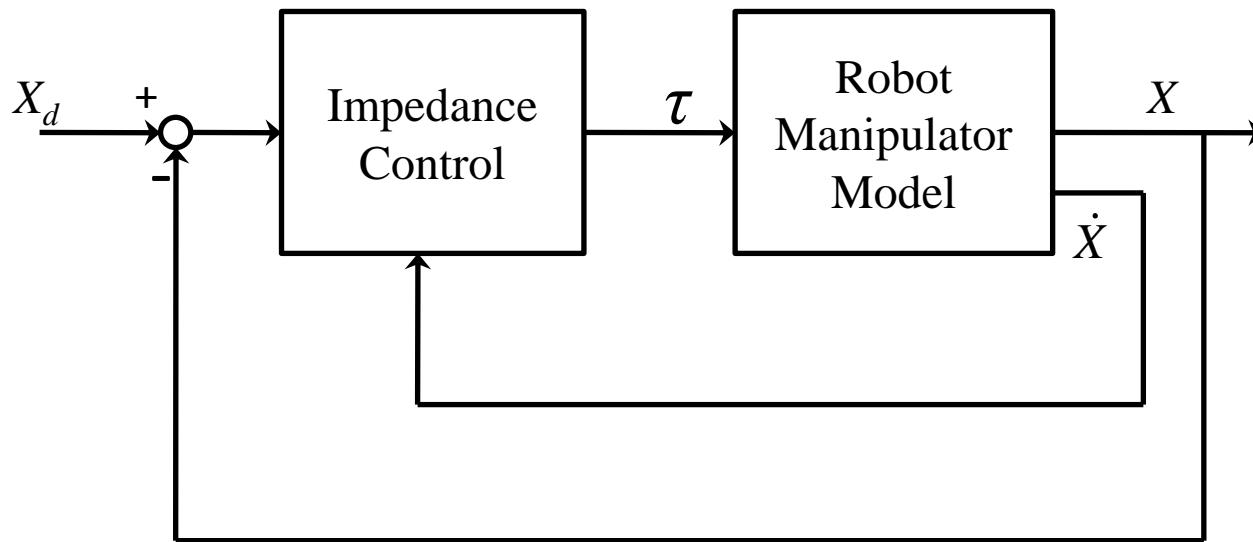


Force Counterbalance Control

Motivation



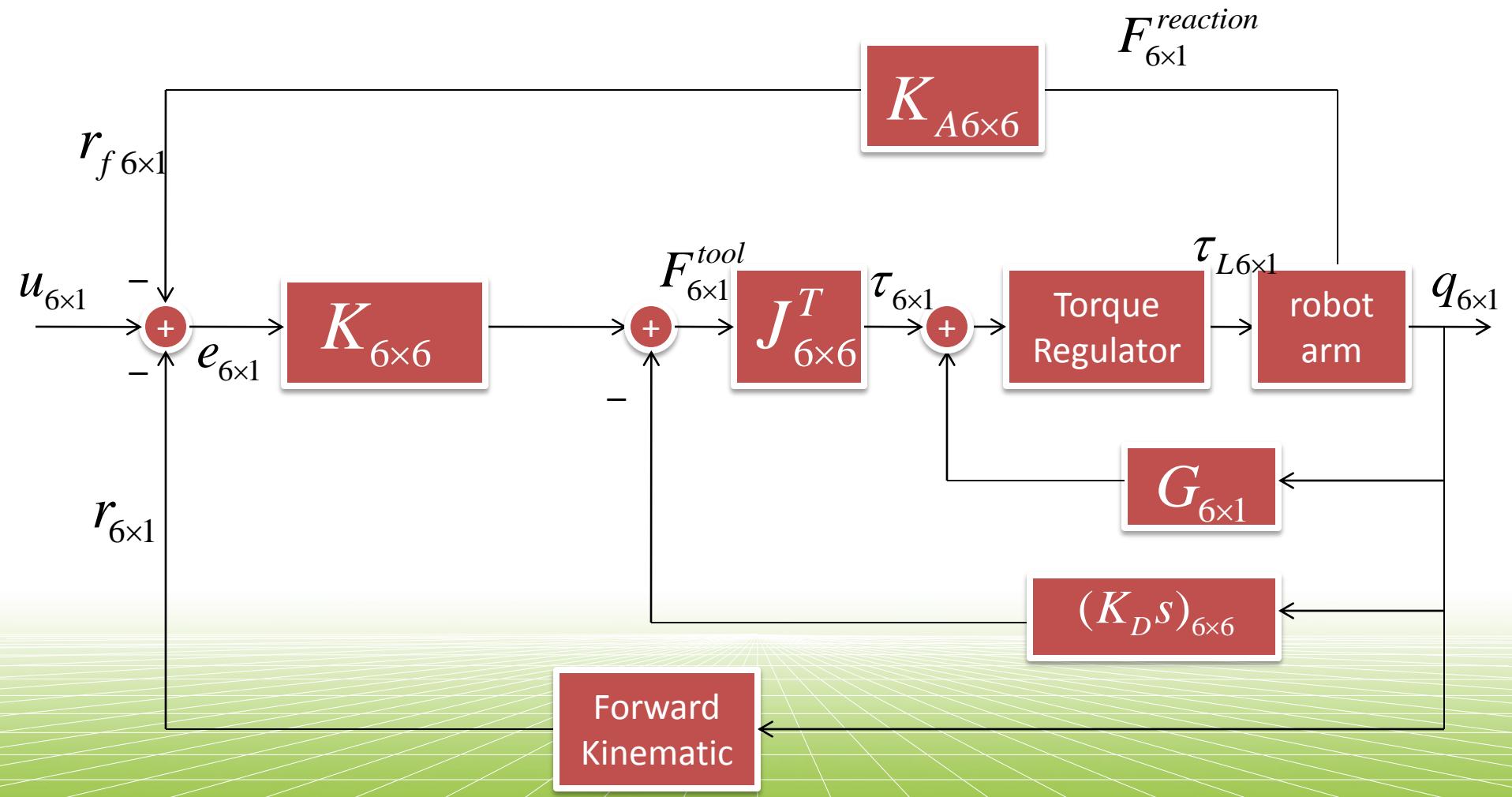
