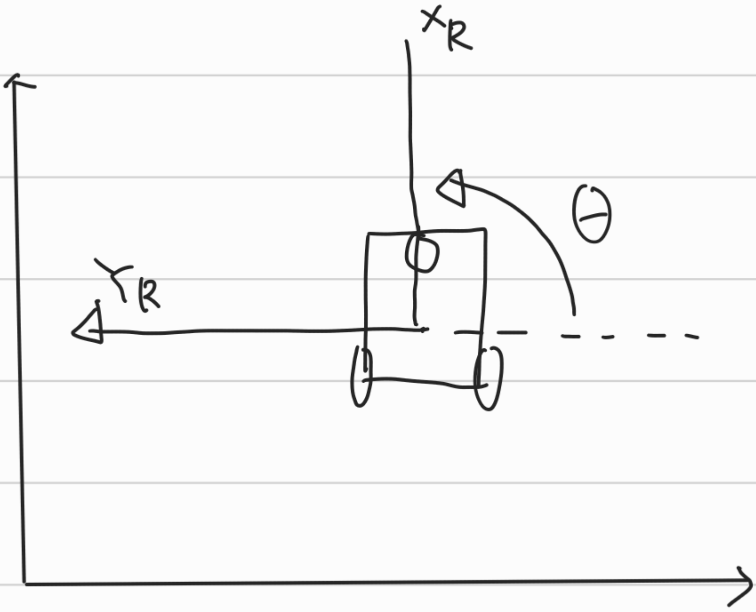


$$R(\theta) = \begin{bmatrix} c & s & 0 \\ -s & c & 0 \\ 0 & 0 & 1 \end{bmatrix} \rightsquigarrow \text{why}$$

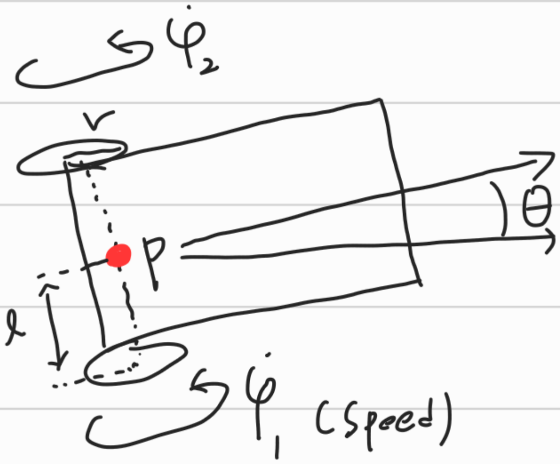
robot arm.

$$R(z, \theta) \begin{bmatrix} c & -s & 0 \\ s & c & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\dot{\xi}_R = \underbrace{R\left(\frac{\theta}{2}\right)}_{\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}} \dot{\xi}_I$$

Velocity $(\dot{x}, \dot{y}, \theta)$

$$\dot{\xi}_R = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \dot{y} \\ -\dot{x} \\ \dot{\theta} \end{bmatrix}$$



spinning speed each wheel

$$\dot{\xi}_I = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = f(l, r, \theta, \dot{\varphi}_1, \dot{\varphi}_2)$$

global reference frame

the robot overall speed

global local

$$\dot{\xi}_I = R(\theta)^{-1} \dot{\xi}_R$$

$\therefore$ Stategy will be to first compute contribution of each the two wheels in the local reference frame $\dot{\xi}_R$

half speed

$$\dot{x}_{r1} = \frac{1}{2} r \dot{\varphi}_1 \quad , \quad \dot{x}_{r2} = \frac{1}{2} r \dot{\varphi}_2$$

ω_1 at p = $\frac{r\dot{\varphi}_1}{2l}$ (바퀴1이 단독으로 회전하면 2볶기 바퀴2 중심으로 회전)

(rotation velocity)

ω_2 at p = $-\frac{r\dot{\varphi}_2}{2l}$ ⇝ − ⇒ clockwise −

$$\dot{\xi}_I = R(\theta)^{-1} \begin{bmatrix} \frac{r\dot{\varphi}_1}{2} + \frac{r\dot{\varphi}_2}{2} \\ 0 \\ \frac{r\dot{\varphi}_1}{2l} + \frac{-r\dot{\varphi}_2}{2l} \end{bmatrix}$$

→ why?

$$\begin{bmatrix} c & -s & 0 \\ s & c & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

