Implementation and Control for an MDOF Cable-Suspended Parallel Robot

Jonqlan Lin, C. Y. Wu, J. Chang

Department of Mechanical Engineering, Chien Hsin University of Science and Technology

Taiwan, ROC

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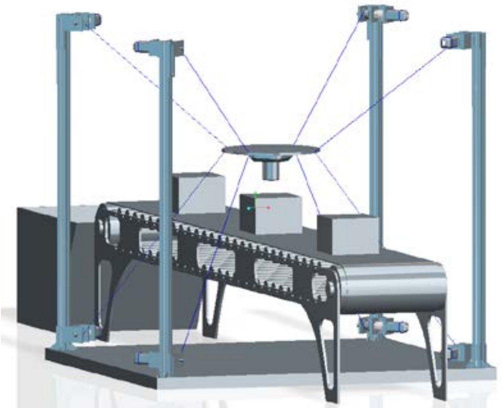
OUTLINE

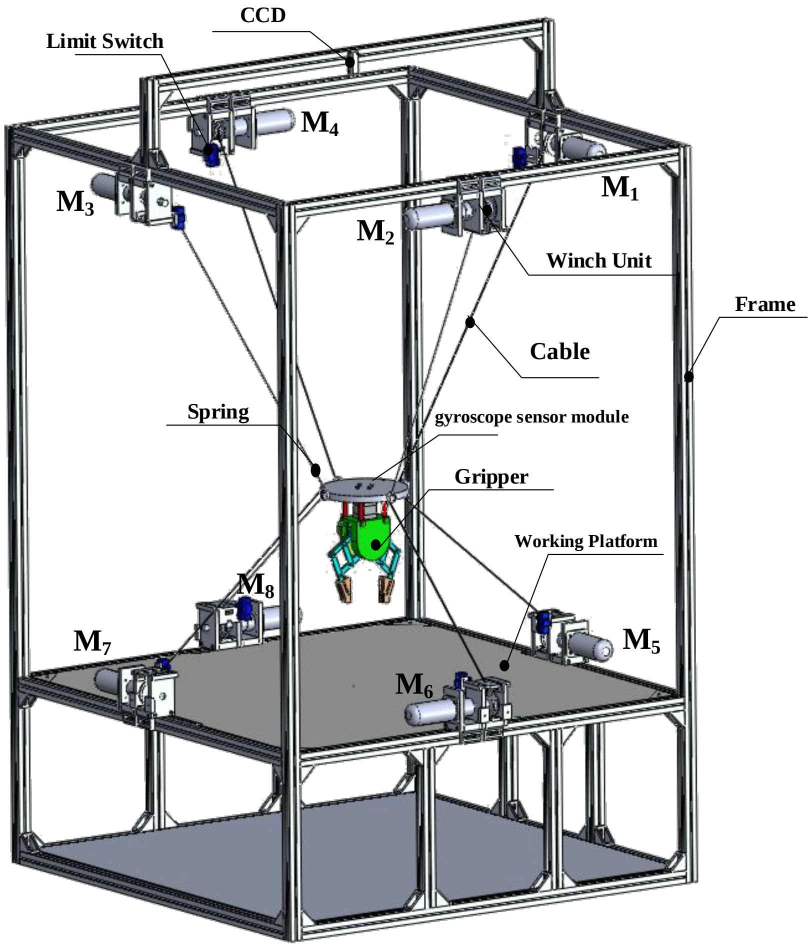
- INTRODUCTION
- SYSTEM CONFIGURATION
- KINEMATIC ANALYSIS
- CONTROLLER DESIGN
- RESULTS AND DISSCUSSIONS