Impedance Control Diagram



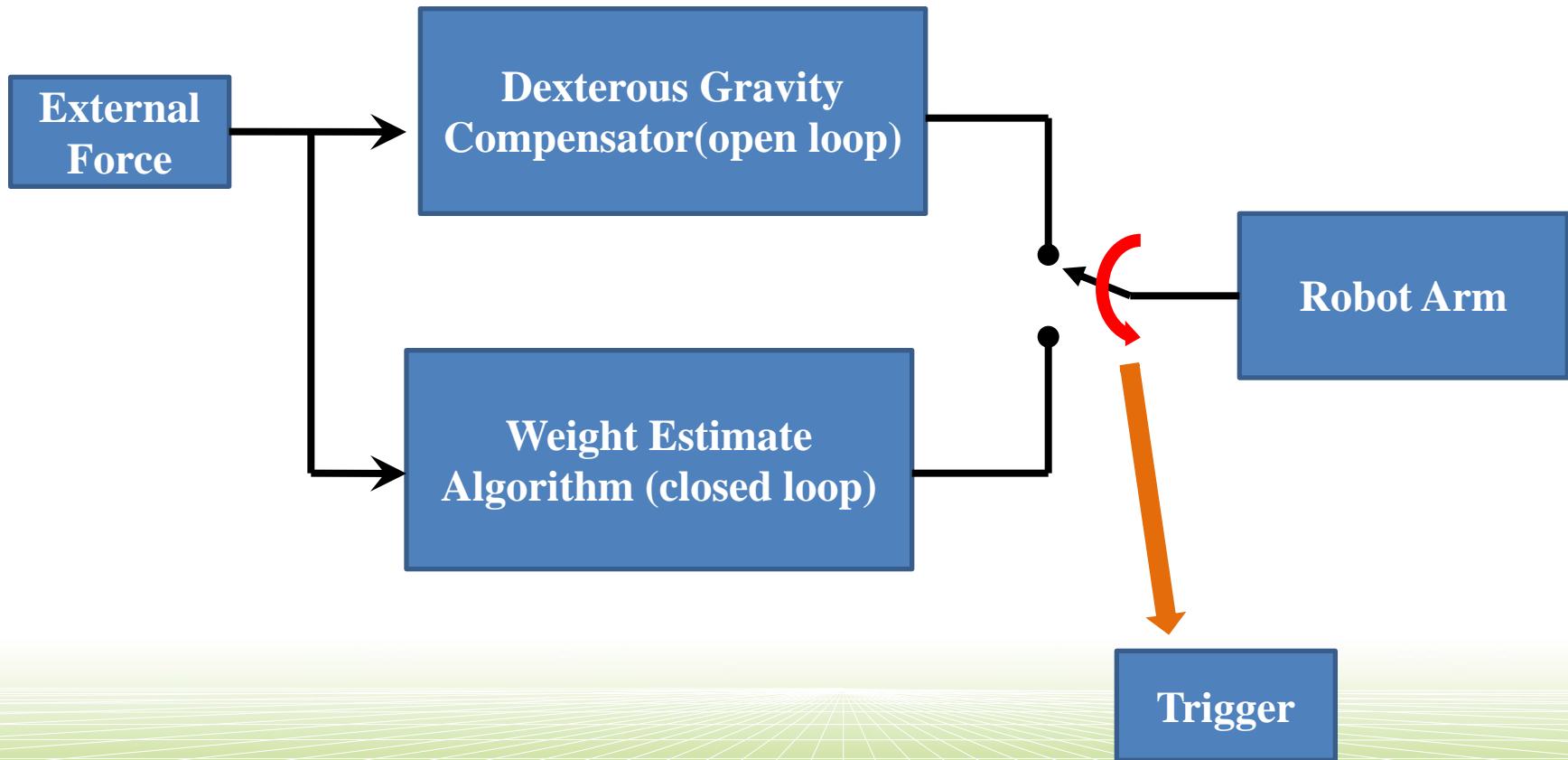
Simple impedance control law:

$$\tau = K(X_d - X)$$

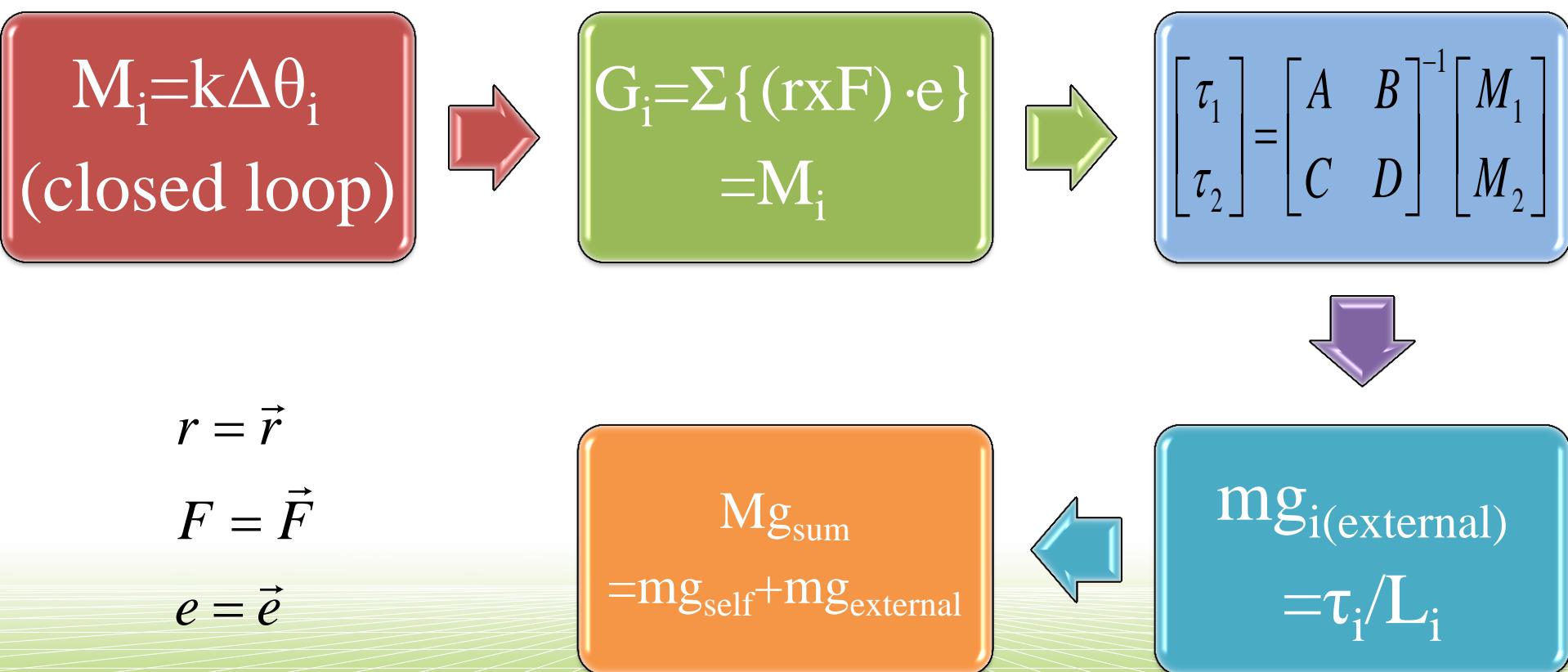
Impedance Control Algorithm



Force/Weight Balance Control Algorithm



Weight Estimate Algorithm



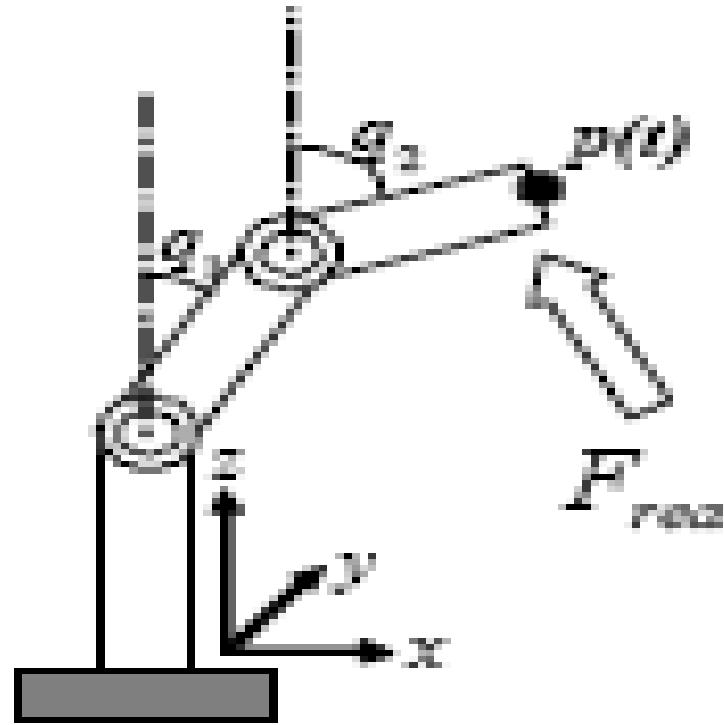


Without_force_balance.avi



with-force_balance.avi

Dynamic equation of robot manipulator



$$I(q) \ddot{q} + C(q, \dot{q}) \dot{q} + G(q) = \tau_{act} + \tau_{rea}$$



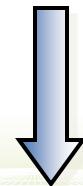
Transformation of the joint angle and the Cartesian coordinate

$$p = f(q)$$

$$J(q) = \frac{\partial f(q)}{\partial q}$$

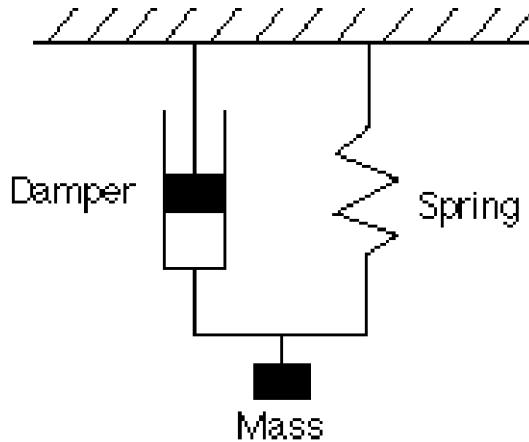
$$\dot{p} = J(q) \dot{q} \quad \tau_{rea} = J(q)^T F_{rea}$$

$$I(q) \ddot{q} + C(q, \dot{q}) \dot{q} + G(q) = \tau_{act} + \tau_{rea}$$



$$I(q) \ddot{q} + C(q, \dot{q}) \dot{q} + G(q) = \tau_{act} + J(q)^T F_{rea}$$

$$I(q) \ddot{q} + C(q, \dot{q}) \dot{q} + G(q) = \tau_{act} + J(q)^T F_{rea}$$



$$M \ddot{p} + C \dot{p} + Kp = F_{rea}$$

$$\tau_{act} = I(q)J(q)^{-1}\{M^{-1}[F_{rea} - C \dot{p} - Kp] - J(q) \dot{q}\}$$

$$+ C(q, \dot{q}) \dot{q} + G(q) - J(q)^T F_{rea}$$

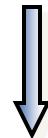
$$M \ddot{p} + C \dot{p} + Kp = F_{rea} \implies \ddot{p} = M^{-1}(F_{rea} - C \dot{p} - Kp)$$