움직이면 3자유도 (x, y, θ)

but 그냥 바퀴면 (y 축으로는 갈수 x)

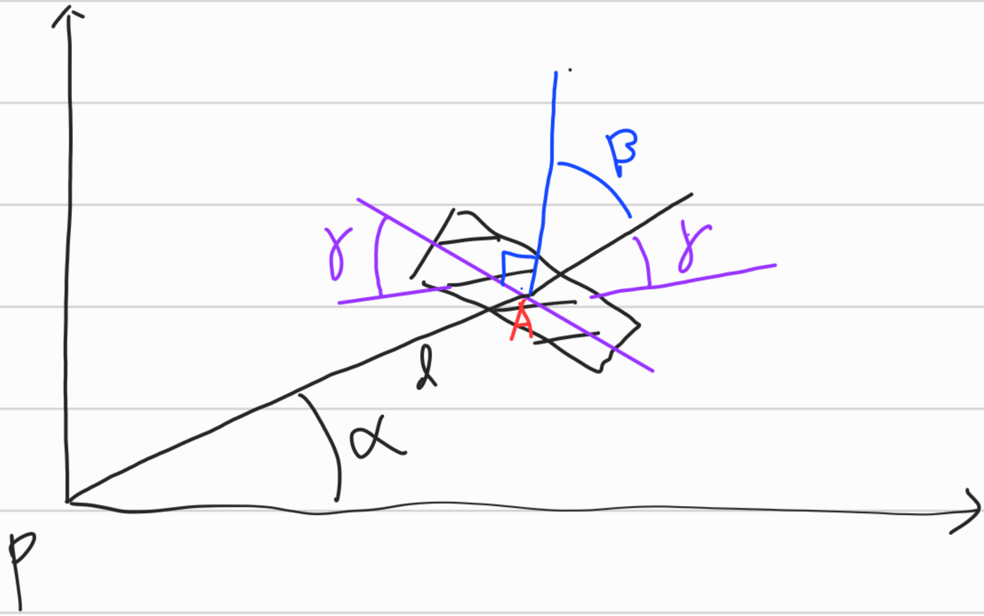
so, x, θ 만 가능.

$\theta = \frac{\pi}{2}$, $r = 1$ and $l = 1$

$\dot{\varphi}_1 = 4$, $\dot{\varphi}_2 = 2$

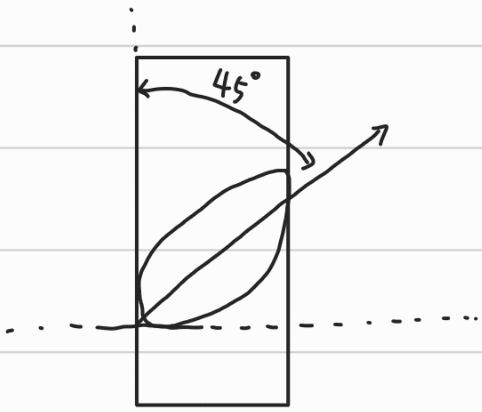
$$\dot{\xi}_I = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 3 \\ 1 \end{bmatrix}$$

