

Implementation and Control for an MDOF Cable-Suspended Parallel Robot

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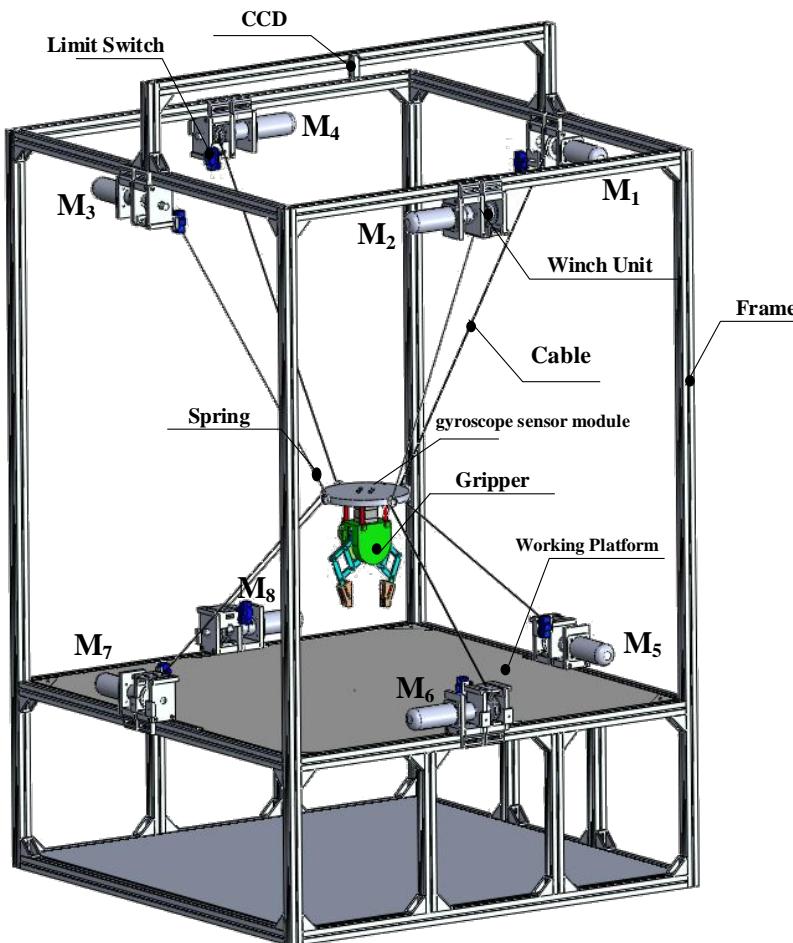
RESULTS AND DISCUSSIONS

INTRODUCTION

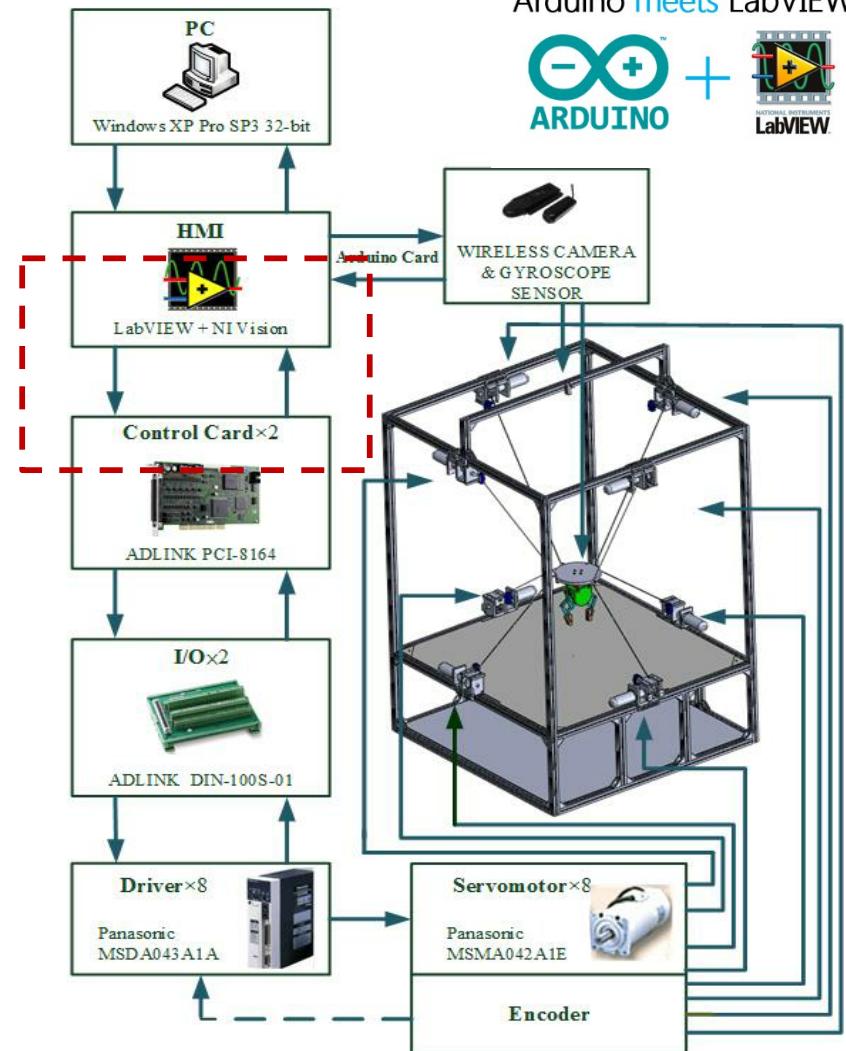


- ◆ Cable Suspended Robot – Parallel Type Robot
 - ◆ parallel manipulators with the end-effector supported by cables with driving motors.
- ◆ Cable Suspended Robot – Low inertia, high load capacity, high re-configurability, high payload-to-weight ratio, large reachable workspace
- ◆ Applications- Aerostats, towing cranes, elevators, locomotion interfaces, large-scale manufacturing
- ◆ Challenges – cables flexibility, tension limit, MDOF control...