Because $\ddot{p} = J(q) \ddot{q} \implies \ddot{p} = \dot{J}(q) \dot{q} + J(q) \ddot{q}$

$$\implies \ddot{q} = J(q)^{-1}(\ddot{p} - \dot{J}(q) \dot{q})$$

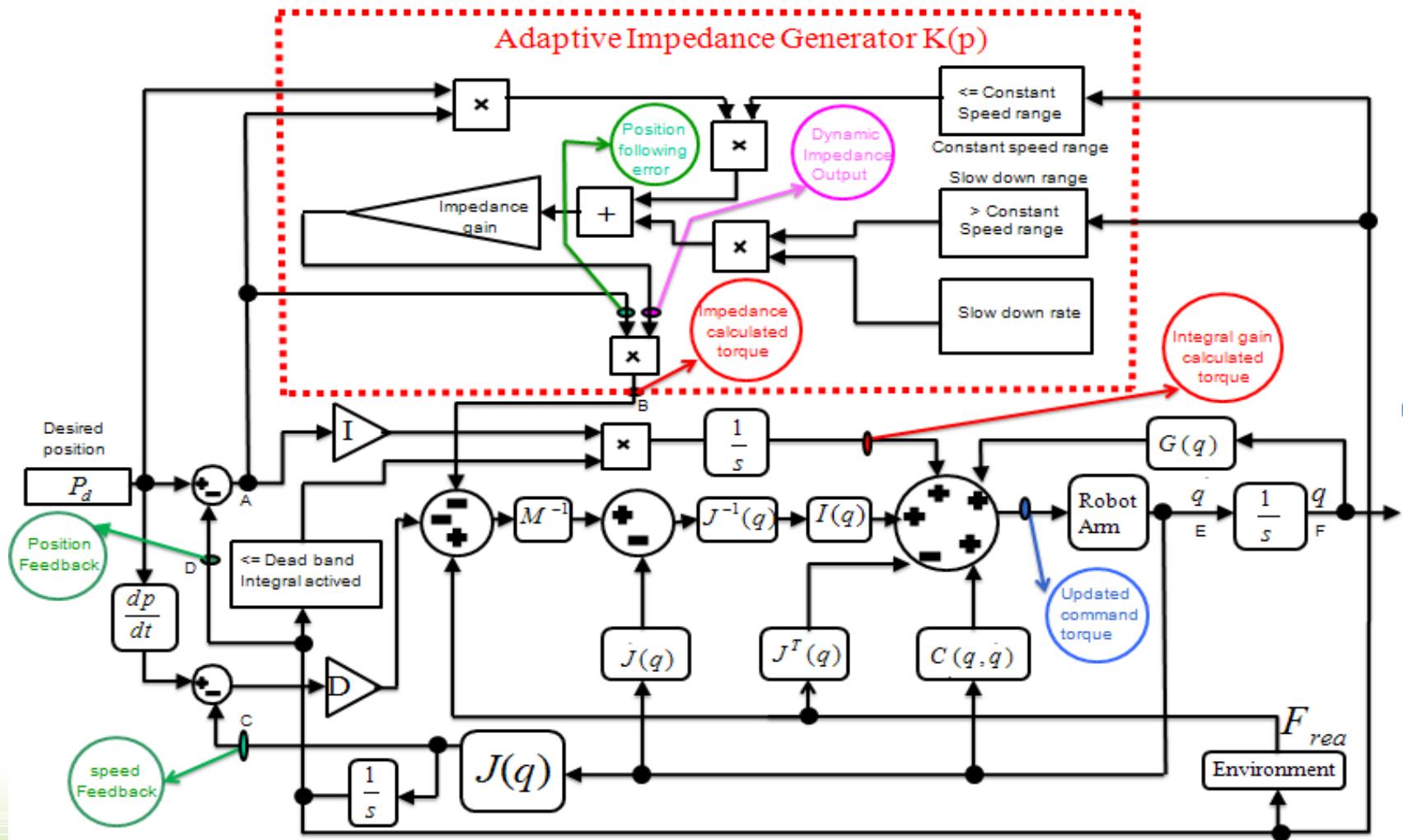
$$\implies \ddot{q} = J(q)^{-1}(M^{-1}(F_{rea} - C \dot{p} - Kp) - \dot{J}(q) \dot{q})$$

$$I(q) \ddot{q} + C(q, \dot{q}) \dot{q} + G(q) = \tau_{act} + J(q)^T F_{rea}$$



$$\tau_{act} = I(q)J(q)^{-1}\{M^{-1}[F_{rea} - C \dot{p} - Kp] - \dot{J}(q) \dot{q}\} + C(q, \dot{q}) \dot{q} + G(q) - J(q)^T F_{rea}$$

Adaptive Impedance Control



$$\tau_{act} = I(q)J(q)^{-1}\{M^{-1}[F_{rea} - C p - Kp] - J(q)q\} + C(q, q)q + G(q) - J(q)^T F_{rea}$$



