pose_callback : T m

ESKF validation

△

△ pose_callback:

T in $\{I\}$

$\Rightarrow T \Rightarrow \xi_I = T_B^I \, \xi_B$

△ y_ref , x_pose

△ twist_callback:

$\begin{cases} \dot{t} \\ \dot{R} \end{cases}$ in $\{I\}$

$\Rightarrow \begin{cases} \dot{t}_B^I \\ \dot{R}_B^I \end{cases}$

① thrust_pub & control_pub

?

② yaw_ref:

→ set in path?

→ user random give & help modifying

△ x, y, z, ϕ, θ, ψ

u v w p q r

why your value so weird?

△ PID & MPC

ctrl allocation (+)

different (−)

△ why don't use default control allocation

(thrust_manager.

$$M\dot{v} + C(v)v + D(v)v + g(\eta) = \tau + w$$

$$\rightarrow M_{rb}\dot{v} + M_A\dot{v} + M_{rb}g + C(v)v + D(v)v + g(\eta) = \tau + \delta$$

all in $\mathcal{B}$

$$\rightarrow \underbrace{M_{rb}(\dot{v}+g)}_{\text{IMU measured}} = \tau + \underbrace{\delta}_{\text{external disturbance}} - \underbrace{M_A\dot{v}}_{\text{added mass}} - \underbrace{C(v)v}_{\text{科氏力}} - \underbrace{D(v)v}_{\text{damping force}} - \underbrace{g(\eta)}_{\text{gravity + buoyancy}}$$

→ MY 用這個去 propagate

→ w/ IMU, we can use this

ESKF

△ equation of motion

for any IMU:

$$\begin{cases} \dot{p} = v \\ \dot{v} = R(\tilde{a} - b_a - \eta_a) + g \\ \dot{R} = R(\tilde{\omega} - b_g - \eta_g)^\wedge \\ \dot{b}_g = \eta_{bg} \\ \dot{b}_a = \eta_{ba} \\ \dot{g} = 0 \end{cases}$$

△ inducing error state

$$\left.\begin{aligned} p &= \bar{p} + \delta p \\ v &= \bar{v} + \delta v \\ R &= \bar{R} \boxplus \delta R \\ b_g &= \bar{b}_g + \delta b_g \ (\text{gyro}) \\ b_a &= \bar{b}_a + \delta b_a \ (\text{accel}) \\ g &= \bar{g} + \delta g \end{aligned}\right\} \quad \begin{aligned} \delta\dot{p} &= \delta v \\ \delta\dot{v} &= -R(\tilde{a} - b_a)^\wedge \delta\theta - R\,\delta b_a - \eta_a + \delta g \\ \delta\dot{\theta} &= -(\tilde{\omega} - b_g)^\wedge \delta\theta - \delta b_g - \eta_g \\ \delta\dot{b}_g &= \eta_g \\ \delta\dot{b}_a &= \eta_a \\ \delta\dot{g} &= 0 \end{aligned}$$

true state, nominal state, error state

$$x = [p, R, v, b_g, b_a, g, \xi]^T$$

△ error state motion of equation

nominal state

$$\begin{cases} p(t+\Delta t) = p(t) + v\Delta t + \frac{1}{2}(R(\tilde{a} - b_a))\Delta t^2 + \frac{1}{2} g \Delta t^2 \\ v(t+\Delta t) = v(t) + R(\tilde{a} - b_a)\Delta t + g\Delta t \\ R(t+\Delta t) = R(t)\,\mathrm{Exp}((\tilde{\omega} - b_g)\Delta t) \\ b_g(t+\Delta t) = b_g(t) \\ b_a(t+\Delta t) = b_a(t) \\ g(t+\Delta t) = g(t) \end{cases}$$

$$\xi(t+\Delta t) = \xi(t)$$

error state

$$\begin{cases} \delta p(t+\Delta t) = \delta p + \delta v \Delta t \\ \delta v(t+\Delta t) = \delta v + (-R(\tilde{a} - b_a)^\wedge \delta\theta - R\,\delta b_a + \delta g)\Delta t - \eta_v \\ \delta\theta(t+\Delta t) = \mathrm{Exp}(-(\tilde{\omega} - b_g)\Delta t)\,\delta\theta - \delta b_g \Delta t - \eta_\theta \\ \delta b_g(t+\Delta t) = \delta b_g + \eta_g \\ \delta b_a(t+\Delta t) = \delta b_a + \eta_a \\ \delta g(t+\Delta t) = \delta g. \end{cases}$$