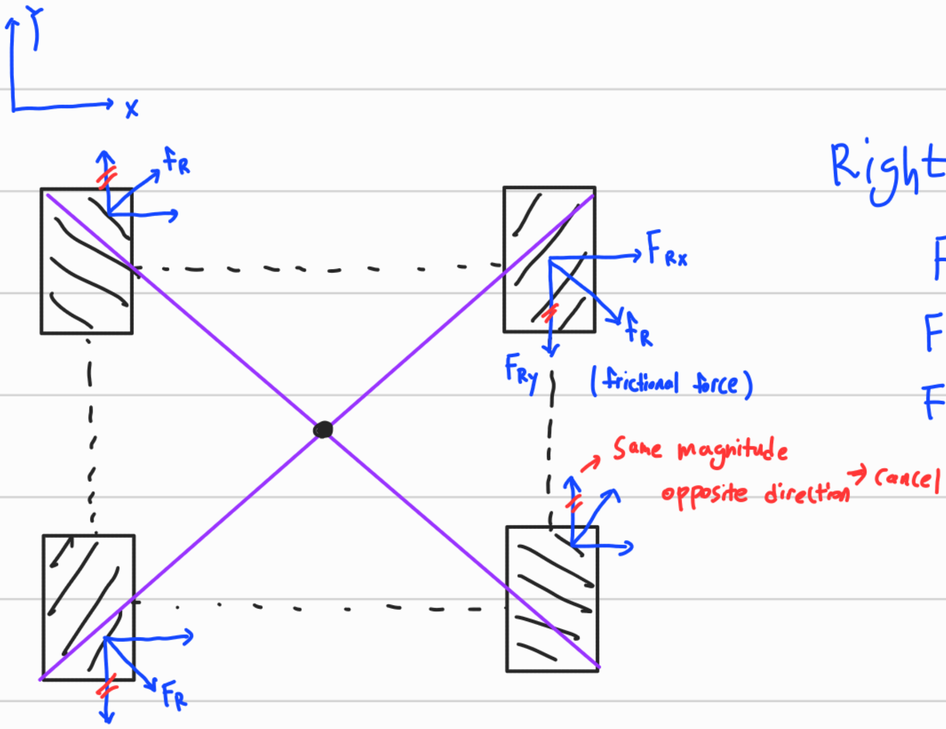
Swedish wheel



$$\begin{bmatrix} \sin(\alpha+\beta+\gamma) & -\cos(\alpha+\beta+\gamma) & -l\cos(\beta+\gamma) \end{bmatrix} R(\theta)\,\dot{\xi}_1 - r\dot{\varphi}\cos\gamma = 0$$

