



$$A_2 [x_{A_2}, y_{A_2}, z_{A_2}]$$

$$A_3 [x_{A_3}, y_{A_3}, z_{A_3}]$$

$$A_4 [x_{A_4}, y_{A_4}, z_{A_4}]$$

$$A_5 [x_{A_5}, y_{A_5}, z_{A_5}]$$

$$A_2B_2 = A_3B_3 = A_4B_4 = A_5B_5 = l$$

$$C_2B_2 = C_3B_3 = O_6B_4 = a, C_2B_5 = 2a$$

$$O_6C_2 = O_6C_3 = d$$

DOFs:

$$i = 6(6-1) - 8_{\text{sph}} \cdot 3 = 30 - 24 = 6 \text{ DOFs}$$

6 DOFs - 4 parasitic rot. of "2", "3", "4", "5" → 2 DOFs

Coordinates:

6 coordinates of "6":  $x_{O_6}, y_{O_6}, z_{O_6}, \varphi_{x_6}, \varphi_{y_6}, \varphi_{z_6}$

$$\underline{T}_{16} = \underline{T}_x(x_{O_6}) \cdot \underline{T}_y(y_{O_6}) \cdot \underline{T}_z(z_{O_6}) \cdot \underline{T}_{\varphi_x}(\varphi_{x_6}) \cdot \underline{T}_{\varphi_y}(\varphi_{y_6}) \cdot \underline{T}_{\varphi_z}(\varphi_{z_6})$$

Discussion:

6 coordinates → 2 DOFs → 4 constraints

Constraints:

- $|r_{1A_2} - r_{1B_2}| = l$  (1)
- $|r_{1A_3} - r_{1B_3}| = l$  (2)
- $|r_{1A_4} - r_{1B_4}| = l$  (3)
- $|r_{1A_5} - r_{1B_5}| = l$  (4)

①

$$\underline{r}_{1B_2} = \underline{T}_{16} \cdot [d, 0, -a, 1]^T = \begin{bmatrix} x_{B_2} \\ y_{B_2} \\ z_{B_2} \\ 1 \end{bmatrix}$$

$$(x_{A_2} - x_{B_2})^2 + (y_{A_2} - y_{B_2})^2 + (z_{A_2} - z_{B_2})^2 = l^2$$

②

$$\underline{r}_{1B_3} = \underline{T}_{16} \cdot [-d, 0, -a, 1]^T = \begin{bmatrix} x_{B_3} \\ y_{B_3} \\ z_{B_3} \\ 1 \end{bmatrix}$$

$$(x_{A_3} - x_{B_3})^2 + (y_{A_3} - y_{B_3})^2 + (z_{A_3} - z_{B_3})^2 = l^2$$

③

$$\underline{r}_{1B_4} = \underline{T}_{16} \cdot [0, 0, a, 1]^T = \begin{bmatrix} x_{B_4} \\ y_{B_4} \\ z_{B_4} \\ 1 \end{bmatrix}$$

$$(x_{A_4} - x_{B_4})^2 + (y_{A_4} - y_{B_4})^2 + (z_{A_4} - z_{B_4})^2 = l^2$$

④

$$\underline{r}_{1B_5} = \underline{T}_{16} \cdot [d, 2a, 0, 1]^T = \begin{bmatrix} x_{B_5} \\ y_{B_5} \\ z_{B_5} \\ 1 \end{bmatrix}$$

$$(x_{A_5} - x_{B_5})^2 + (y_{A_5} - y_{B_5})^2 + (z_{A_5} - z_{B_5})^2 = l^2$$