

Study On Golf Swing Robot

-Motion control method based on energy control-
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Background

Motion control of hyper-dynamic manipulation

Capability of hyper-dynamic manipulation like humans'
Smart structure Motion control skill

Offline motion generation + PD control

Optimization based mathematical method

- Problems:**
1. Difficult to solve strong nonlinear problems
 2. Difficult to converge to a global solution
 3. High time cost of calculation

Research Object

2R Hyper Dynamic Manipulator Based on the Dynamically-Coupled Driving



State equation: $\dot{x} = F(x, \tau) = \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ M^{-1}(-N(x) + \tau) \end{bmatrix}$
Smart structure → Utilization of dynamically-coupled driving

Driving torque limitation:
DD Motor1: Maximum Torque 100 Nm
DD Motor2: Maximum Torque 11 Nm
Smart Structure

Torque compensation of DD motor 2

Impact position: both the arm and the club are downward vertically in the swing plane

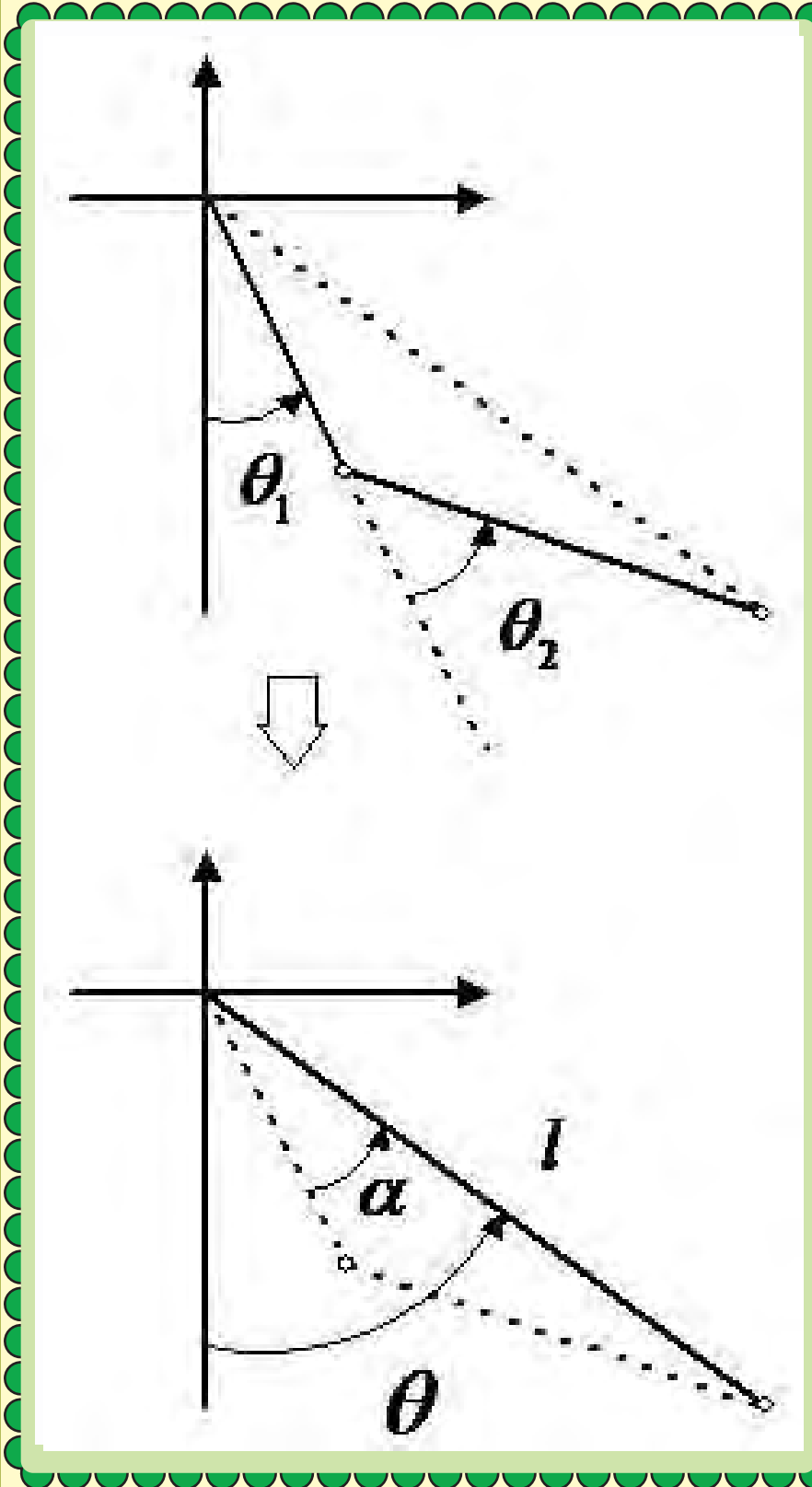
Realization of hyper dynamic manipulation while in a smart structure