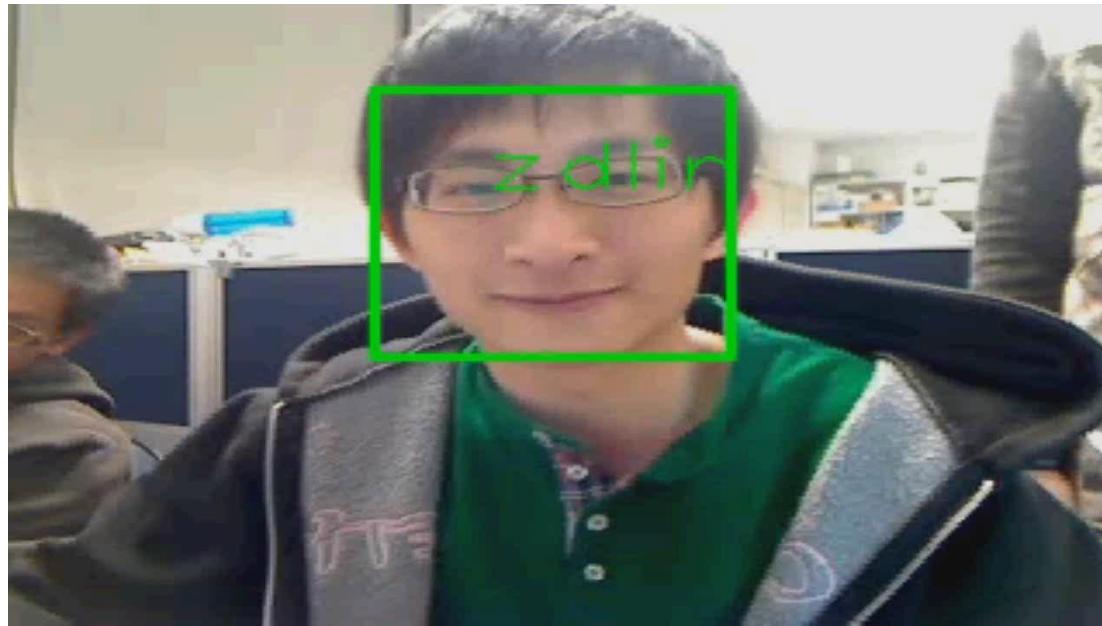
Arm control

- 3min_version.avi

Arm teach and play simultaneous auto play

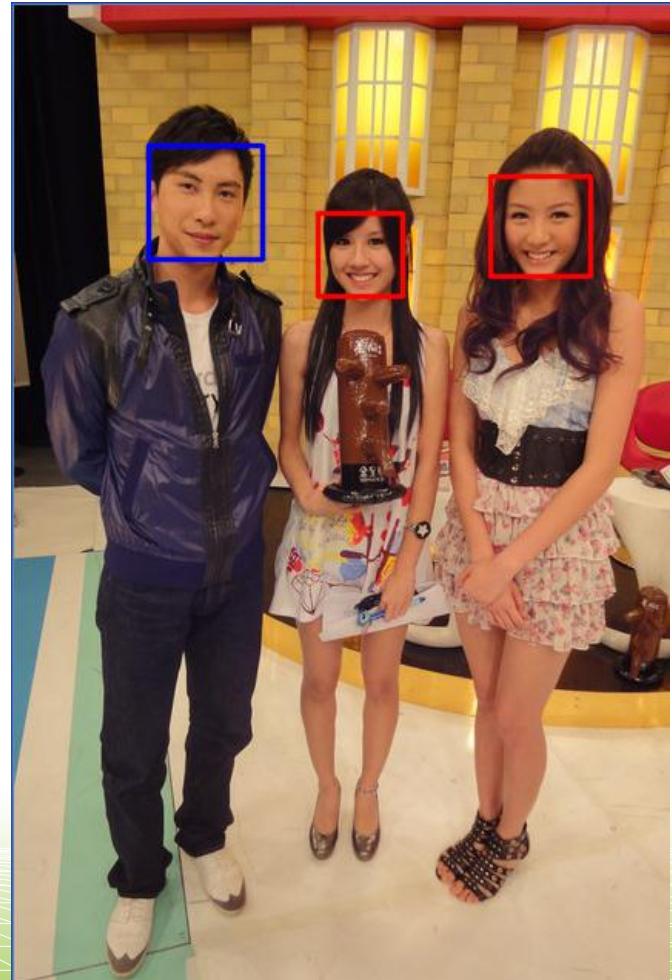


Gender Recognition





- 人臉偵測 Face detection
- 前置處理 Preprocess
- 特徵萃取 Feature extraction
- 分類 Classifier
- 學習 Ensemble learning

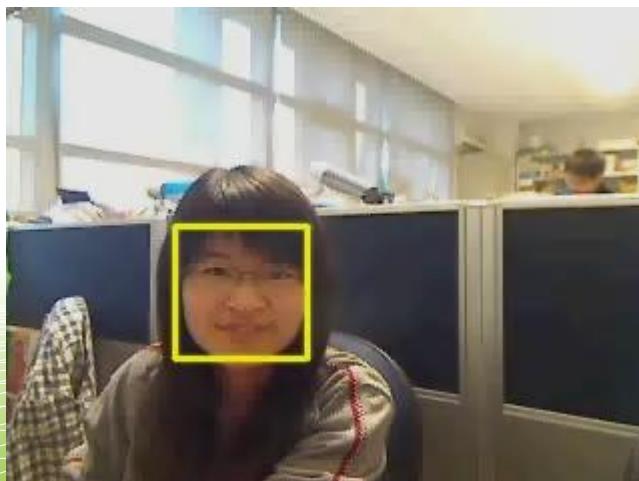
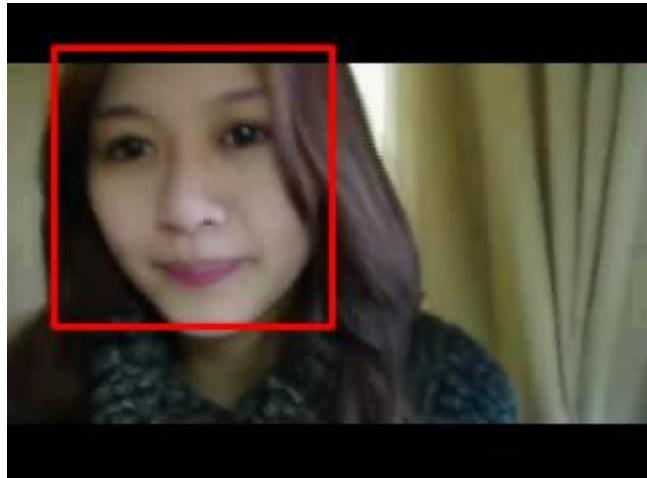