$$\delta\xi(t+\Delta t) = \delta\xi$$

- $\delta x_{k+1} = f(\delta x_k) + w \ , \ w \sim N(0, Q)$

$$z = \begin{bmatrix} p \\ R \\ \tau \end{bmatrix} = \begin{bmatrix} p \\ R \\ \underbrace{M_{rb}(\dot{v}+g)}_{\text{no states dep.}} - \overset{\text{w.r.t. } \xi}{\xi} + \underbrace{M_A\dot{v}}_{\text{no states dep.}} + \underbrace{C(v)v}_{\text{no pose dep.}} + \overset{\text{w.r.t. } v}{D(v)v} + g(\eta) \end{bmatrix} + \eta$$

where

△ △

$$D(v)v = D_L + D_{NL}(v)$$

$$\frac{\partial D(v)v}{\partial \delta v} = \frac{\partial D_L v}{\partial \delta v} + \frac{\partial}{\partial \delta v} D_{NL}(v)v$$

- $D_L v = D_L(\bar{v} + \delta v)$

$\therefore \frac{\partial D_L v}{\partial \delta v} = D_L$

- $D_{NL}(v)v = D_{NL}(\bar{v} + \delta v)(\bar{v} + \delta v)$

$$= \begin{bmatrix} -X_{u|u|}\,|u+\delta u|\,(u+\delta u) \\ -Y_{v|v|}\,|v+\delta v|\,(v+\delta v) \\ -Z_{w|w|}\,|w+\delta w|\,(w+\delta w) \end{bmatrix} \approx \begin{bmatrix} -X_{u|u|} \cdot f_p(u+\delta u) \\ -Y_{v|v|} \cdot f_p(v+\delta v) \\ -Z_{w|w|} \cdot f_p(w+\delta w) \end{bmatrix}.$$

$$\begin{bmatrix} q \\ \dot q \\ \tau_d \end{bmatrix} =$$

$$\begin{matrix} \dot q \\ \ddot q \\ \dot\tau_d \end{matrix} = \begin{bmatrix} \dot q \\ M(q)^{-1}(\tau - \tau_d - H(q,\dot q)) \\ \dot\tau_d \end{bmatrix}$$

$q - (q + \dot q \tau)$

$$\therefore \frac{\partial D_{NL}(v)v}{\partial \delta v} = \begin{bmatrix} -X_{u|u|} \frac{\partial}{\partial \delta u} f_p \\ -Y_{v|v|} \frac{\partial}{\partial \delta v} f_p \\ -Z_{w|w|} \frac{\partial}{\partial \delta w} f_p \end{bmatrix}$$

$21\times21\times21\times9\ (9\times21\ \cancel{\times 21 \times 21 \times 21} \times 9 + 9\times9)$

$21\times21\ \cancel{\times 21 \times 9\ \times 9} \times 9$

21×9 $\quad$ 9×1

$$\delta x_{k+1} = f(\delta x_k)$$

$$\delta p_{k+1} = \delta p_k + \delta v \Delta t$$

$$\delta v_{k+1} = \delta v_k - R(\tilde a - b_a)^\wedge \delta\theta \Delta t - R\delta b_a \Delta t + I\delta g \Delta t$$

$$= \delta v_k + (-R(\tilde a - b_a)^\wedge \delta\theta - R\delta b_a + \delta g)\Delta t$$

$$\delta\theta_{k+1} = \mathrm{Exp}(-(\tilde\omega - b_g)\Delta t)\delta\theta - \delta b_g \Delta$$

