Implementation and Control for an MDOF Cable-Suspended Parallel Robot

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OUTLINE

INTRODUCTION

SYSTEM CONFIGURATION

KINEMATIC ANALYSIS

CONTROLLER DESIGN

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...
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

\[ r \cdot \sin \theta_1 + l_1 \cdot \sin \theta_2 = Z \]

\[ r \cdot \cos \theta_1 + l_1 \cdot \cos \theta_2 = D \]

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

\[ Z = Z_{\text{max}} - Z_h \]
KINEMATIC ANALYSIS

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

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

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

\[ l_2 = l_8 = \sqrt{(D + r \cdot \cos \theta_1 - X_d)^2 + Y_d^2 + (Z_p + Z_h + r \cdot \sin \theta_1)^2} \]

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

\[ l_4 = l_6 = \sqrt{(D + r \cdot \cos \theta_1 - Y_d)^2 + X_d^2 + (Z_p + Z_h + r \cdot \sin \theta_1)^2} \]

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

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

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

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

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

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

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**Point-to-Point Control**

**Desired Point Input**

**Select Target Quadrant**

**Determine Main Control Type**

- If tracking error $e < \varepsilon$
- By Eq. (8) & (9) to determine the cable lengths and to estimate the robot position

**Lower-Level Control**

**Fuzzy Modification Control**

**END**
CONTROLLER DESIGN

Point-to-Point Control

Upper-Level Control

I: M₁, M₄, M₅, M₈
II: M₃, M₄, M₇, M₈
III: M₂, M₃, M₆, M₇
IV: M₁, M₂, M₅, M₆
X-axis: M₁, M₅
Y-axis: M₄, M₈
Z-axis: M₁, M₂, M₇
θₓ: M₁, M₁′
θᵧ: M₁′, M₆

Fining Action
By Fuzzy Logic
(Lower-Level Control)

End-effector (Gripper)
RESULTS AND DISCUSSIONS

Oscillation Control for 4-Cables & 8-Cables

- $\theta_x$
- $\theta_y$
# RESULTS AND DISCUSSIONS

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

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