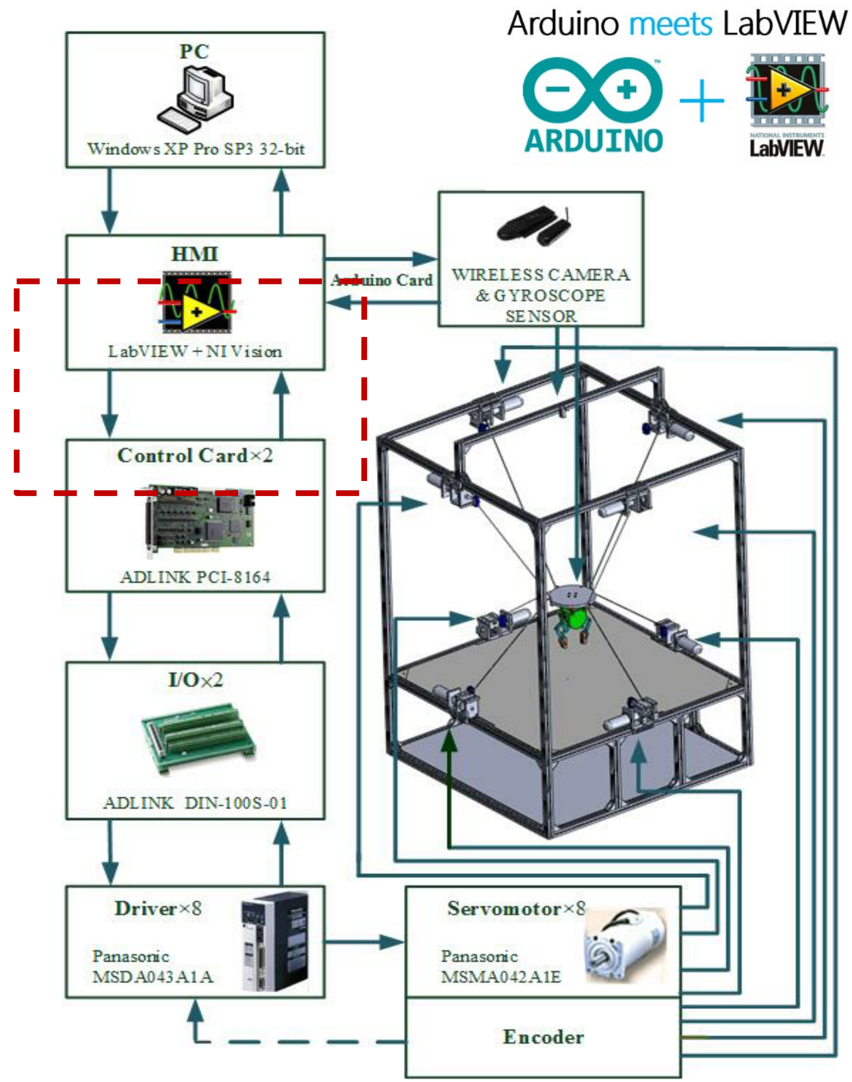
INTRODUCTION



- 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

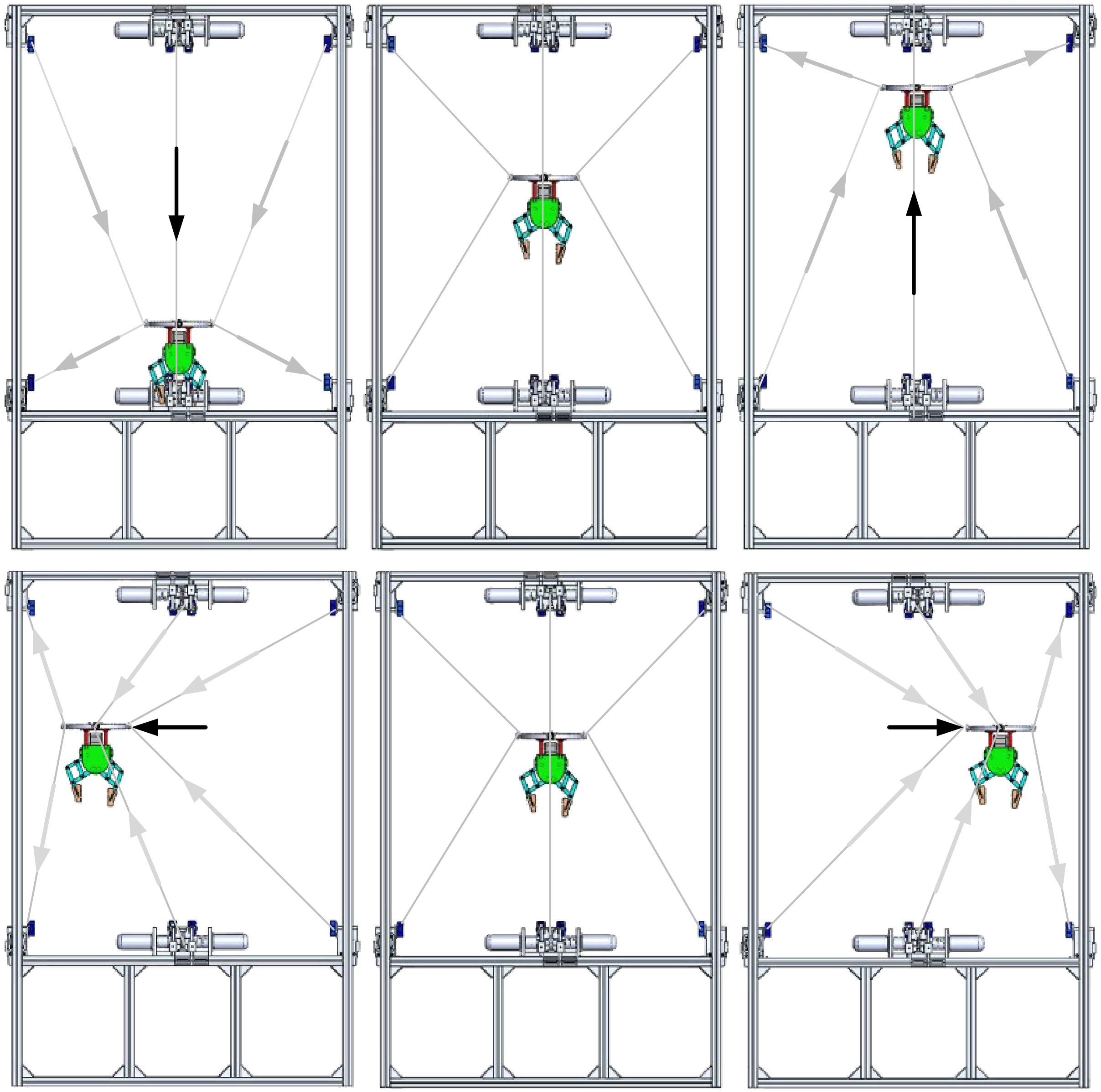




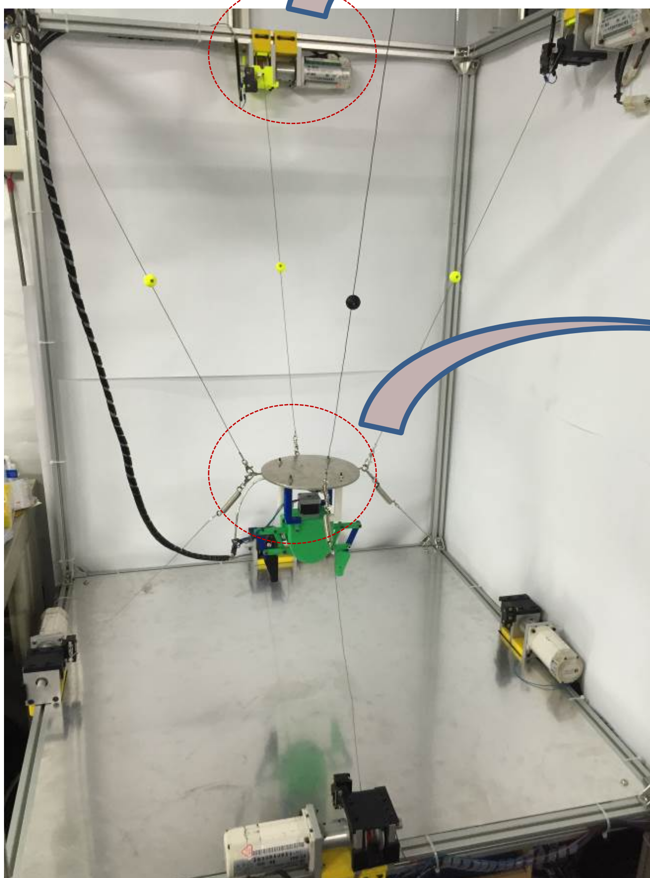
The CCD and the standard image processing algorithm (NI Vision builder) are