72 ~ 78

$$x = [\,p \;\; v \;\; R \;\; b_a \;\; b_g \;\; g \;\; \xi\,]^T$$

$$z = [\,p \;\; R \;\; \tau\,]^T$$

$$\begin{bmatrix} \frac{\partial p}{\partial p} & \frac{\partial p}{\partial v} & \frac{\partial p}{\partial R} & \frac{\partial p}{\partial b_a} & \frac{\partial p}{\partial b_g} & \frac{\partial p}{\partial g} & \frac{\partial p}{\partial \xi} \\ \frac{\partial R}{\partial p} & \frac{\partial R}{\partial v} & \frac{\partial R}{\partial R} & \frac{\partial R}{\partial b_a} & \frac{\partial R}{\partial b_g} & \frac{\partial R}{\partial g} & \frac{\partial R}{\partial \xi} \\ \frac{\partial \tau}{\partial p} & \frac{\partial \tau}{\partial v} & \frac{\partial \tau}{\partial R} & \frac{\partial \tau}{\partial b_a} & \frac{\partial \tau}{\partial b_g} & \frac{\partial \tau}{\partial g} & \frac{\partial \tau}{\partial \xi} \end{bmatrix} \text{ — } A.$$

$$\tau_B = \underbrace{M_{rb}\left(\begin{bmatrix}\tilde a \\ \tilde\omega\end{bmatrix} - \begin{bmatrix} b_a \\ b_g \end{bmatrix}\right)}_{①} \underbrace{-\,\xi}_{②} + \underbrace{M_a\left(\begin{bmatrix}\tilde a \\ \tilde\omega\end{bmatrix} - \begin{bmatrix} b_a \\ b_g \end{bmatrix}\right)}_{③} + \underbrace{C(v)v}_{④} + \underbrace{D(v)v}_{⑤} + \underbrace{g(\eta)}_{⑥}$$

$= mI[\tilde a - b_a] + \begin{bmatrix} 0 & mz_g & 0 \\ -mz_g & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}[\tilde\omega - b_g]$ ① M_{rb}

$-\,\xi_B$ ② external ξ

$+ \begin{bmatrix} -X_{\dot u} & & \\ & -Y_{\dot v} & \\ & & -Z_{\dot w} \end{bmatrix}[\tilde a - b_a]$ ③ added mass

$+ [0]\,V_B + \begin{bmatrix} 0 & Z_{\dot w}w & Y_{\dot v}v \\ Z_{\dot w}w & 0 & -X_{\dot u}u \\ -Y_{\dot v}v & X_{\dot u}u & 0 \end{bmatrix} V_B$ ④ central.

$+ \begin{bmatrix} -X_u & & \\ & -Y_v & \\ & & -Z_w \end{bmatrix}[V_B] + \begin{bmatrix} -X_{u|u|}\,|u|\,u \\ -Y_{v|v|}\,|v|\,v \\ -Z_{w|w|}\,|w|\,w \end{bmatrix}$ ⑤ damping

$+ [\,g + B\,]$ ⑥

$$\mathcal{X}\quad \tau_I = R\tau_B$$

$$\tau_I = mI\,R(\tilde a - b_a) + M_{rbR}\,R(\tilde\omega - b_g)$$
$$-\,\xi_I$$
$$+\,M_a R(\tilde a - b_a)$$
$$+\,R[V_B]_\times V_B$$
$$+\,R[D_L V_B + D_{NL}\, f(V_B)]$$
$$+\,[g + B]$$

$$H = \frac{\partial h}{\partial x}\frac{\partial x}{\partial \delta x}$$

$$\begin{bmatrix} p \\ v \\ R \\ \xi \end{bmatrix} = \begin{bmatrix} p \\ v \\ R \\ \xi \end{bmatrix} + PH^T(HPH^T + R)^{-1}\begin{bmatrix} p \\ R \\ \tau \end{bmatrix}$$

g

$\tau_B = mI(\tilde a - b_a)$
$+ M_{rbR}(\tilde\omega - b_g)$
$- \xi_B$
$+ M_a(\tilde a - b_a)$
$\alpha \leftarrow + [V_B]_\times V_B$
$\beta \leftarrow + D_L V_B + D_{NL} f(V_B)$

w.r.t. V_I, R

0.95

$$\boxed{\underbrace{z - h(x)}_{\text{error term}}}$$

$\delta\xi = \tau - \underbrace{(\text{一堆剩下的})}_{\text{no one depends on } \delta x}$