Mecanum wheel



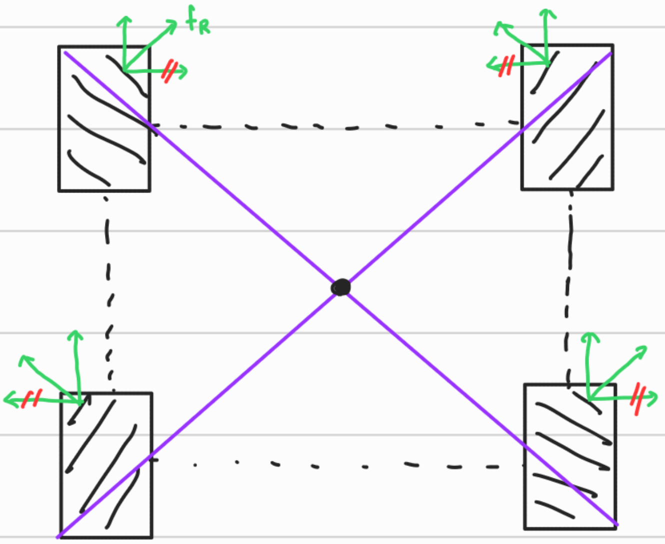


Right →

$F_{Nx} = 4f_{Rx}$

$F_{Ny} = 0$

$F_N = F_{Nx} + F_{Ny} = 4f_{Rx}$

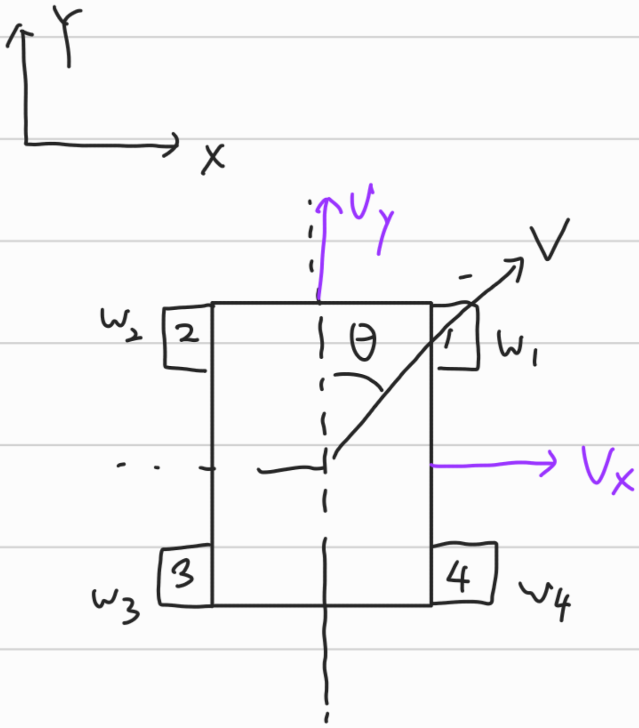


forward ↑

$F_{Nx} = 0$

$F_{Ny} = 4f_{Fy}$

$F_N = F_{Nx} + F_{Ny} = 4f_{Fy}$



$$V_x = V \sin\theta$$

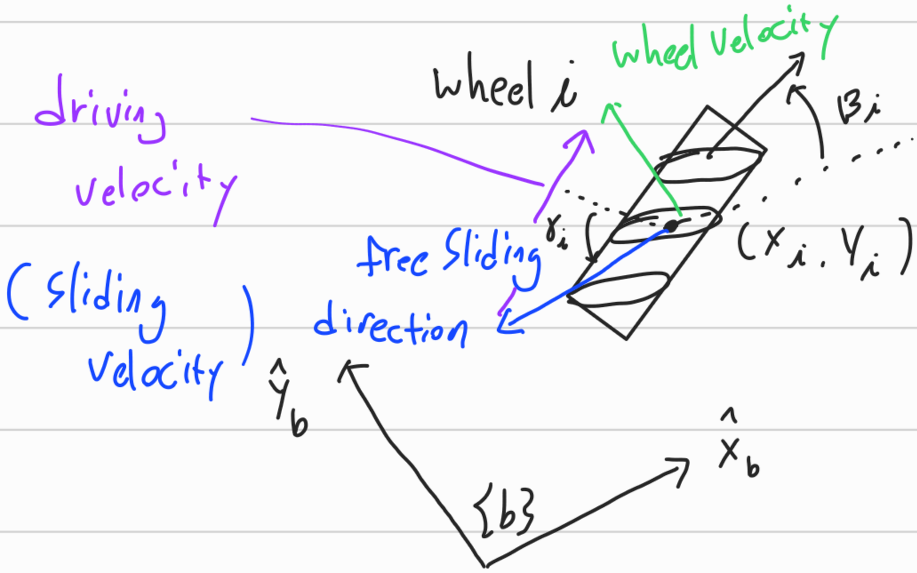
$$V_y = V \cdot \cos\theta$$

$$w_1 = V_x + V_y$$

$$w_2 = V_x - V_y$$

$$w_3 = V_x + V_y$$

$$w_4 = V_x - V_y$$



wheel driving speed

$$u_i = \frac{1}{r_i} \underbrace{[1 \quad \tan\gamma_i]}_{\text{component in driving direction}} \underbrace{\begin{bmatrix} \cos\beta_i & \sin\beta_i \\ -\sin\beta_i & \cos\beta_i \end{bmatrix} \begin{bmatrix} -y_i & 1 & 0 \\ x_i & 0 & 1 \end{bmatrix} \mathcal{V}_b}_{\text{linear velocity at wheel, wheel frame}}$$