used to monitor real-time scenarios and to estimate the real position of the suspended end-effector.

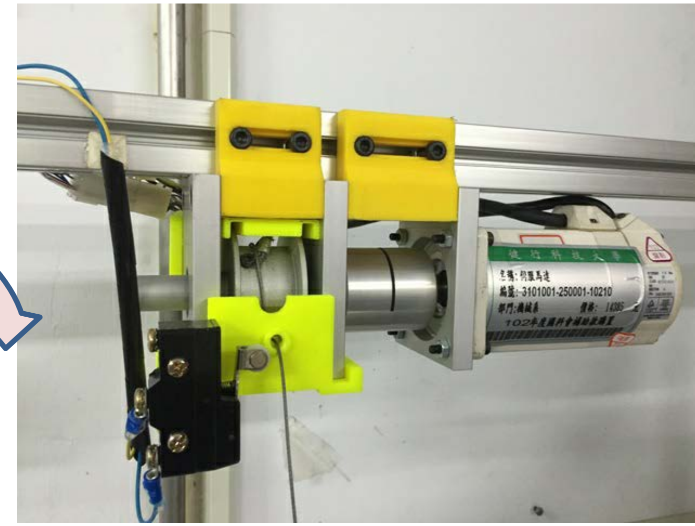
The control programming and machine algorithms was established using the **National Instrument (NI) commercial package LabVIEW**.