SYSTEM CONFIGURATION

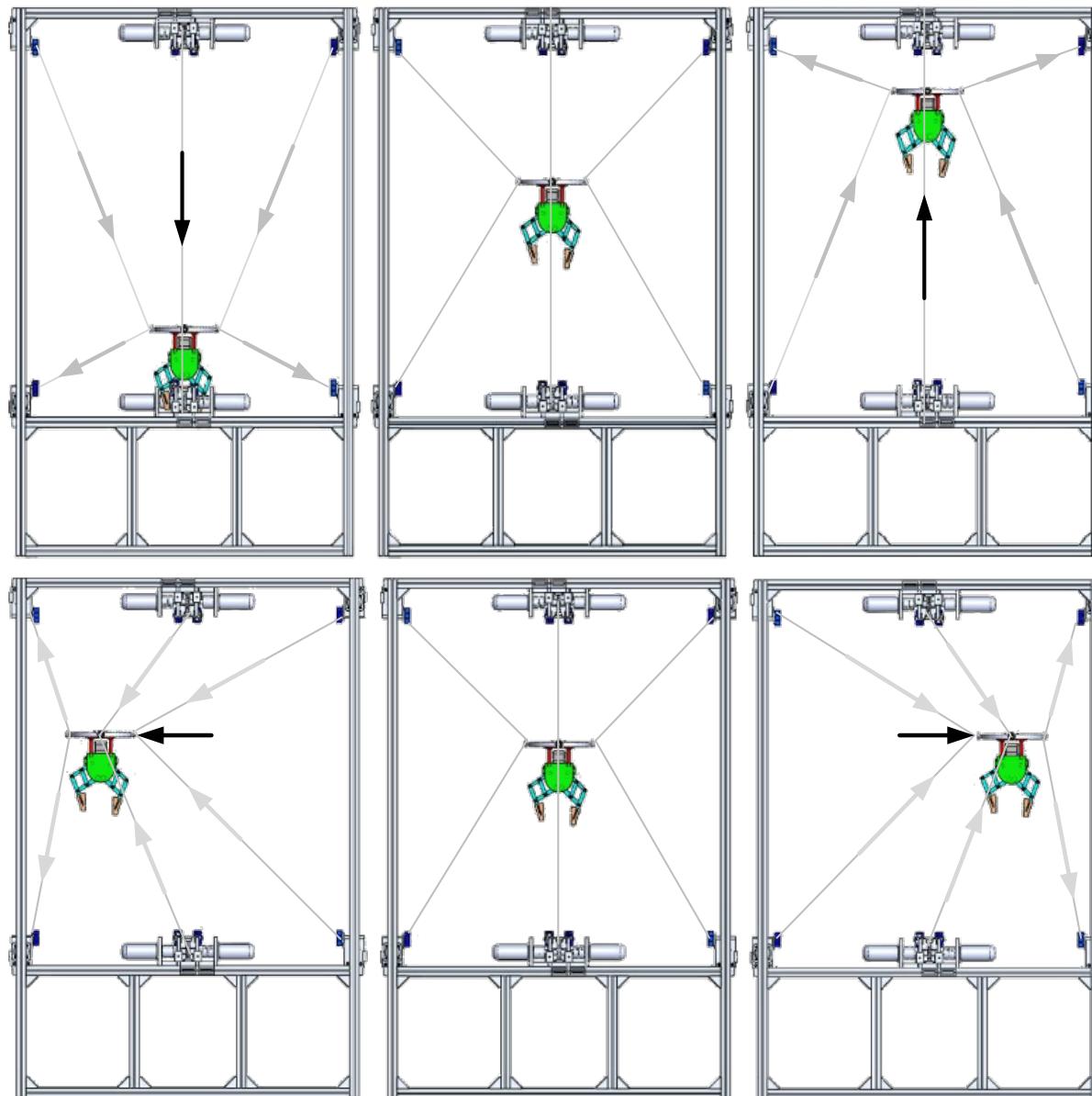


The CCD and the standard image processing algorithm (NI Vision builder) are used to monitor real-time scenarios and to estimate the real position of the suspended end-effector.