①
$$\frac{\partial \tau_I}{\partial V_I} : \frac{\partial}{\partial V_I}\left(R\cdot V_B \times V_B + RD_L V_B + RD_{NL} f_p(V_B)\right)$$
$$= \frac{\partial}{\partial V_I} V_I \times V_B + \frac{\partial}{\partial V_I} D_L V_I + \frac{\partial}{\partial V_I} R D_{NL} f_p(R^{-1} V_I)$$
$$= \cancel{V_I^\times J(V_B)} - V_B^\times J(V_I) + D_L + RD_{NL}$$
$$= -[V_B]_\times + D_L$$

C_{rb}

$$\begin{bmatrix} & \\ & \end{bmatrix}\begin{bmatrix} u \\ v \\ w \\ p \\ q \\ r \end{bmatrix}$$

$$[v]_\times = \begin{bmatrix} 0 & -v_3 & v_2 \\ v_3 & 0 & -v_1 \\ -v_2 & v_1 & 0 \end{bmatrix}$$

$C_{rb} = $

- in your path,
  u actually give psi = 0
  this could cause a problem

$$[a]_\times = \begin{bmatrix} 0 & -a_3 & a_2 \\ a_3 & 0 & -a_1 \\ -a_2 & a_1 & 0 \end{bmatrix} \left(- \begin{bmatrix} 0 & -m \cdot w & mv \\ mw & 0 & -mu \\ -mv & mu & 0 \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \right)$$

$$= \begin{bmatrix} mwq - mvr \\ -mwp + mur \\ mvp - muq \end{bmatrix}$$

$$\text{mass} \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

$u = 1.27$
$v = 0.047$
$w = -0.1157$

$p = 0.10$
$q = -0.05$
$r = 0.93$

$$\begin{array}{cc} 6 & u \\ 7 & v \\ 8 & w \\ & \\ 9 & p \\ 10 & q \\ 11 & r \end{array}$$

$$\begin{bmatrix} -m \cdot r \cdot v + m \cdot q\, w \\ m \cdot r \cdot u - m \cdot \overset{1.27}{p}\, w \\ -m \cdot q \cdot u + m \cdot p\, v \end{bmatrix}$$

$$\begin{bmatrix} 0.707 & 0.707 & -0.707 & -0.707 \end{bmatrix} \begin{bmatrix} 385 \\ 407 \\ -625 \\ -170 \\ -279 \\ -280 \end{bmatrix}$$

$$\tau = Kt$$

$$\boxed{\begin{aligned} \tau_x = &\; m_{rb} \cdot a_x \\ &+ m_a \cdot a_x \\ &+ C(v_B) v_B \\ &- \xi \\ &+ D(v_B) v_B. \end{aligned}}$$

$$\xi = -\tau$$

$$3 - h(x).$$

$$\check{\xi} + K \left(\underbrace{\tau - \left(M_{rb} \dot{v} - \check{\xi} + M_a \dot{v} - D(v) v - g \right)} \right)$$

$$\hat{\xi} = \check{\xi} + K \cdot \left(\tau - M_{rb} \dot{v} + 0 - M_a \dot{v} - D(v) v - g. \right)$$

$$\xi = M_{rb} \dot{v} - (\tau - Dv(v) - M_a \dot{v} - g)$$

$$= M_{rb} \dot{v} - \tau + Dv(v) + M_a \dot{v} + g.$$

3-hx

7

$$\zeta = M_{rb} - (\bar{\tau} - D - M_a - g).$$

code raw

$$\Rightarrow \zeta = M_{rb} \underbrace{- \tau}_{z} + D + M_a + g.$$

$$\Rightarrow \boxed{\tau = M_{rb} + D + M_a + g - \zeta}$$

$$z - h(x).$$

$$= \tau - (M_{rb} + D + M_a + g \cancel{- \check{\zeta}})$$

$$\Rightarrow \tau - M_{rb} - D - M_a - g \cancel{+ \zeta}$$

$$\check{x} + K(z - hx)$$

@ init

$x = -0.221723$

$y = 1.6379$

$z = -1924$

$v = 1.00184$

-0.32815

-0.0067426