MOTION CONCEPT



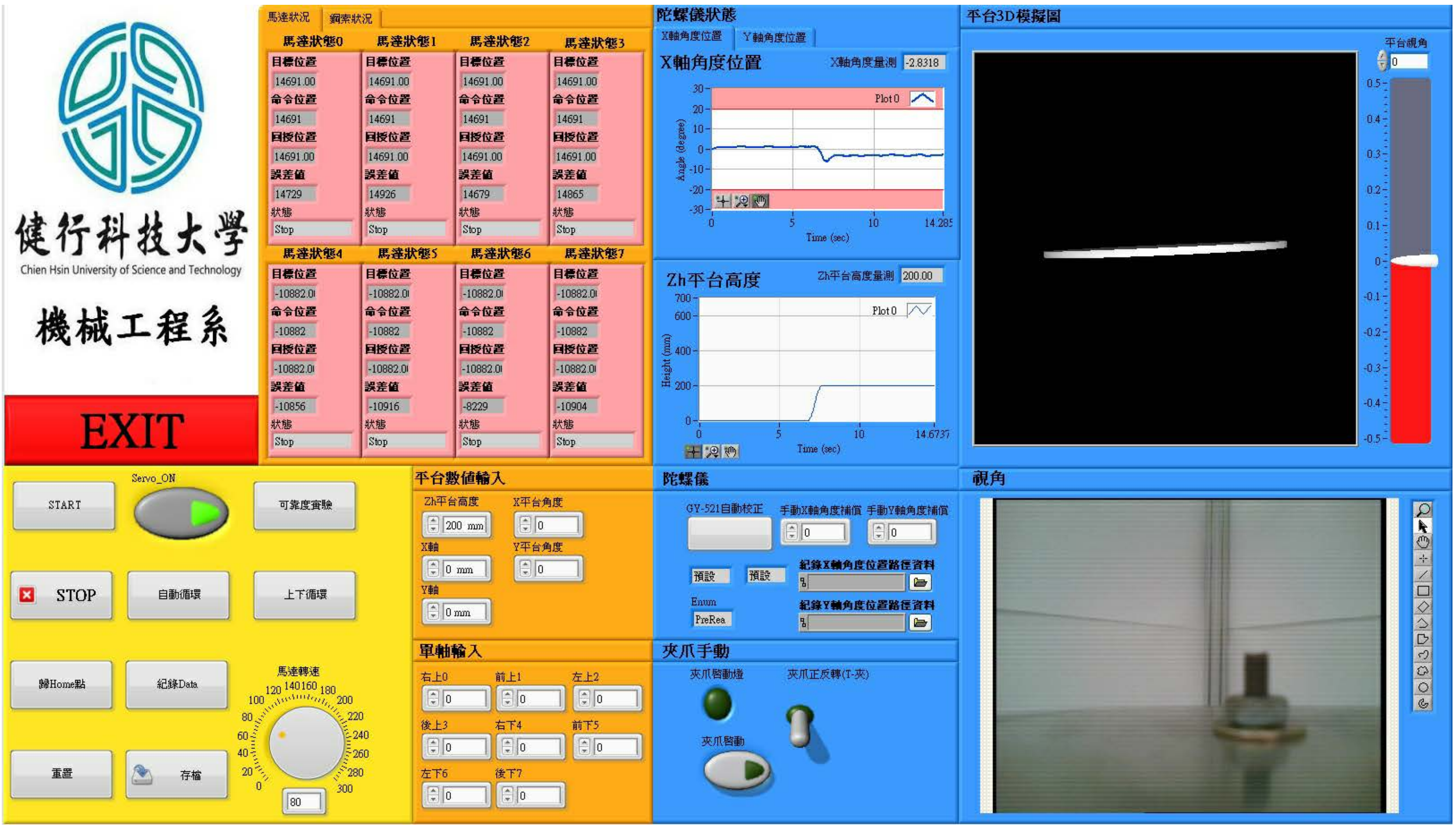
SYSTEM CONFIGURATION – Hardware Implementation