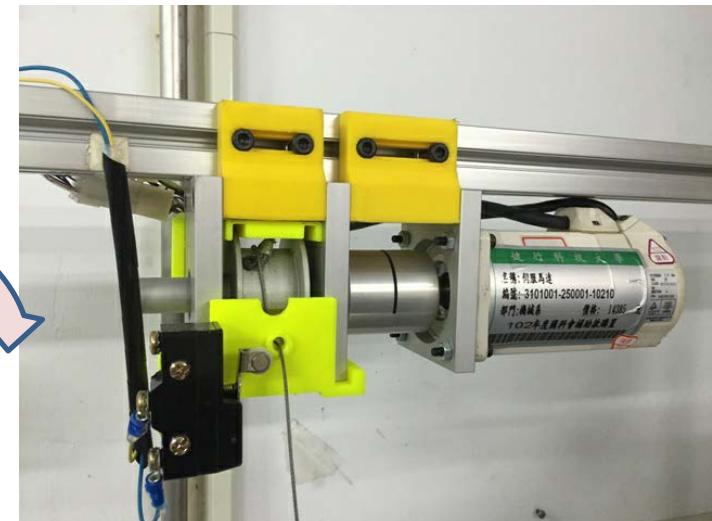
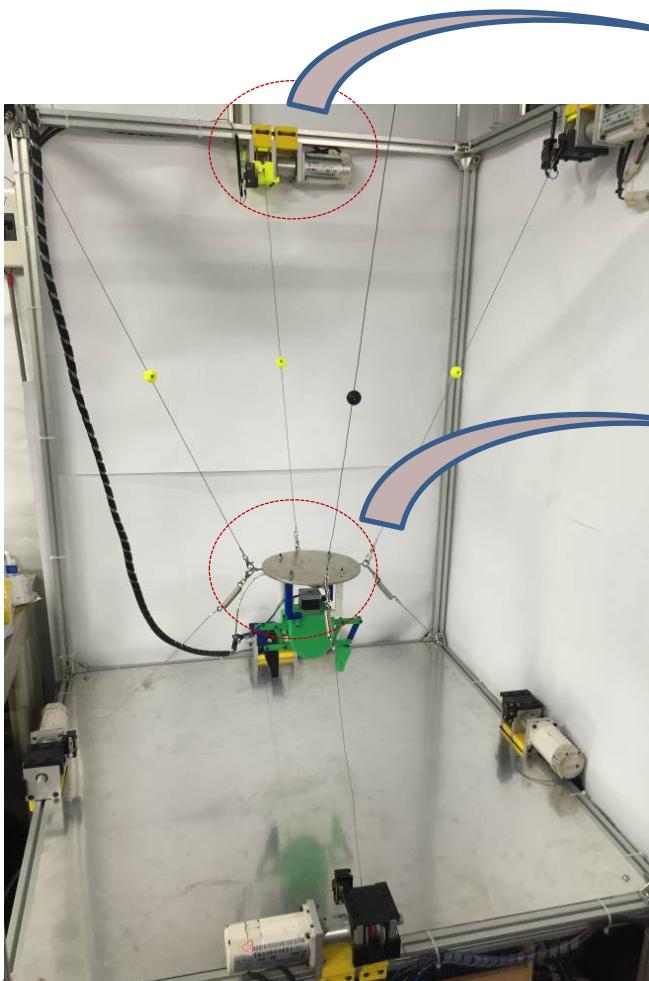


The control programming and machine algorithms was established using the National Instrument (NI) commercial package LabVIEW.

MOTION CONCEPT



SYSTEM CONFIGURATION – Hardware Implementation



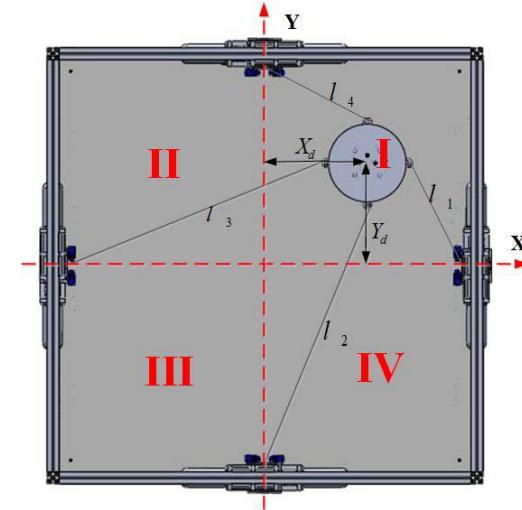
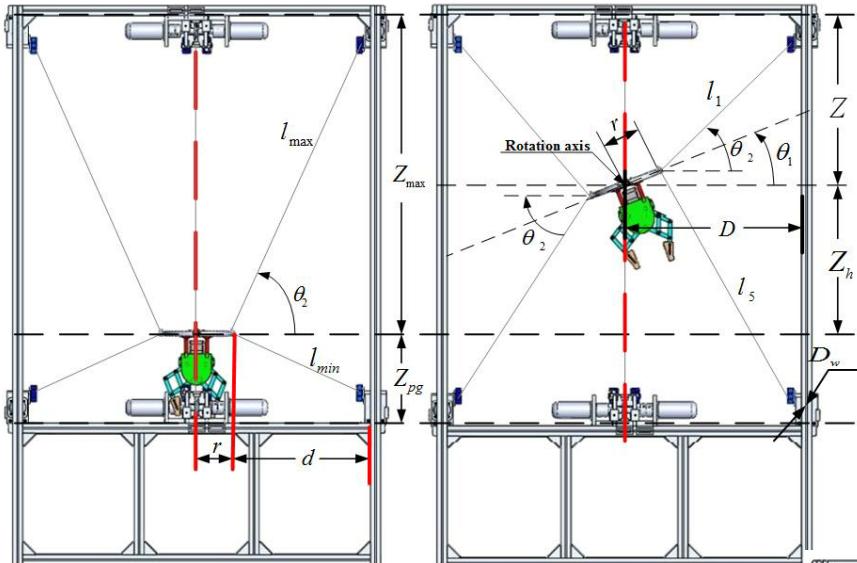
HMI – LabVIEW

Standard Image Processing – NI Vision Builder

The image displays a complex Human-Machine Interface (HMI) for a mechanical system, likely a robotic arm or similar precision equipment. The interface is divided into several panels:

- Top Left:** Logo of Chien Hsin University of Science and Technology (健行科技大学) and the Mechanical Engineering Department (機械工程系).
- Top Right:** A 3D simulation window showing a platform with a red base and a white top, with a vertical scale for "Platform Angle".
- Central Top:** Two tables showing servo status. The first table has columns for 馬達狀態0 through 馬達狀態3, and the second for 馬達狀態4 through 馬達狀態7. Both tables list Target Position, Command Position, Actual Position, and Error Value.
- Middle Left:** A large red button labeled "EXIT". Below it is a control panel with buttons for START, STOP, 自動循環 (Automatic Loop), 上下循環 (Up-Down Loop), 開Home點 (Open Home Point), 紀錄Data (Record Data), 重置 (Reset), and 存檔 (Save). It also features a circular dial for "馬達轉速" (Motor Speed) ranging from 0 to 300, with a yellow dot at approximately 150.
- Middle Center:** A "平臺數值輸入" (Platform Numerical Input) panel with fields for Z-axis height (200 mm), X-axis angle (0), X-axis (0 mm), Y-axis angle (0), and Y-axis (0 mm).
- Middle Right:** A "陀螺儀" (Gyroscope) panel with buttons for GY-521自動校正 (GY-521 Automatic Calibration), 手動X軸角度補償 (Manual X-axis Angle Compensation), 手動Y軸角度補償 (Manual Y-axis Angle Compensation), 預設 (Default), 預設 (Default), 紀錄X軸角度位置路徑資料 (Record X-axis Angle Position Path Data), and 紀錄Y軸角度位置路徑資料 (Record Y-axis Angle Position Path Data).
- Bottom Left:** A "單軸輸入" (Single-axis Input) panel with buttons for Right Up 0, Front Up 1, Left Up 2, Back Up 3, Right Down 4, Front Down 5, Left Down 6, and Back Down 7.
- Bottom Right:** A "夾爪手動" (Pneumatic Claw Manual) panel with buttons for 夾爪啓動 (Claw Start) and 夾爪停止 (Claw Stop).
- Bottom Center:** A camera view window showing a close-up of a mechanical part being processed, with a toolbar for image processing operations on the right.

KINEMATIC ANALYSIS

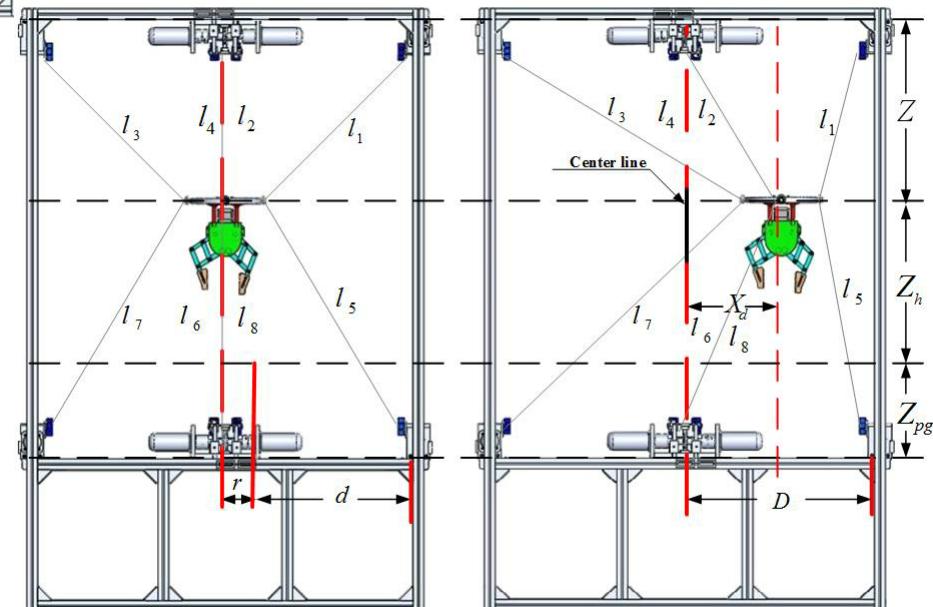


$$r \cdot \sin \theta_1 + l_1 \cdot \sin \theta_2 = Z$$

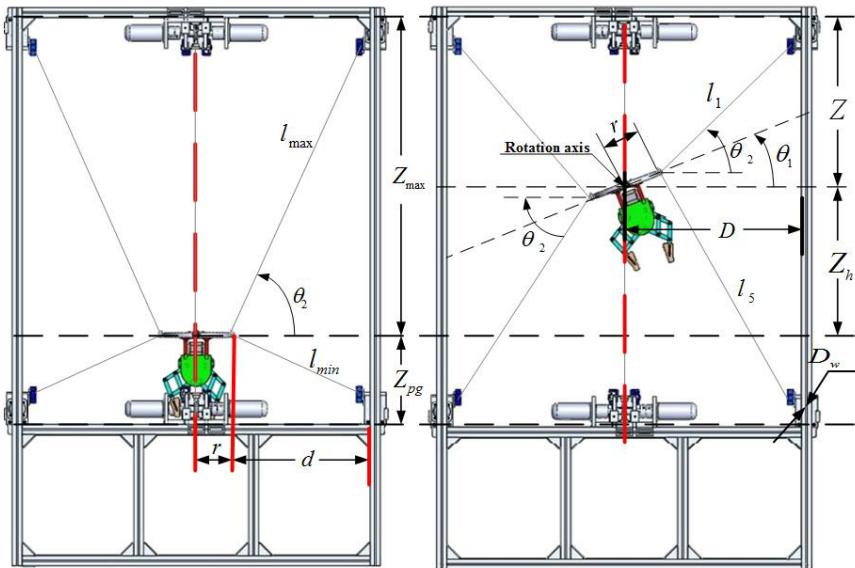
$$r \cdot \cos \theta_1 + l_1 \cdot \cos \theta_2 = D$$

