

Fig. 1 Mechanical and servo manipulator

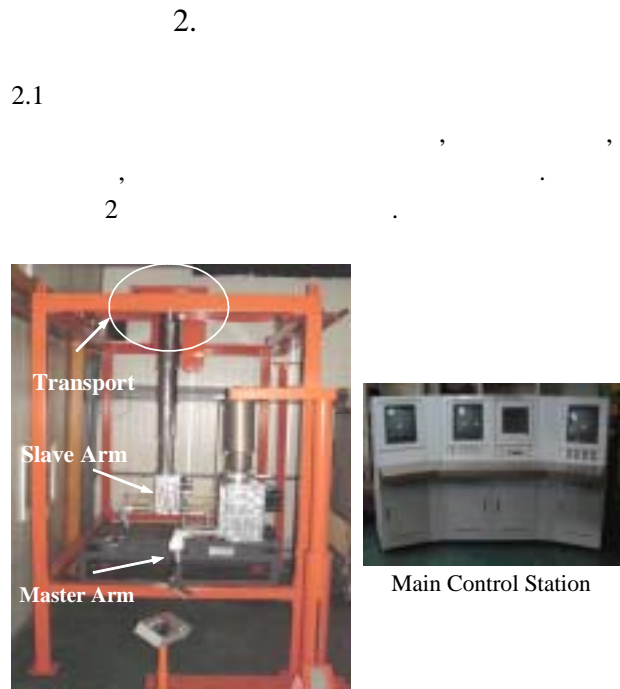


Fig. 2 Servo manipulator system by KAERI

[1,2]

X-Y
Z

2.2

KAERI

, 6

. 2

, 3

, 4



Fig. 3 Gripper

2.3

(Force reflection)

1:1

(Force

3.2

()

가 가 가

4

가

2.4

가

가 가

3.

3.1

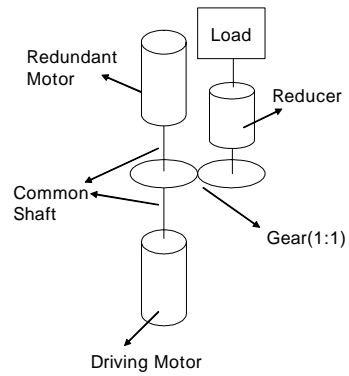


Fig. 4 Duplicated motor module

4.

4.1

(Reconfiguration)

가

가

Tamakawa 社 TBL-i
(: <http://www.tamagawa-seiki.co.jp>)

6.7×10^4 rad
 10^8 rad

(1)

[3]

가

Ecolab 社(<http://www.leoni-elocab.ca/>)
Lemo 社(<http://www.lemo.com/>)

2 가 , 가 . 2 , 6

[4-6]

가 . 가 가

가

가

가

[7]

1 가

5

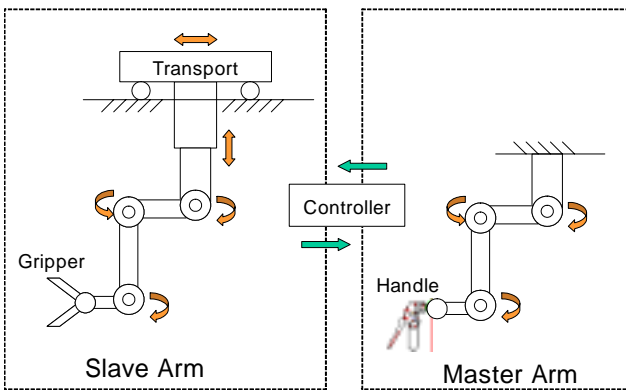


Fig. 5 Schematic diagram of the servo manipulator

1 가

1:1

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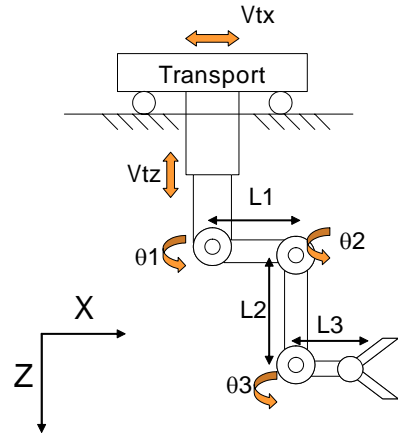


Fig. 6 Notations of the slave arm

$$\begin{aligned}
 x_e &= x_t + L_1 \cos \theta_1 + L_2 \sin(\theta_1 + \theta_2) + L_3 \cos(\theta_1 + \theta_2 + \theta_3) \\
 z_e &= z_t - L_1 \sin \theta_1 + L_2 \cos(\theta_1 + \theta_2) - L_3 \sin(\theta_1 + \theta_2 + \theta_3) \\
 \theta_e &= \theta_1 + \theta_2 + \theta_3
 \end{aligned}
 \tag{1}$$

$$\begin{aligned}
 v_{xe} &= v_{xt} - \dot{\theta}_1 L_1 \sin \theta_1 + (\dot{\theta}_1 + \dot{\theta}_2) L_2 \cos(\theta_1 + \theta_2) \\
 &\quad - (\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3) L_3 \sin(\theta_1 + \theta_2 + \theta_3) \\
 v_{ze} &= v_{zt} - \dot{\theta}_1 L_1 \cos \theta_1 - (\dot{\theta}_1 + \dot{\theta}_2) L_2 \sin(\theta_1 + \theta_2) \\
 &\quad - (\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3) L_3 \cos(\theta_1 + \theta_2 + \theta_3) \\
 \omega_e &= \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3
 \end{aligned}
 \tag{2}$$

