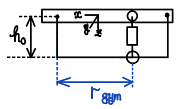
좌측



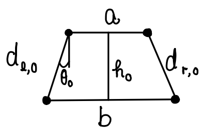
Upper joint 사이 거리 = a
Bottom joint 사이 거리 = b

초기 균형 잡힌 상태일 조건

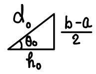
h_o : Given

$d_{l,0} = d_{r,0} = d_0$: unknown

앞쪽



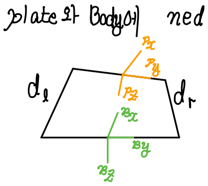
$$t\theta_0 = \frac{b-a}{2h_0}$$

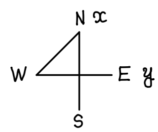


$$\therefore d_0 = \sqrt{\left(\frac{b-a}{2}\right)^2 + h_0^2}$$

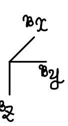
Upper plate의 자세는 thrust frame의 자세와 동일 (같이 붙어있는 강체로 해석할 수 있음)
3점 지지 해석을 통해 Inverse Kinematics 분석

plate와 Body에 ned 좌표계 설정





Body frame



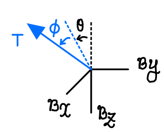
$\xrightarrow[\text{about } z]{\text{yaw } \psi}$ $\boxed{\psi = 0}$ 메카니즘 상에서 고정시켜야 함. $\longrightarrow$ SPR joint 추가 $\xrightarrow[\text{about } y]{\text{pitch } \theta}$ $\xrightarrow[\text{about } x']{\text{roll } \phi}$

$$^BR_I = \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix} \qquad ^IR_P = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & -s\phi \\ 0 & s\phi & c\phi \end{bmatrix}$$

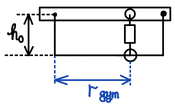
※ θ, ϕ : Given

$$^BR_P = \begin{bmatrix} c\theta & s\theta s\phi & s\theta c\phi \\ 0 & c\phi & -s\phi \\ -s\theta & c\theta s\phi & c\theta c\phi \end{bmatrix}$$

Plate 좌표계에서 추력 = $[\,0 \;\; 0 \;\; -T\,]^T$ $\longrightarrow$ Body frame에서 추력 $= -T\,[\, s\theta c\phi \;\; -s\phi \;\; c\theta c\phi \,]^T$



파란 점선은 $^Bx\,^Bz$ 평면 상에 놓여 있다.
파란 벡터는 $^Bx\,^Bz$ 평면을 수직으로 자르는 평면 위에 놓여 있다.



Gymbal의 pivot point에 ned 좌표계 설정 and Body frame 또한 pivot point에 원점 일치시킴.

각 upper joint들의 위치

Left one $^{B}b_l = {}^{B}R_p\,{}^{p}b_l$ where $^{p}b_l = \begin{bmatrix} -r_{gym} & -a/2 & 0 \end{bmatrix}^T$

Right one $^{B}b_r = {}^{B}R_p\,{}^{p}b_r$ where $^{p}b_r = \begin{bmatrix} -r_{gym} & a/2 & 0 \end{bmatrix}^T$

각 lower joint들의 위치

Left one $^{B}a_l = [\,-r_{gym} \;\; -b/2 \;\; -h_0\,]^T$

Right one $^{B}a_r = [\,-r_{gym} \;\; b/2 \;\; -h_0\,]^T$

Sol : $d_l = \sqrt{({}^{B}b_l - {}^{B}a_l)^T({}^{B}b_l - {}^{B}a_l)}$ $\quad d_r = \sqrt{({}^{B}b_r - {}^{B}a_r)^T({}^{B}b_r - {}^{B}a_r)}$

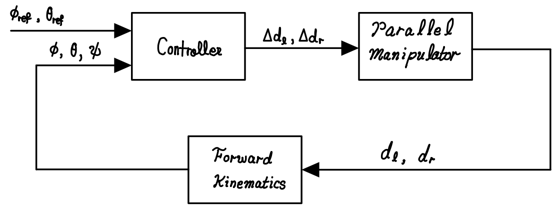
Check ! Let $^{B}R_p = I_3$ (no roll, pitch and yaw)

$d_l = \sqrt{\left(\frac{b-a}{2}\right)^2 + h_0^2}$ yes !

출저 : Robot Analysis 저자 Lung-Wen Tsai

Forward Kinematics

$$\begin{cases} f_1(\theta, \phi) = d_l^2 - ({}^{B}b_l - {}^{B}a_l)^T({}^{B}b_l - {}^{B}a_l) = 0 \\ f_2(\theta, \phi) = d_r^2 - ({}^{B}b_r - {}^{B}a_r)^T({}^{B}b_r - {}^{B}a_r) = 0 \end{cases}$$



ϕ_{ref} , θ_{ref}
ϕ, θ, ψ
Controller
Δd_l , Δd_r
Parallel Manipulator
d_l, d_r
Forward Kinematics