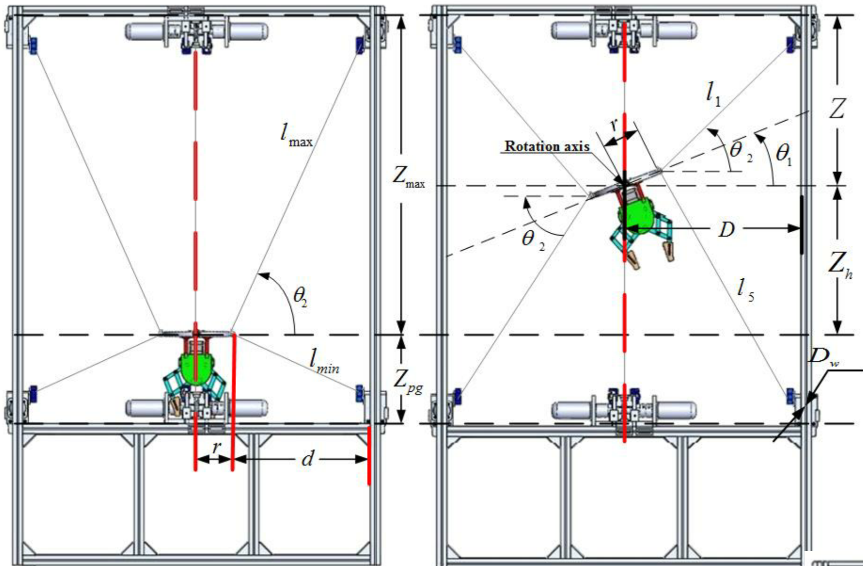


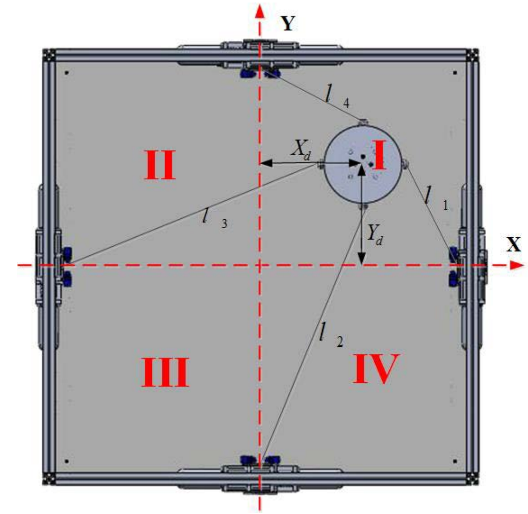
HMI – LabVIEW

Standard Image Processing – NI Vision Builder



KINEMATIC ANALYSIS



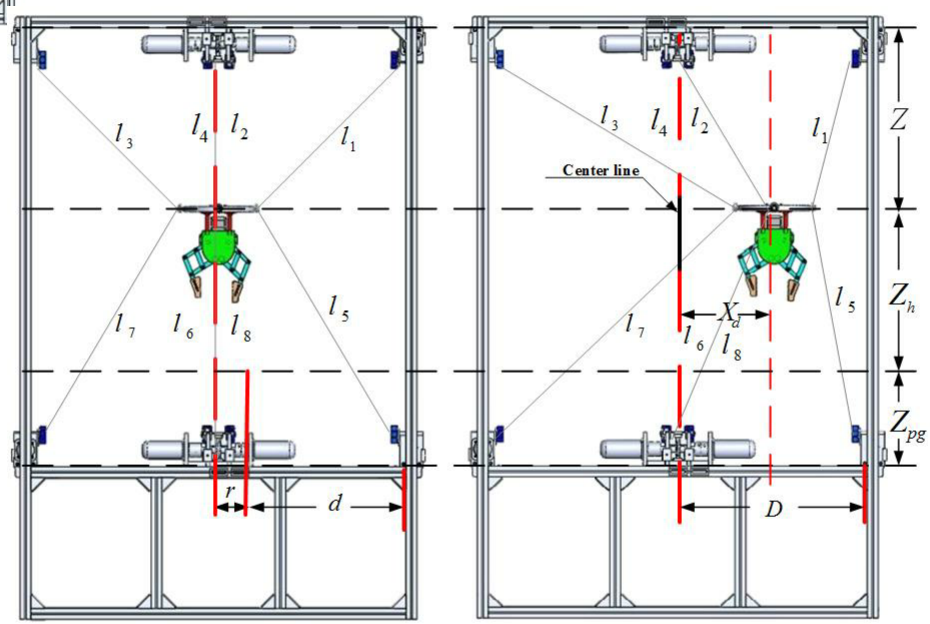


$$r \cdot \sin\theta_1 + l_1 \cdot \sin\theta_2 = Z$$

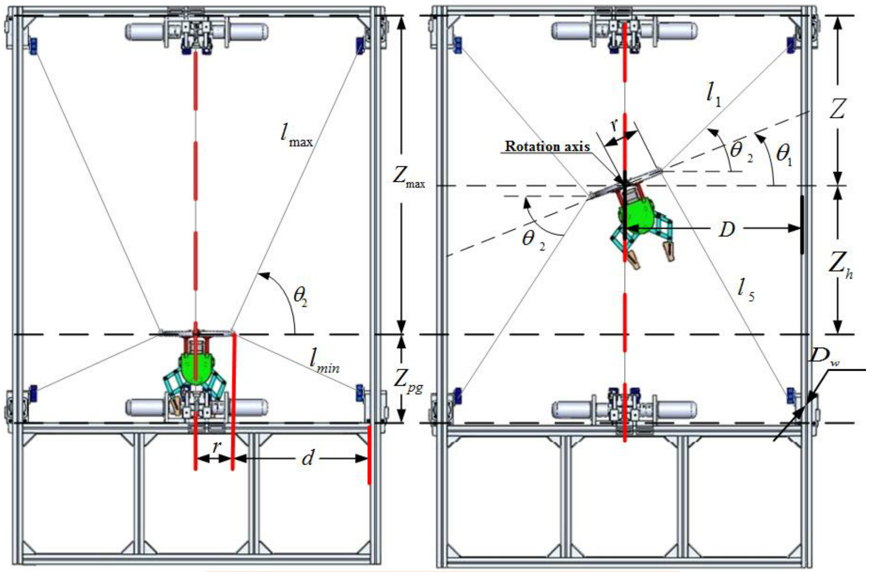
$$r \cdot \cos\theta_1 + l_1 \cdot \cos\theta_2 = D$$

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

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



KINEMATIC ANALYSIS