Research Purpose

To establish a new control method to realize accurate control of high-speed golf swings with utilizing dynamically coupled driving:

- * Stable and high accurate control of golf swings
- * Active torque compensation

Target Dynamics Method



Assume a plant

$$\dot{x} = F(x, u), y = H(x, u)$$

is linearizable, We define the Lie derivative as

$$L_F H = \frac{\partial H}{\partial x} \cdot F$$

Then, if

$$L_F^2 H = w$$

the system will follow the motion of the system

$$\dot{y} = w$$

in control of the following law:

$$u = L_F^{-1} H^{-1}(x, \dot{y})$$

Pre-impact controller design

State equation:

$$\dot{x} = F(x, \tau) = \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ M^{-1}(-N(x) + \tau) \end{bmatrix}$$

Output function:

$$y = H(x) = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \theta_1 + \alpha \\ \dot{\theta}_1 + \frac{l_1(l_1 + l_2 \cos \theta_2)}{l_1^2 + l_2^2 + 2l_1 l_2 \cos \theta_2} \dot{\theta}_2 \end{bmatrix}$$

Control law:

$$a_1 \tau_1 + a_2 \tau_2 = -\omega^2 \theta - K_v (E - E^*) \dot{\theta} + a_3 + a_1 N_1 + a_2 N_2$$

Target dynamics:

harmonic oscillator in control of energy law

$$\dot{y} = \begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\omega^2 & -K_v(E - E^*) \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}$$

$$E = \dot{\theta}^2 / 2 + \omega^2 \theta^2 / 2$$

$$\tau_1 = K_v (E - E^*) (\dot{\theta}_1 - \dot{\theta}_2) \quad (\text{Port-controlled Hamilton system})$$

$$\tau_2 = \left[-\omega^2 \theta - K_v (E - E^*) \dot{\theta} + a_3 + a_1 N_1 + a_2 N_2 - a_1 \tau_1 \right] / a_2$$

Active torque compensation of the wrist

$$\begin{aligned} \tau_2 > \tau_{2max} : \tau_2 &= \tau_{2max} \\ \tau_2 < -\tau_{2max} : \tau_2 &= -\tau_{2max} \end{aligned}$$

$$\begin{aligned} \tau_2 > \tau_{2max} : \tau_2 &= \tau_{2max} \\ \tau_2 < -\tau_{2max} : \tau_2 &= -\tau_{2max} \end{aligned}$$

Post-impact controller design

Target dynamics:

Single pendulum in control of Proportional Plus Gravity Compensation (PPGC)

$$\dot{y} = \begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -K_p & -K_v \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} - \begin{bmatrix} 0 \\ -K_g \theta_f \end{bmatrix}$$

Control law of the pseudo angle:

$$a_1 \tau_1 + a_2 \tau_2 = -K_p (\theta - \theta_f) - K_v \dot{\theta} + c + a_1 N_1 + a_2 N_2$$