$$l_1 = \sqrt{(D - r \cdot \cos \theta_1)^2 + (Z - r \cdot \sin \theta_1)^2}$$

$$Z = Z_{max} - Z_h$$



KINEMATIC ANALYSIS



$$l_{uo_i} = l_{\max} - l_i, \text{ for } i=1 \text{ to } 4$$

$$l_{lo_i} = l_{\min} - l_i, \text{ for } i=5 \text{ to } 8$$

$$l_1 = l_7 = \sqrt{(D - r \cdot \cos \theta_1 - X_d)^2 + Y_d^2 + (Z - r \cdot \sin \theta_1)^2}$$

$$l_2 = l_8 = \sqrt{(D + r \cdot \cos \theta_1 - X_d)^2 + Y_d^2 + (Z_{pg} + Z_h + r \cdot \sin \theta_1)^2}$$

$$l_3 = l_5 = \sqrt{(D - r \cdot \cos \theta_1 - Y_d)^2 + X_d^2 + (Z - r \cdot \sin \theta_1)^2}$$

$$l_4 = l_6 = \sqrt{(D + r \cdot \cos \theta_1 - Y_d)^2 + X_d^2 + (Z_{pg} + Z_h + r \cdot \sin \theta_1)^2}$$

$$M_{a,u_i} = \frac{l_{uo_i}}{\pi \cdot D_w} \cdot 360^\circ, \text{ for } i=1 \text{ to } 4$$

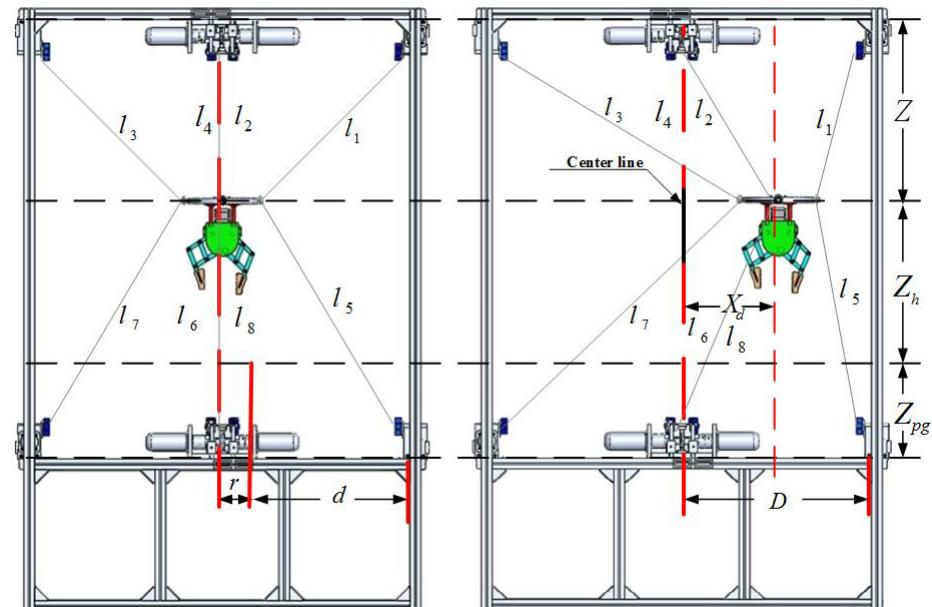
$$M_{a,l_i} = \frac{l_{lo_i}}{\pi \cdot D_w} \cdot 360^\circ, \text{ for } i=5 \text{ to } 8$$

$$M_{p,u_i} = M_{a,u_i} \cdot \frac{10000 \text{ pulse}}{360^\circ}, \text{ for } i=1 \text{ to } 4$$

$$M_{p,l_i} = M_{a,l_i} \cdot \frac{10000 \text{ pulse}}{360^\circ}, \text{ for } i=5 \text{ to } 8$$

$$l_i = l_{\max} - \frac{M_{p,u_i} \cdot \pi \cdot D_w}{10000 \text{ pulse}}, \text{ for } i=1 \text{ to } 4$$

$$l_i = l_{\max} - \frac{M_{p,l_i} \cdot \pi \cdot D_w}{10000 \text{ pulse}}, \text{ for } i=5 \text{ to } 8$$