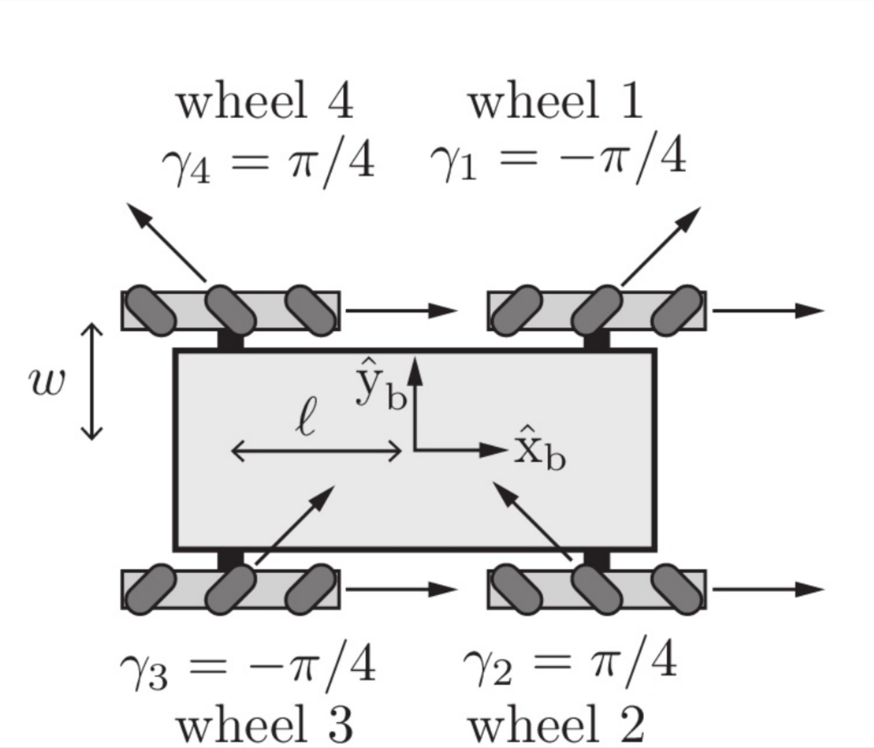
component in driving direction

linear velocity at wheel, wheelframe

linear velocity at wheel $\{b\}$

$$\underbrace{u_i = \underbrace{\frac{1}{r_i}}_{\text{wheel radius}} \underbrace{[1 \quad \tan\gamma_i]}_{\text{component in driving direction}} \underbrace{\begin{bmatrix} \cos\beta_i & \sin\beta_i \\ -\sin\beta_i & \cos\beta_i \end{bmatrix}}_{\text{linear velocity at wheel, in wheel frame}} \underbrace{\begin{bmatrix} -y_i & 1 & 0 \\ x_i & 0 & 1 \end{bmatrix} \mathcal{V}_b}_{\text{linear velocity at wheel, in } \{b\}}}_{1 \times 3 \text{ vector.}}$$

$$u = H(0) \mathcal{V}_b$$



$$u = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix} = H(0)\mathcal{V}_b = \frac{1}{r} \begin{array}{c} \begin{bmatrix} -\ell-w & 1 & -1 \\ \ell+w & 1 & 1 \\ \ell+w & 1 & -1 \\ -\ell-w & 1 & 1 \end{bmatrix} \\ \begin{matrix} \text{rotate} & \text{x direction} & \text{y direction} \end{matrix} \end{array} \begin{bmatrix} \omega_{bz} \\ v_{bx} \\ v_{by} \end{bmatrix}$$

$$\text{wheel speed} = H(0)\mathcal{V}_b$$

$$u = \underbrace{H(0) \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & s\phi \\ 0 & -s\phi & c\phi \end{bmatrix}}_{H(\phi)} \begin{bmatrix} \dot{\phi} \\ \dot{x} \\ \dot{y} \end{bmatrix}$$

$$u = H(\phi)\dot{q}$$

(vector of wheel speed)

Feed forward plse PI feedback control

$$\dot{q}(t) = \dot{q}_d(t) + k_p(q_d(t) - q(t)) + k_i \int_0^t (q_d(t) - q(t))\,dt.$$

estimate $\underset{\sim}{q}$.

↳ using odometry, $\underline{\text{external sensor}}$
주행거리
camera, GPS, laser range finders

○

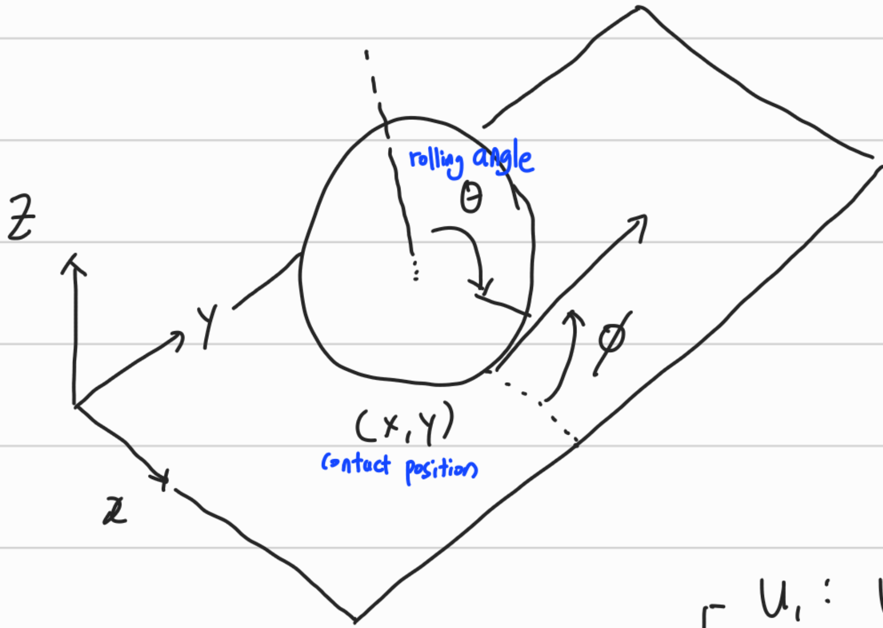
↓

$$u = H(\phi)\dot{q}$$

$$\begin{bmatrix} u_1 \\ \vdots \\ u_m \end{bmatrix} = H(0)V_b = \begin{bmatrix} h_1(0) \\ \vdots \\ h_m(0) \end{bmatrix} V_b$$