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

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

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

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

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

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

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

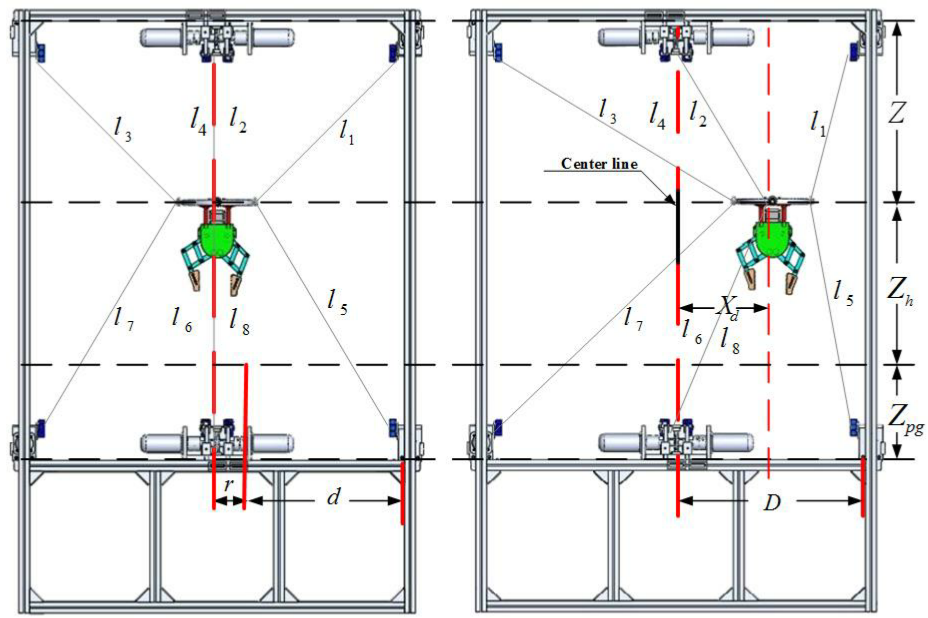
$$M_{a,l_i} = \frac{l_{lo_i}}{\pi\cdot D_w}\cdot 360°\text{, for } i = 5 \text{ to } 8$$