Control law:

$$\tau_1 = \left[-K_p (\theta - \theta_f) - K_v \dot{\theta} + c + (a_1 N_1 + a_2 N_2) \right] / (a_1 + a_2) + a_2 \left[c_1 + \Omega_1 \sin \theta_1 - K_{g1} \theta_1 - K_{g2} (\theta_1 - \theta_f) \right] / (a_1 + a_2)$$

$$\tau_2 = \left[-K_p (\theta - \theta_f) - K_v \dot{\theta} + c + (a_1 N_1 + a_2 N_2) \right] / (a_1 + a_2) - a_1 \left[c_1 + \Omega_1 \sin \theta_1 - K_{g1} \theta_1 - K_{g2} (\theta_1 - \theta_f) \right] / (a_1 + a_2)$$

Control law of the arm:

$$\tau_1 - \tau_2 - c_1 = M_1 \ddot{\theta}_1 + \Omega_1 \sin \theta_1$$

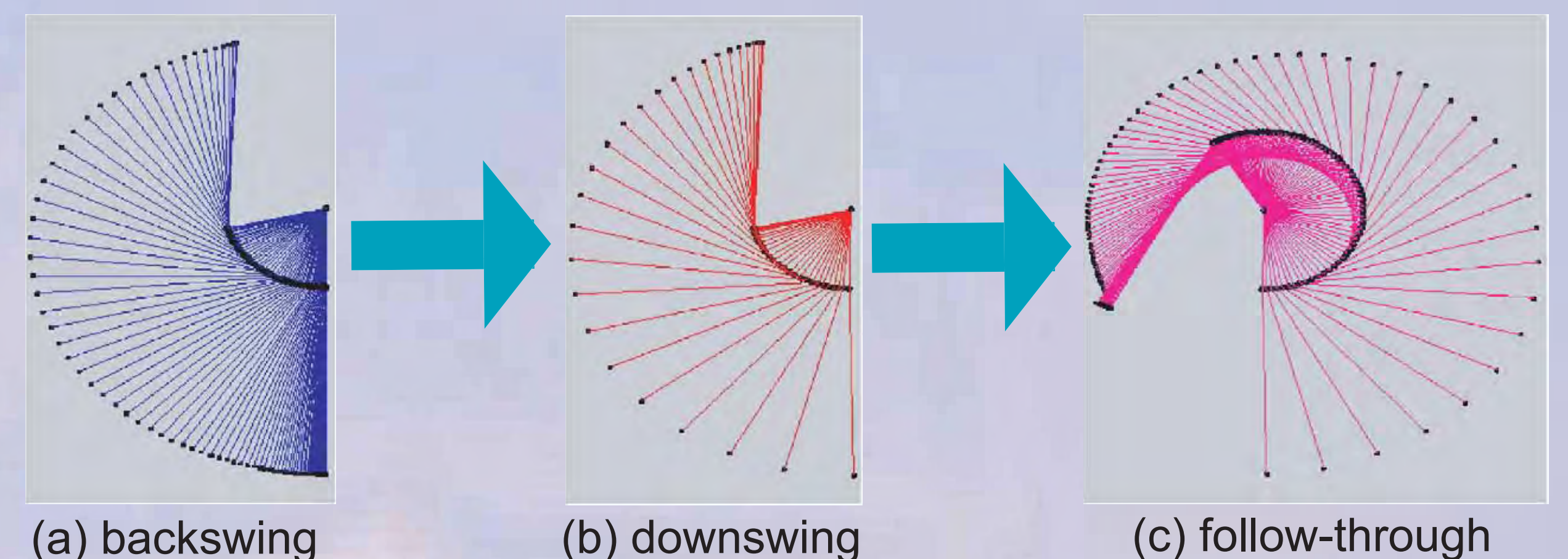
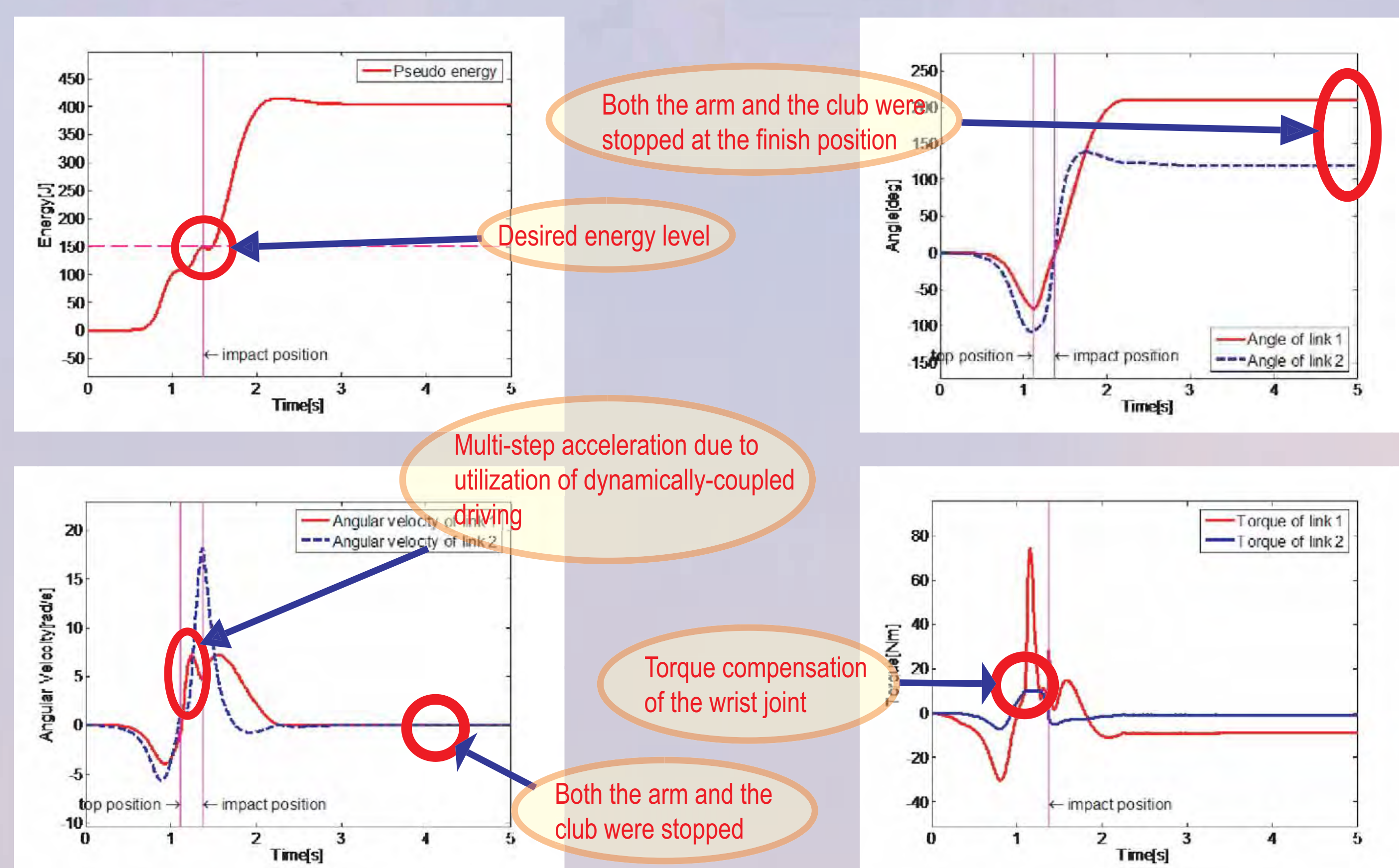
where:

$$M_1 = (m_1 l_{g1}^2 + m_2 l_1^2 + J_1), \Omega_1 = (m_1 g l_{g1} + m_2 g l_1)$$

$$c_1 = m_2 l_1 l_{g2} \left[(\dot{\theta}_1 + \dot{\theta}_2) \cos \theta_2 - \sin \theta_2 (\dot{\theta}_1 + \dot{\theta}_2)^2 \right]$$

Results of Numerical Examples

Impact speed: 20m/s
Impact position: the angular positions of the arm and the club are 0 [deg]



Energy control

PPGC control

Conclusion

A target dynamics based energy control law for pre-impact swing and proportional plus gravity compensation control law for post-impact swing has been proposed. Numerical results show:

- * Stable and high accurate control of golf swings
- * Utilization of dynamically-coupled driving by active torque compensation