$$\begin{aligned}
 V_E &= A \Omega \tag{3} \\
 V_E &= [v_{xe} \quad v_{ze} \quad \omega_e]^T, \quad \Omega = [v_{xt} \quad v_{zt} \quad \dot{\theta}_1 \quad \dot{\theta}_2 \quad \dot{\theta}_3]^T, \\
 A &= \begin{bmatrix} 1 & 0 & -L_1 s_1 + L_2 c_{12} - L_3 s_{123} & L_2 c_{12} - L_3 s_{123} & -L_3 s_{123} \\ 0 & 1 & -L_1 c_1 - L_2 s_{12} - L_3 c_{123} & -L_2 s_{12} - L_3 c_{123} & -L_3 c_{123} \\ 0 & 0 & 1 & 1 & 1 \end{bmatrix}
 \end{aligned}$$

$$s_{ijk} = \sin(\theta_1 + \theta_2 + \theta_3), \quad c_{ijk} = \cos(\theta_1 + \theta_2 + \theta_3)$$

$$V_E, \quad \Omega, \quad V_D$$

$$\begin{aligned} \text{minimize } J &= \|V_D - V_E\| = \|V_D - A\Omega\| \\ \text{subject to } |\Omega_i| &< \Omega_{i,\max} \end{aligned} \quad (4)$$

Durham[8]

Goel[7]

$$\text{minimize } J = \|V_D - AA^+V_D\| \quad (5)$$

(4)

Pseudo inverse

$$\Omega = A^+V_D = A^T(AA^T)^{-1}V_D \quad (6)$$

(scaled) 가

$$\begin{aligned} \bar{\Omega} &= \Omega / \alpha \\ \alpha &= \max\left(1, \max_i\left(|\Omega_i| / \Omega_{i,\max}\right)\right) \end{aligned} \quad (7)$$

$$\alpha > 1, \quad V_D \neq A\bar{\Omega}$$

$$\alpha = 1$$

Pseudo inverse

$$V_D = AL\hat{\Omega} \quad (8)$$

$$L = \text{diag}\left(|\Omega_{i,\max}|\right),$$

$$\hat{\Omega} = (AL)^+V_D = (AL)^T(ALL^T A^T)^{-1}V_D \quad (9)$$

$$\alpha = \max\left(1, \max_i\left(|\Omega_i|\right)\right)$$

(7) (9) 가

가

A

(4), (7), (9)

(4), (7), (9)

A가

(7), (9)

가

(6), (9)

A

(4)

A⁺

(AL)⁺

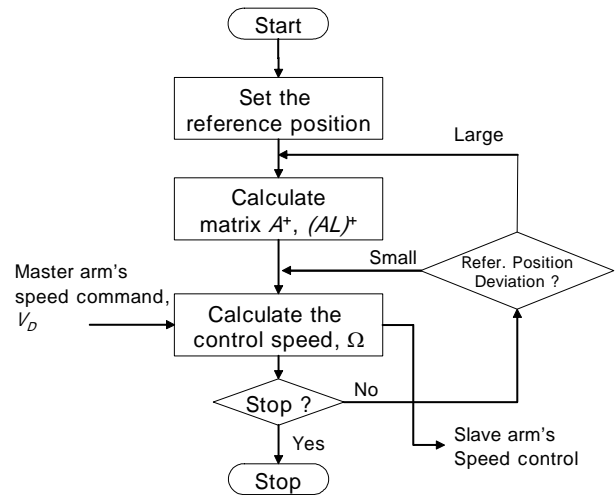


Fig. 7 Reconfiguration procedure

4.2

KAERI

Table 1

Table 1. Numerical data for the servo manipulator.

Parameters	Values	Dimension
L_1, L_2, L_3	0.3, 0.3, 0.25	m
Max. v_{xt}, v_{zt}	0.13, 0.1	m/sec
Max. $\omega_1, \omega_2, \omega_3$	2.5, 2.5, 6.9	rad/sec
Reference $\theta_1, \theta_2, \theta_3$	0.0, 0.0, 0.0	rad

2

가

(4),

(7), (9)

V_D	V by (4)	V by (5)	V by (8)
0.3, 0.1, 0.7	0.13,-0.07,0.66	0.08,0.03,0.19	0.11,0.04, 0.25
0.3,0.1,-0.7	0.3,0.1,-0.7	0.1,0.03,-0.24	0.27,0.09,-0.63
0.3,-0.1,0.7	0.23,-0.17,0.68	0.17,-0.06,0.39	0.17,-0.06,0.39
0.3,-0.1,-0.7	0.3,-0.1,-0.7	0.09,-0.03,-0.20	0.3,-0.1,-0.7
-0.3,0.1,0.7	-0.3,0.1,0.7	-0.26,0.1,-0.14	-0.3,0.1,0.7

-0.3,0.1,-0.7	-0.23,0.17,-0.68	-0.17,0.06,-0.39	-0.17,0.06,-0.39
-0.3,-0.1,0.7	-0.3,-0.1,0.7	-0.1,-0.03,0.24	-0.27,-0.1,0.63
-0.3,-0.1,-0.7	-0.13,0.07,-0.66	-0.08,-0.03,-0.19	-0.11,-0.04,-0.25

(9) 가

5.

가

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