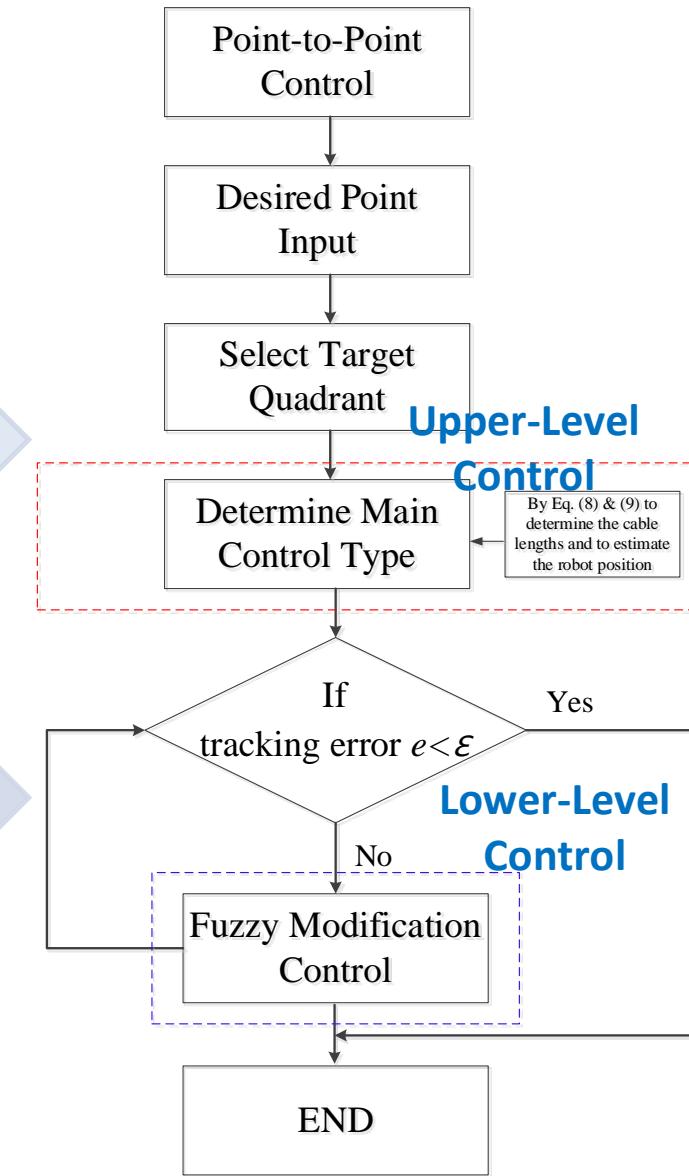
CONTROLLER DESIGN

Upper-Level Control

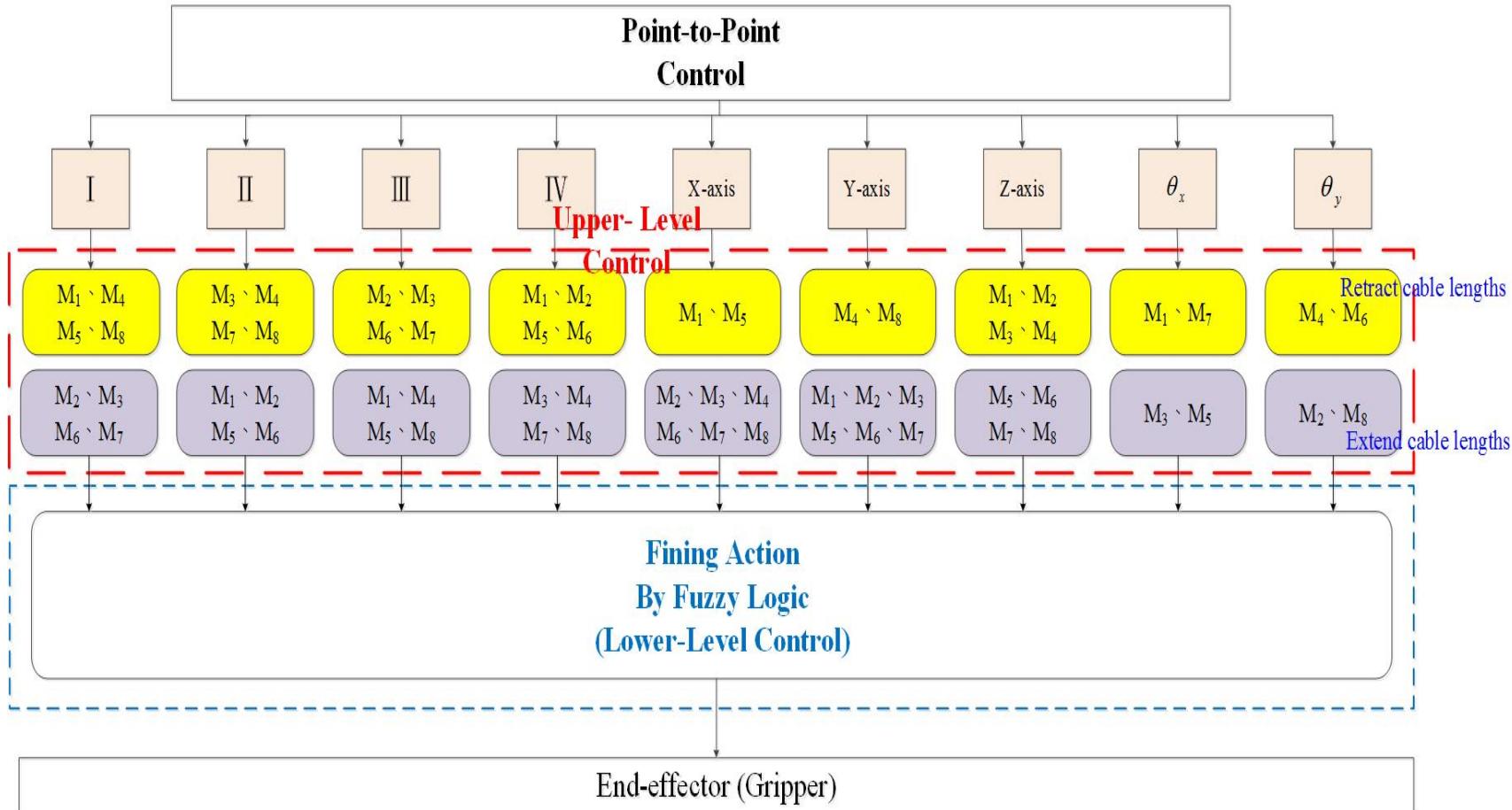
- Main Control Mode
- Four Quadrants
- Three Axes
- Two Rotation Angles
- Group Motors Concept

