pose_callback : T in

ESKF validation

△

△ pose_callback:

T in {I}

⇒ T ⇒ $q_I = T^I_B \, q_B$

△ y_ref , x_pose

△ twist_callback:

$\left\{ \begin{array}{l} \dot{t} \\ \dot{R} \end{array} \right.$ in {I}

⇒ $\left\{ \begin{array}{l} \dot{t}^I_B \\ \dot{R}^I_B \end{array} \right.$

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.

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

→ $M_{rb}\dot{v} + M_a\dot{v} + M_{rb}g + C(v)v + D(v)v + g(\eta) = \tau + \xi$

all in B

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

→ MY 用這個去 propagate

→ w/ IMU, we can use this

ESKF

△ equation of motion

for any IMU:

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

△ inducing error state

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

true state / nominal state / error state

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

△ error state motion of equation

nominal state

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

error state

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

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

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

w.r.t. ξ ✓ ; w.r.t. v ✓ ; w.r.t.

where

△ △

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

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

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

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

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

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

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

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

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

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

$$21\times 21 \times 21 \times 9 \; (9\times 21 \cancel{\times 21 \times 21 \times 21} \times 9 + 9\times 9)$$

$$21 \times \cancel{21 \times 21 \times 9 \;\; \times 9} \times 9.$$

$$21 \times 9 \qquad 9 \times 1$$

$\delta X_{k+1} = f(\delta X_k)$

$\delta P_{k+1} = \delta P_k + \delta V \Delta t$

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

$= \delta V_k + (- R(\tilde{a} - b_a)^{\wedge} \delta\theta - R\,\delta b_a + \delta g) \Delta t$

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

72 ~ 78

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

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

$$\begin{bmatrix} \frac{\partial P}{\partial P} & \frac{\partial P}{\partial v} & \frac{\partial P}{\partial R} & \frac{\partial P}{\partial b_a} & \frac{\partial P}{\partial b_g} & \frac{\partial P}{\partial g} & \frac{\partial P}{\partial \xi} \\ \frac{\partial R}{\partial P} & \frac{\partial R}{\partial v} & \frac{\partial R}{\partial R} & \frac{\partial R}{\partial b_a} & \frac{\partial R}{\partial b_g} & \frac{\partial R}{\partial g} & \frac{\partial R}{\partial \xi} \\ \frac{\partial \tau}{\partial P} & \frac{\partial \tau}{\partial v} & \frac{\partial \tau}{\partial R} & \frac{\partial \tau}{\partial b_a} & \frac{\partial \tau}{\partial b_g} & \frac{\partial \tau}{\partial g} & \frac{\partial \tau}{\partial \xi} \end{bmatrix} \longrightarrow A.$$

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

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

$\tau_I = R\,\tau_B$

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

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

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

g

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

w.r.t. V_I, R

0.95

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

$\delta\xi = \tau - \underbrace{(一定积桥)}_{\text{no one depends on } \delta x}$

①
$$\frac{\partial \tau_I}{\partial V_I} : \frac{\partial}{\partial V_I}(R \cdot V_B \times V_B + R D_L V_B + R D_{NL} f_p(V_B))$$

$$= \frac{\partial}{\partial V_I} V_I \times V_B + \frac{\partial}{\partial V_I} D_L V_I + \frac{\partial}{\partial V_I} R D_{NL} f_p(R^{-1} V_I)$$

$$= \cancel{V_I^\times J(V_B)} - V_B^\times J(V_I) + D_L + R D_{NL}$$

$$= -[V_B]_\times + D_L$$

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 $\dot{psi} = 0$ this could cause a problem

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

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

$$mws \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

$u = 1.27$
$v = 0.047$
$w = -0.157$

$p = 0.10$
$q = -0.45$
$r = 0.93$

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

6 u
7 v
8 w

9 p
" q
" r

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

$T = Kt$

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

$\xi = -\tau$

$z - h(x).$

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

$$\hat{\xi} = \check{\xi}_0 + K\cdot\left(\tau - M_{rb}\dot{v} + 0 - M_a\dot{v} - D(v)v - g.\right)$$

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

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

$z - hx$

?

7

$$\xi = M_{rb} - (\tau - D - M_a - g)$$

code raw

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

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

$$z - \dot{h}(x).$$

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

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

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

@ init

$x = -0.221723$

$y = 1.6379$

$z = -1924$

$$V = \begin{matrix} 1.00184 \\ -0.32815 \\ -0.0067426 \end{matrix}$$