$$-u_{i,max} \le u_i = h_i(0)V_b \le u_{i\,max}$$

$q = (\phi, x, y, \theta)$



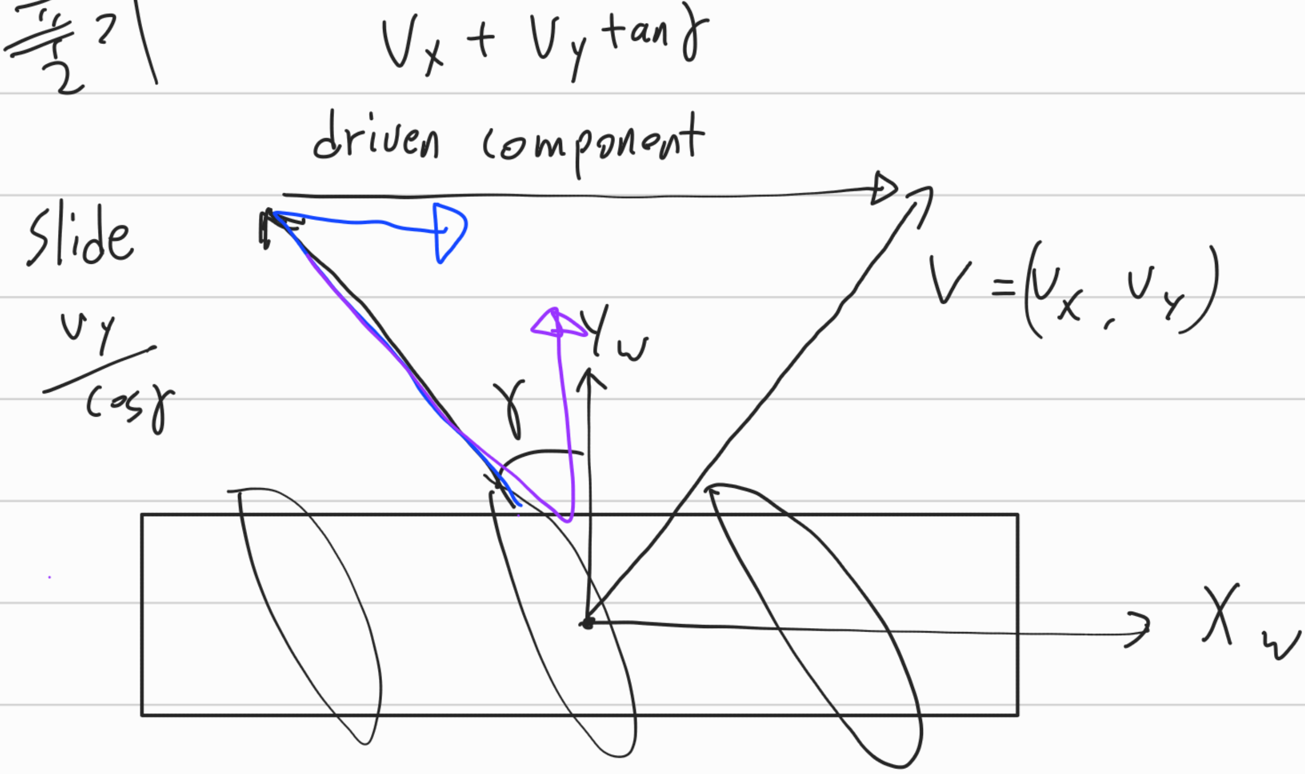
Control driving wheel

- u_1 : rolling speed
  - forward-backward rolling angular speed
- u_2 : turning speed
  - the speed of turning the heading direction ϕ

$$\dot{q} = \begin{bmatrix} \dot{\phi} \\ \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ r c\phi & 0 \\ r s\phi & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = G(q)u$$

$$= \underbrace{g_1(q)u_1 + g_2(q)u_2}_{\text{vector field}}$$

My $\frac{\pi}{2}$?