Lower-Level Control

- Fuzzy Modification Control
- Fining Modification
- Rule Base and MF Design

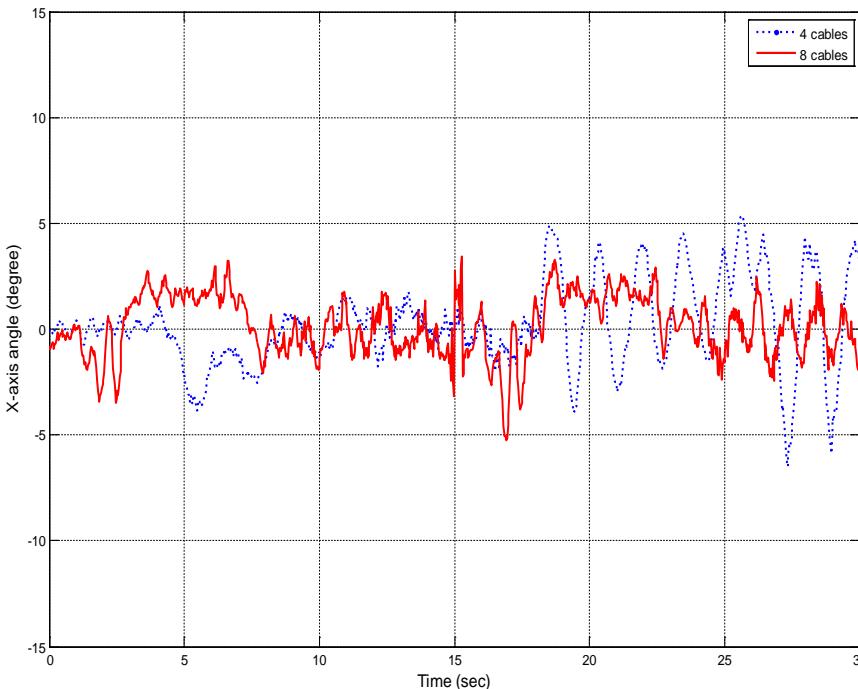


CONTROLLER DESIGN

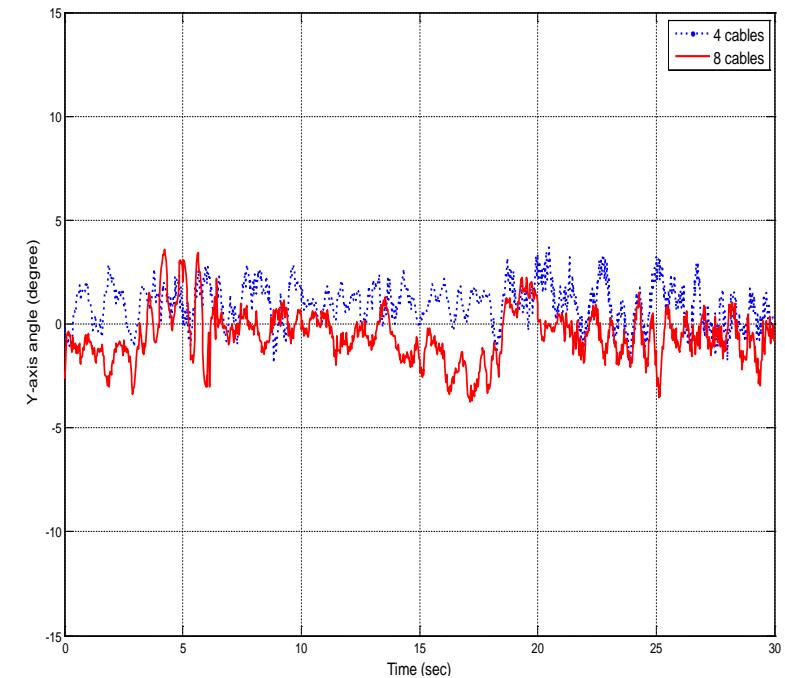


RESULTS AND DISCUSSIONS

Oscillation Control for 4-Cables & 8-Cables



➤ θ_x



θ_y

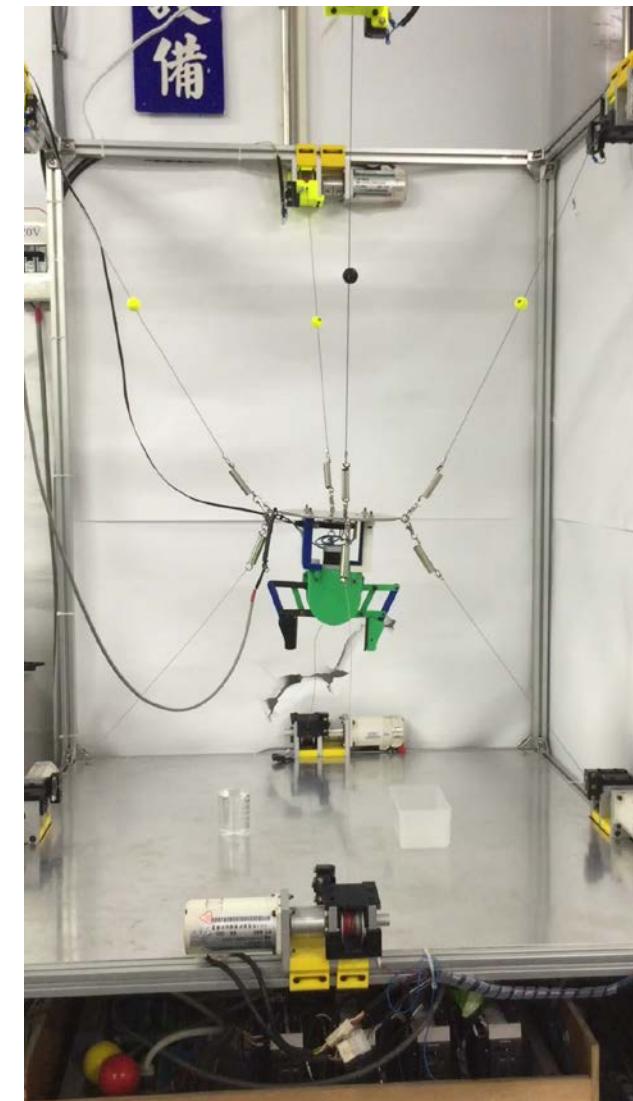
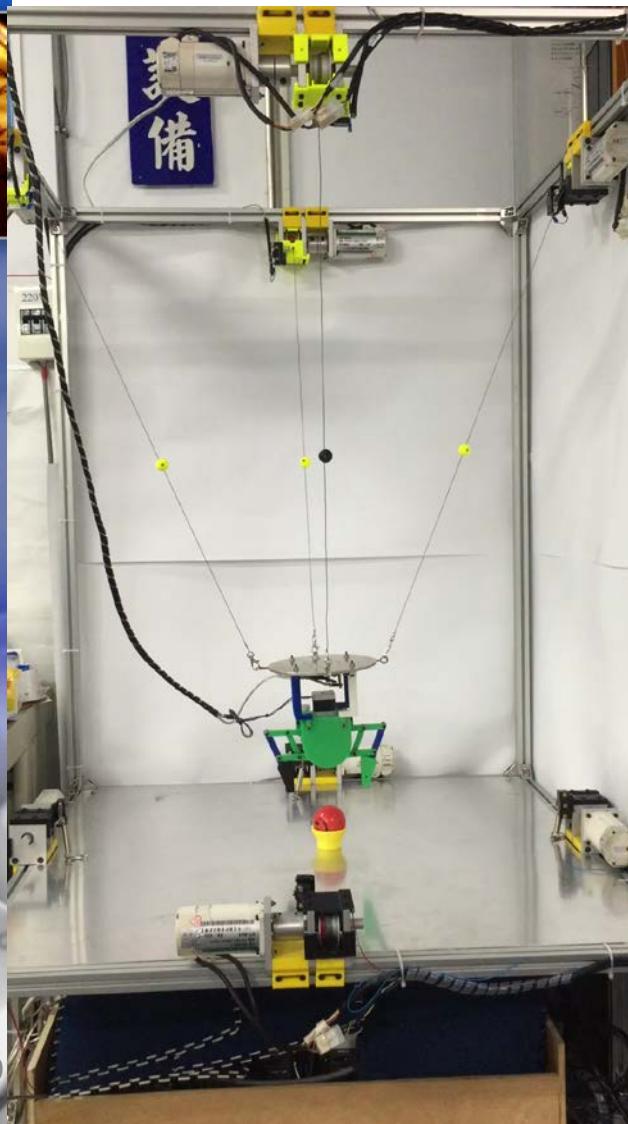
RESULTS AND DISCUSSIONS

Positioning error for the measured point by Control Mode A (unit: mm)

Test No. Point No.	1	2	3	4	5	Standard Deviation (σ)	RMSE
1	(-205, 206)	(-207,207)	(-205,207)	(-206,209)	(-207,208)	(1, 1.14)	(2.7, 3.3)
2	(2, 218)	(1,216)	(2,217)	(4,221)	(3,218)	(1.14, 1.87)	(1.1, 8.1)
3	(211, 214)	(208,216)	(209,213)	(210,214)	(201,213)	(3.96, 1.22)	(3.8, 6.2)
4	(-206, 11)	(-208,14)	(-209,11)	(-206,13)	(-209,11)	(1.51, 1.41)	(3.4, 5.4)
5	(0, 0)	(0,-1)	(-1,1)	(1,0)	(1,1)	(0.84, 0.84)	(0.3, 0.3)
6	(216, -1)	(210,0)	(215,0)	(212,-1)	(215,-2)	(2.50, 0.84)	(6.1, 0.5)
7	(-205, -221)	(-200,-220)	(-201,-220)	(-201,-218)	(-200,-218)	(2.07, 1.34)	(1.1, 8.6)
8	(-5, -228)	(-2,-229)	(-2,-228)	(-3,-230)	(-5,-230)	(1.51, 1)	(1.6, 12.9)
9	(203, -224)	(201,-221)	(203,-221)	(201,-222)	(205,-224)	(1.67, 1.5)	(1.3, 10)

RESULTS AND DISCUSSIONS

Video Demonstration



CONCLUSION

- This study develops a MDOF cable-driven parallel robot with suspended end-effector.
- this research proposes a hierarchical control methodology to satisfy the control requirement, which includes main control mode and fuzzy modification control mode.
- The upper-level control is responsible for tracking the suspended end-effector to the target region.
- The lower-level control is concentrated on the fining modification for the positioning.
- The discussion of the broad issues deliberated in this investigation will be applied in aerostats, towing cranes, locomotion interface, and large-scale manufacturing applications that require cable-driven parallel robot.

Thanks ~~