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

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

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

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



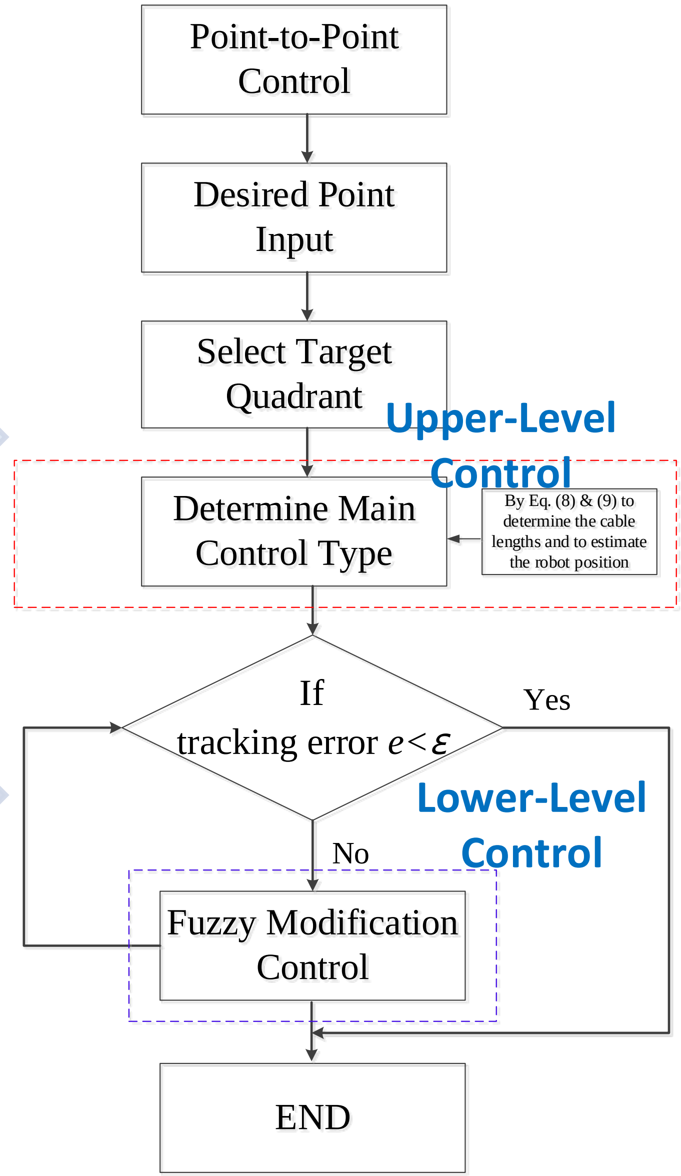
CONTROLLER DESIGN

Upper-Level Control

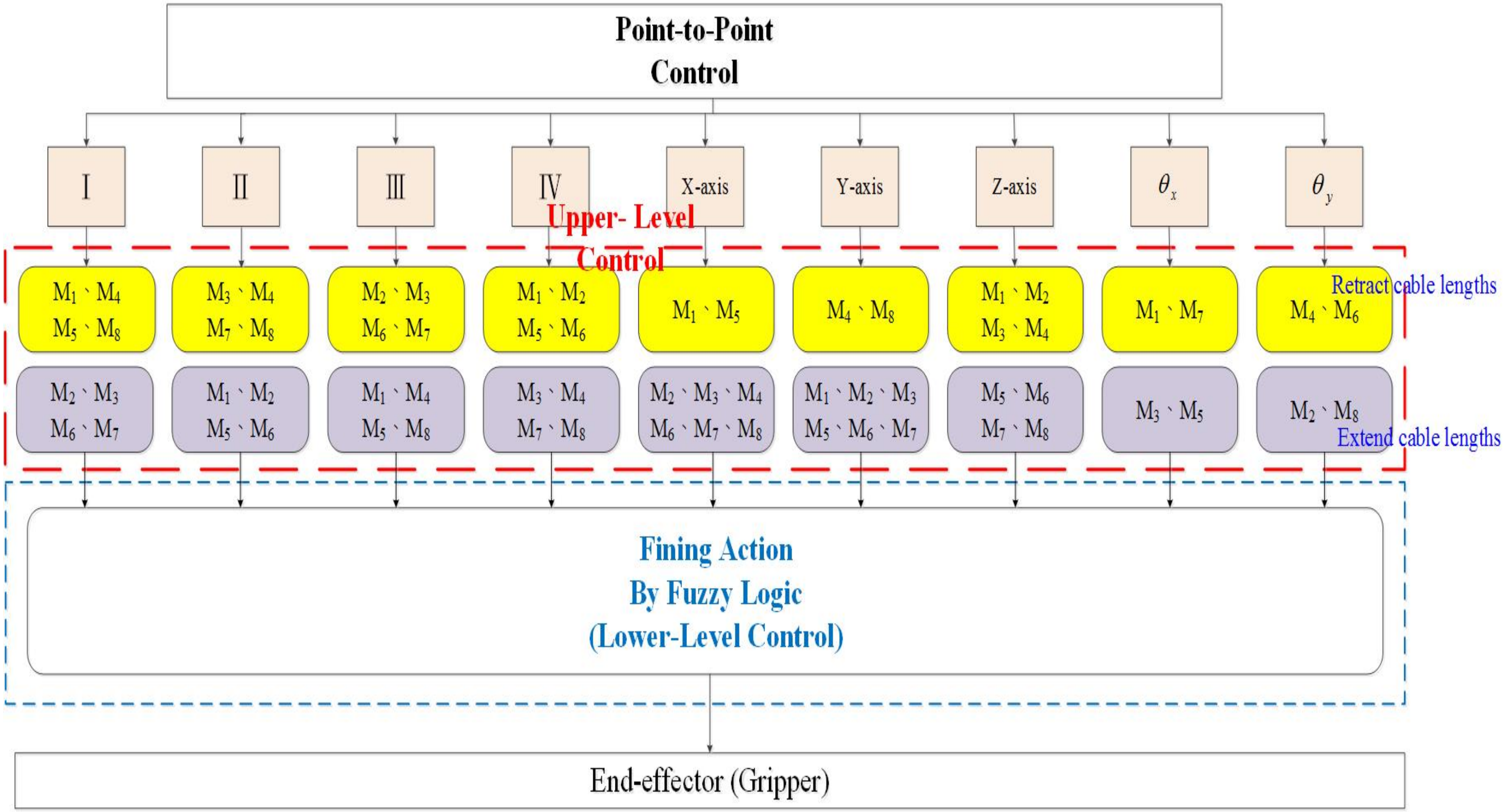
- Main Control Mode
- Four Quadrants
- Three Axes
- Two Rotation Angles
- Group Motors Concept