$$\gamma = \pm 45^\circ$$

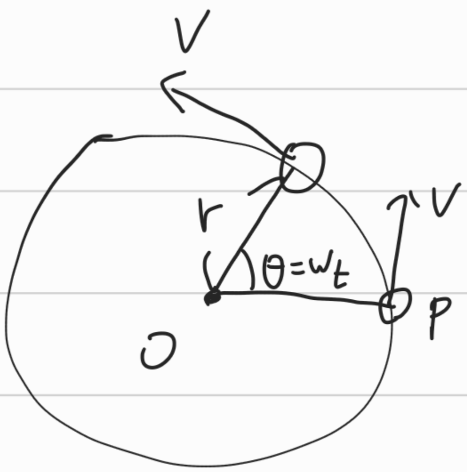
Slide opposite

$$V_x = V_{drive} - v_{slide} \sin\gamma$$

$$v_y = 0 + V_{slide} \cos\gamma$$

$$V_{drive} = V_x + \underbrace{V_{slide} \sin\gamma}_{\hookrightarrow\ v_y \tan\gamma}$$

$$V_{slide} = \frac{v_y}{\cos\gamma}$$



$$V = r\omega$$

$$\omega = \frac{1}{r} V$$

$$u = \frac{1}{r} V_{drive}$$

$$= \frac{1}{r} (V_x + V_y \tan\gamma)$$

$$u_i = \frac{1}{r_i} \begin{bmatrix} 1 & \tan\gamma_i \end{bmatrix} \begin{bmatrix} V_x \\ V_y \end{bmatrix}$$

ok.

How to get $\begin{bmatrix} V_x \\ V_y \end{bmatrix}$?

robot frame. S

$$\text{pose} \begin{bmatrix} \dot\phi \\ \dot x \\ \dot y \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & s\phi \\ 0 & -s\phi & c\phi \end{bmatrix} \begin{bmatrix} \dot\phi \\ \boxed{\begin{matrix} \dot x \\ \dot y \end{matrix}} \end{bmatrix}$$

$\#\ v_x, v_y$

wheel driving speed

$$u_i = \frac{1}{r_i} \begin{bmatrix} 1 & \tan\gamma_i \end{bmatrix} \begin{bmatrix} \cos\beta_i & \sin\beta_i \\ -\sin\beta_i & \cos\beta_i \end{bmatrix} \begin{bmatrix} -y_i & 1 & 0 \\ x_i & 0 & 1 \end{bmatrix} \mathcal{V}_b$$

component in driving direction

linear velocity at wheel, wheelframe

linear velocity at wheel $\{b\}$

$$u_i = \underbrace{\frac{1}{r_i} \begin{bmatrix} 1 & \tan\gamma_i \end{bmatrix} \begin{bmatrix} \cos\beta_i & \sin\beta_i \\ -\sin\beta_i & \cos\beta_i \end{bmatrix} \begin{bmatrix} -y_i & 1 & 0 \\ x_i & 0 & 1 \end{bmatrix}}_{1 \times 3 \text{ vector.}} \mathcal{V}_b$$

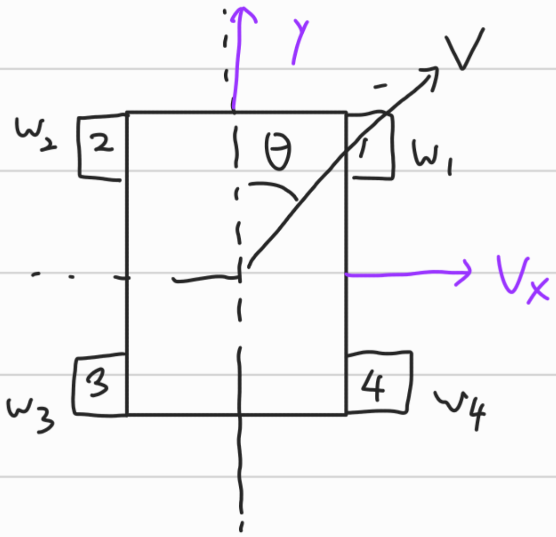
wheel radius

component in driving direction

linear velocity at wheel, in wheel frame

linear velocity at wheel, in $\{b\}$

$$u = H(0)\mathcal{V}_b$$



$$V_x = V \sin\theta$$

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