Gender Recognition

Male

Female

Unknown

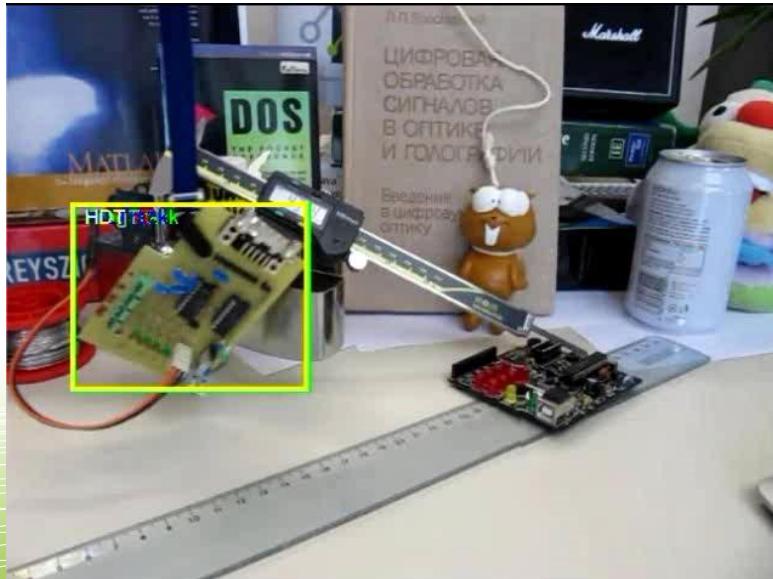


Face Recognition DEMO



Object Tracking

- Hybrid Discriminative Tracking
 - *HDT* (proposed) — yellow
- *MILTRack* (Babenko *et al.*, *CVPR’09*) — blue
- *FragTrack* (Grabner *et al.*, *ECCV’08*) — green
- *PROST* (Santner *et al.*, *CVPR’10*) — red