Lower-Level Control

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

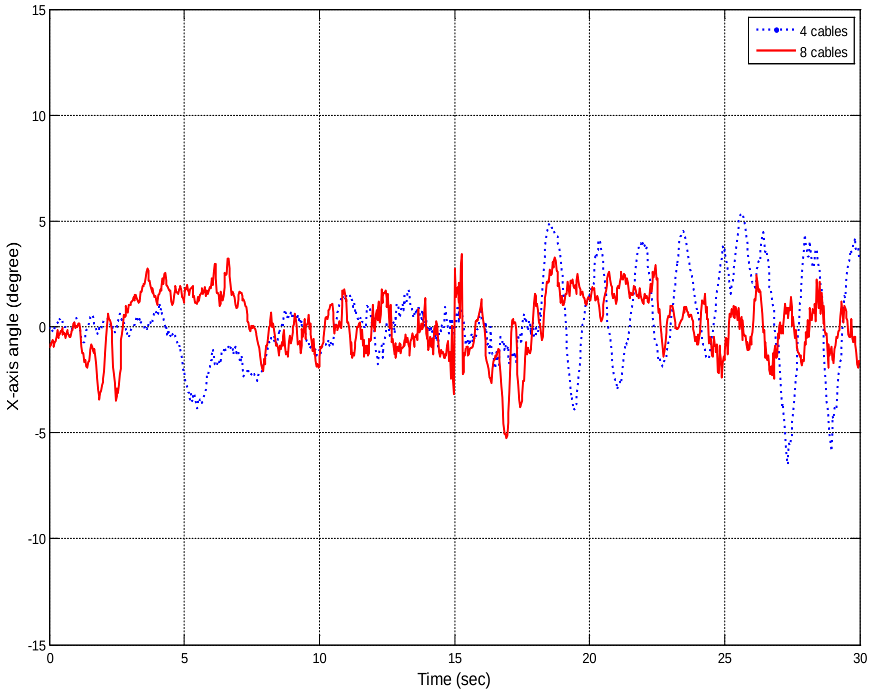


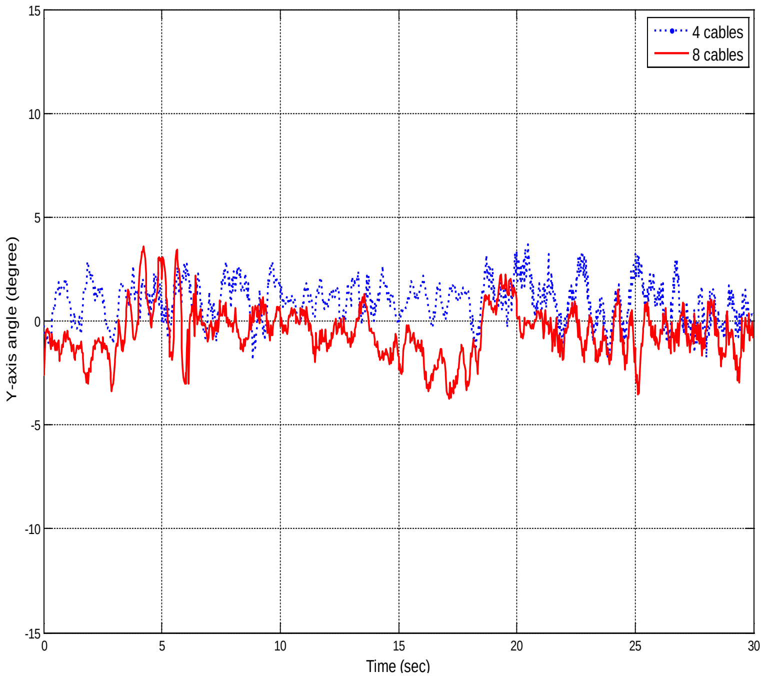
CONTROLLER DESIGN



RESULTS AND DISSCUSSIONS

Oscillation Control for 4-Cables & 8-Cables





- θ_x θ_y

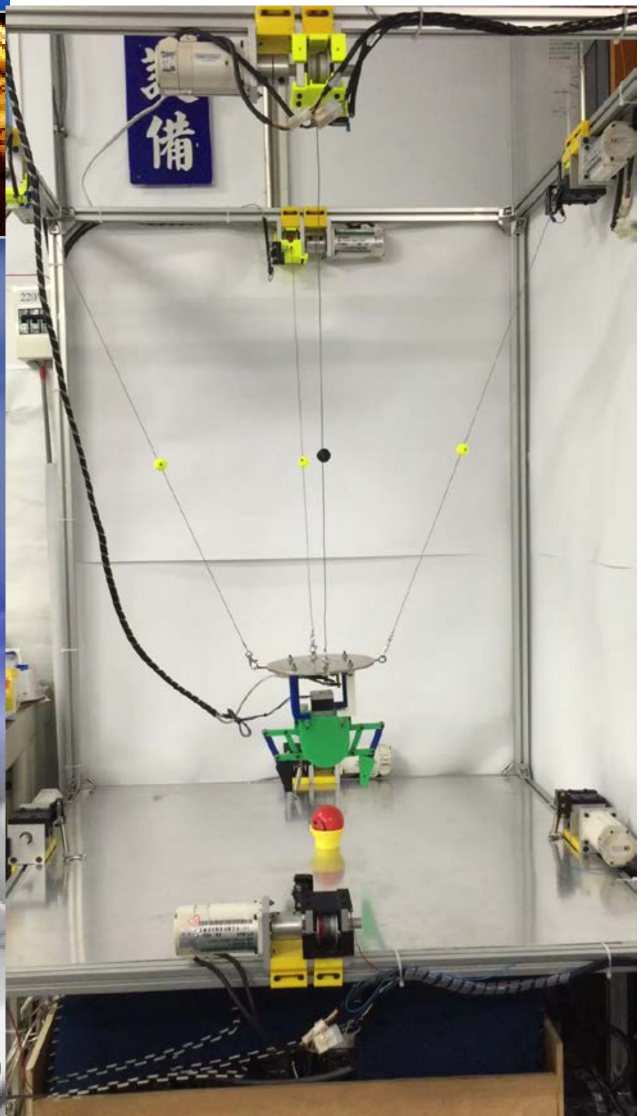
RESULTS AND DISSCUSSIONS

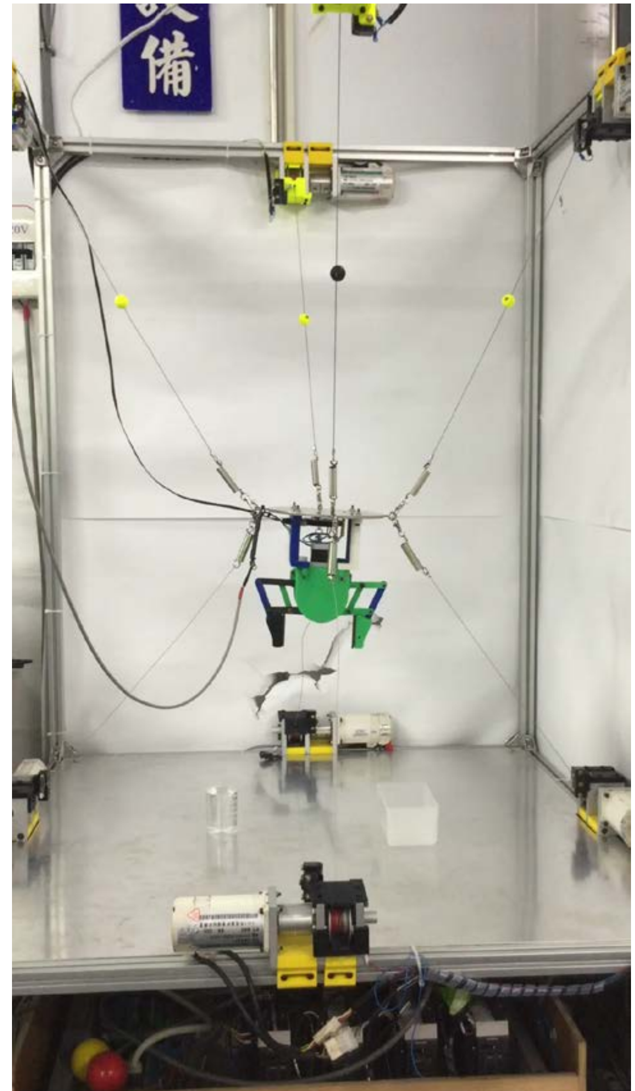
Positioning error for the measured point by Control Mode A (unit: mm)

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 DISSCUSSIONS

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 ~~