board



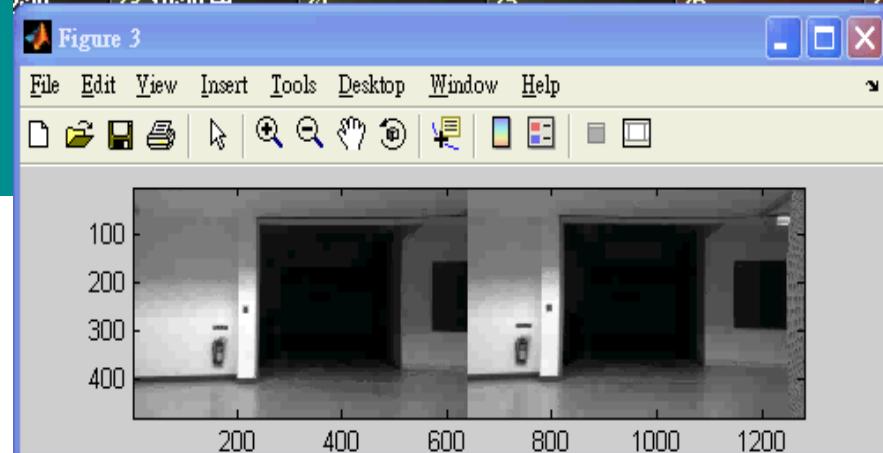
lemming

DEMO

Surveillance

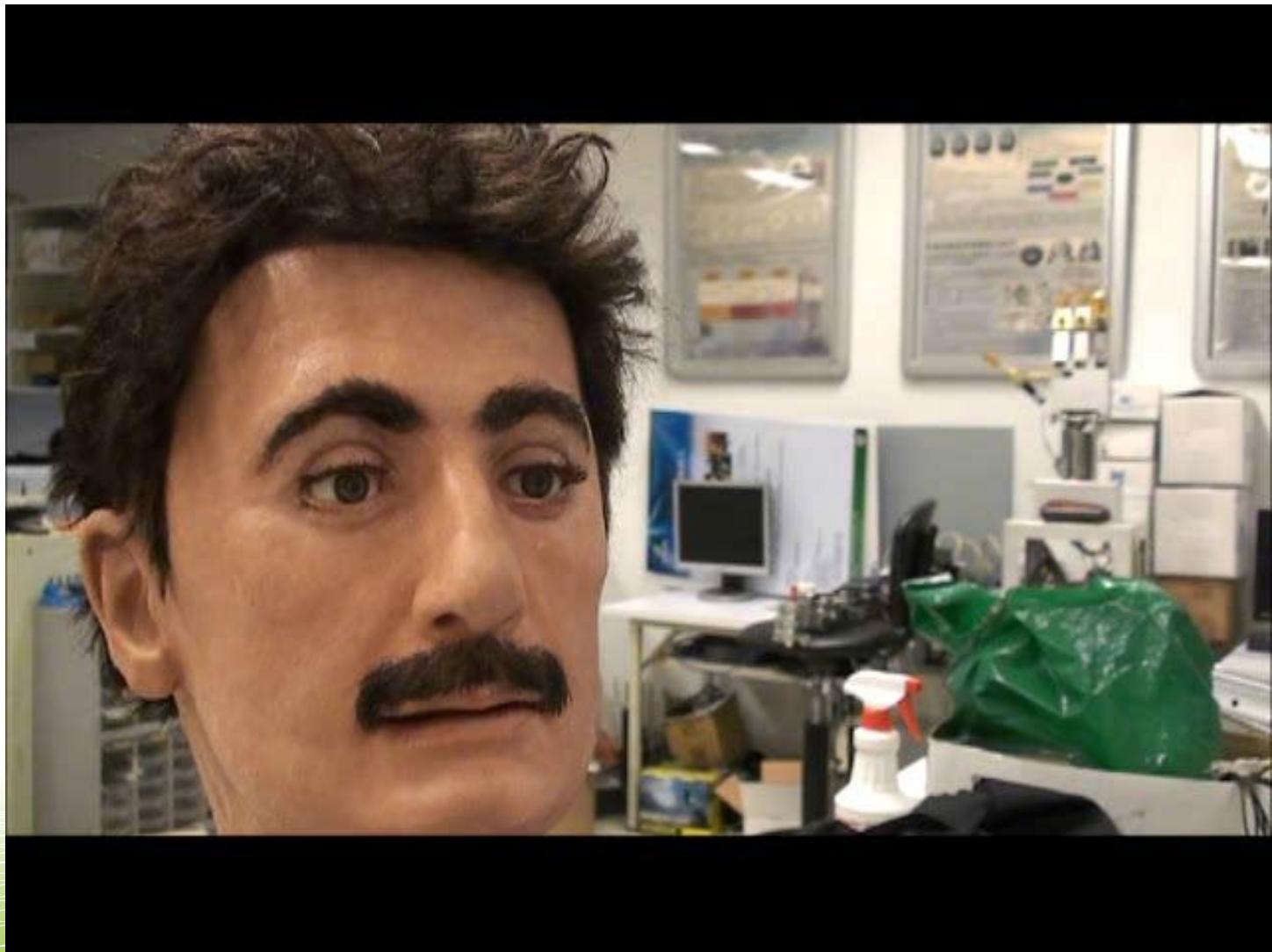


3D visual tracking





Einstein Facial Exp. Demo





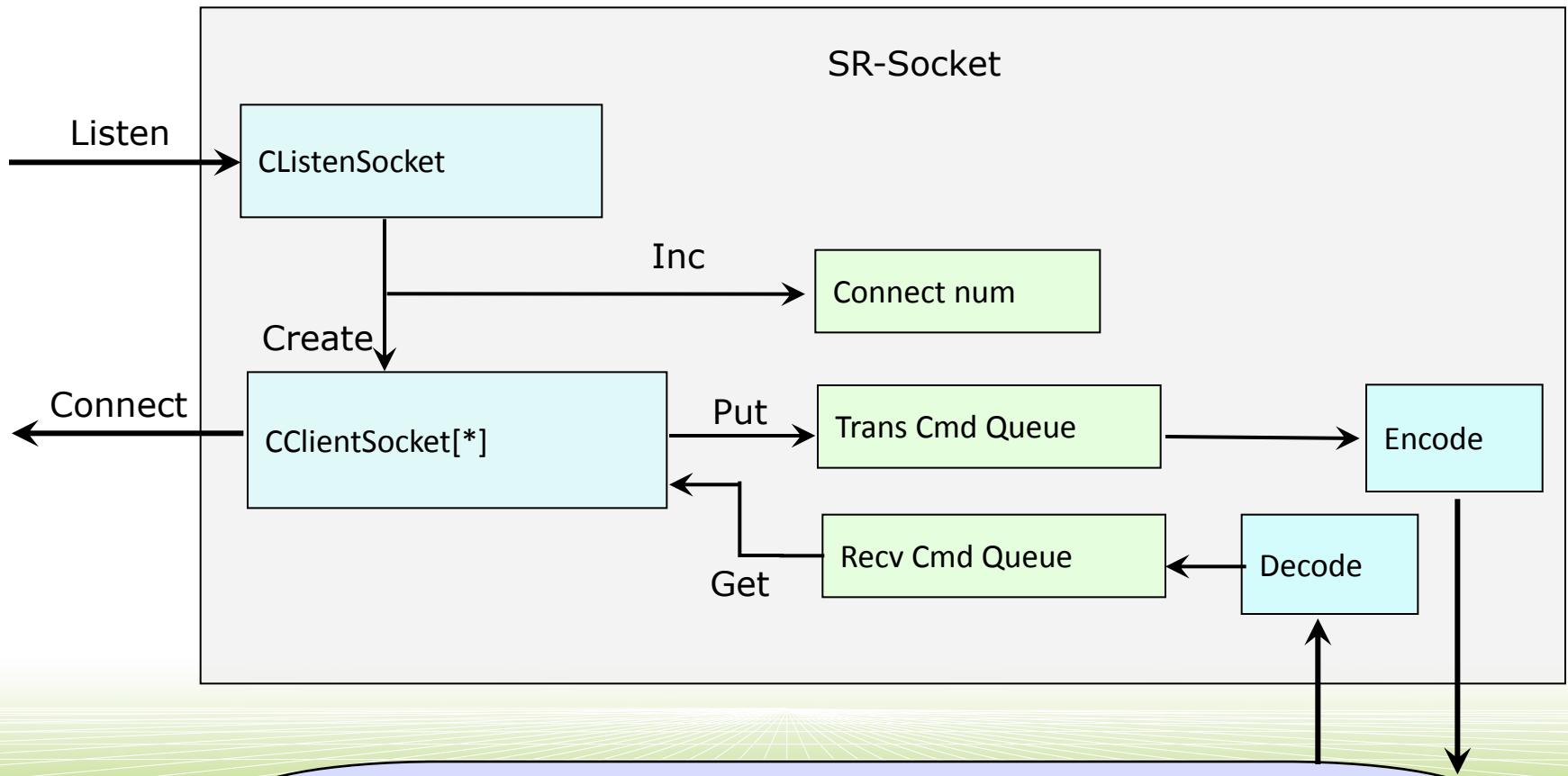
Einstein Interaction

- Facial+expression-min
tsai\scenario_surprise.wmv

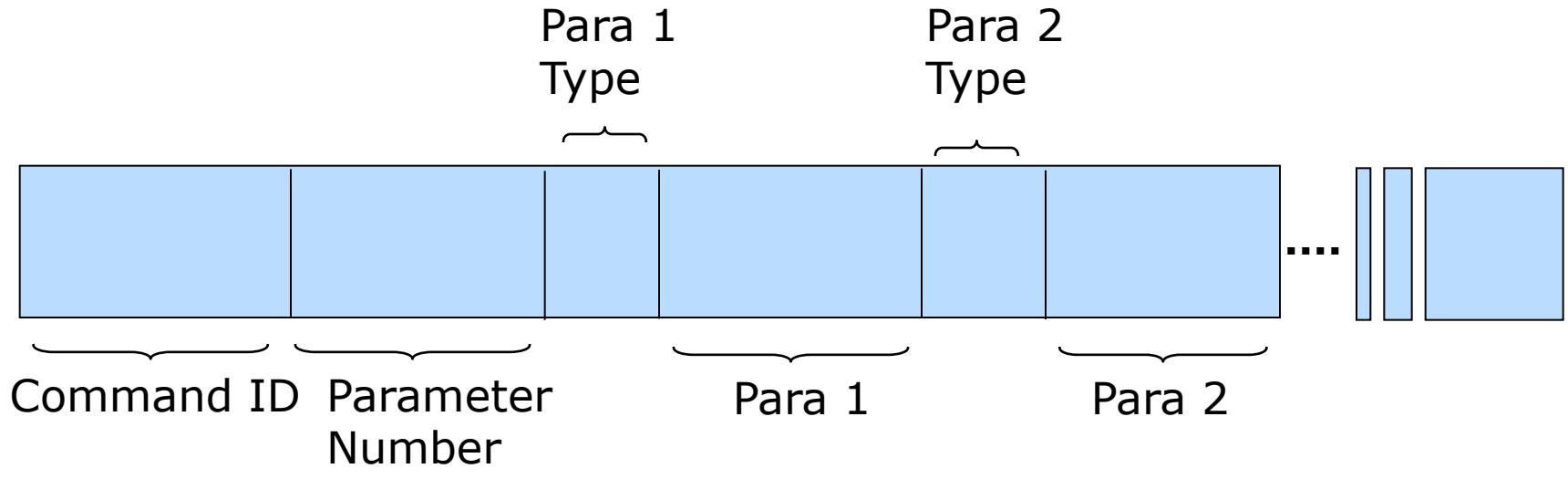
facial+expression-min
tsai\scenario_disgust.wmv

facial+expression-min
tsai\scenario_fearful.wmv

Remote Control– SRSocket



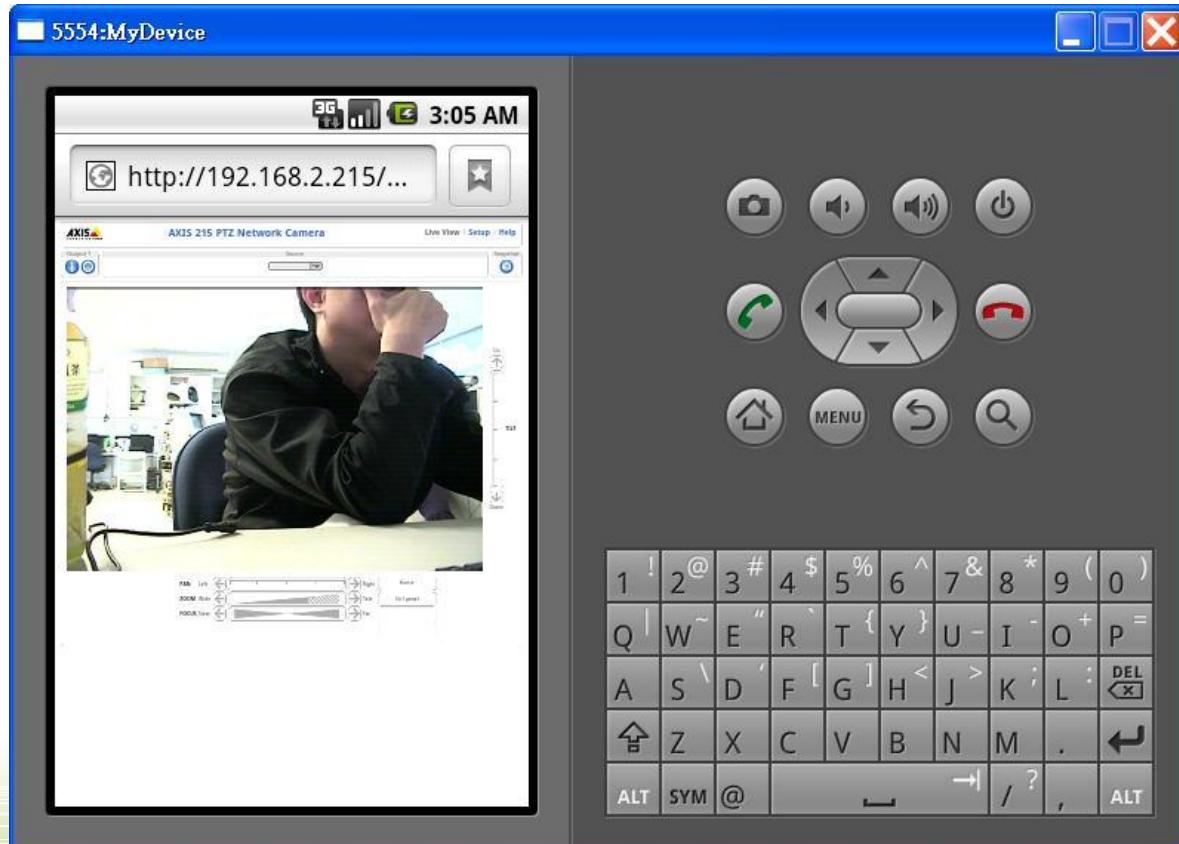
Remote Control – Command Format



Parameter Type

- | | |
|------------|-----------------------|
| 1. Int | 5. Long |
| 2. CString | 6. Byte Stream |
| 3. Word | 7. Byte Stream Packet |
| 4. Double | |

Remote Control - Android & iPhone



Android



iPhone



Thank You !

<http://ira.ee.ntu.edu.tw/rst/index.php>



RST, Robotics Society of Taiwan