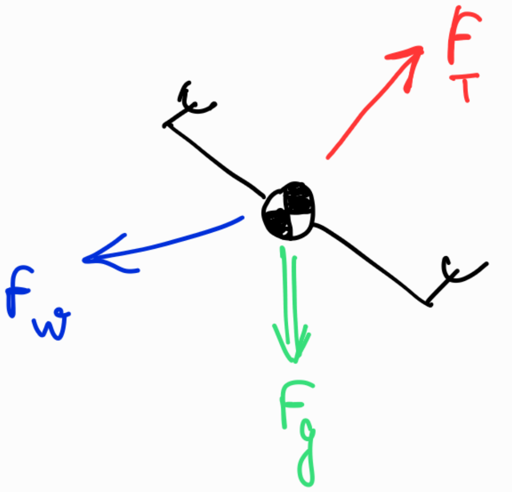
ESTIMATE WIND & FIND ORIENTATION - I



Hover equilibrium:

$$^{B}\vec{\mathbb{F}}_{total} = m\left(\underbrace{^{B}\vec{\omega} \times {}^{B}\vec{v}}_{\approx 0} + \underbrace{^{B}\dot{\vec{v}}}_{0}\right)$$

(equilibrium)

$$\Rightarrow \; ^{B}\vec{\mathbb{F}} = 0$$

$$\left(\begin{aligned} &\Rightarrow \; Q\,^{B}\vec{\mathbb{F}} = Q(0) \\ &\Rightarrow \; ^{W}\vec{\mathbb{F}} = 0 \end{aligned}\right)$$

$$\Rightarrow \; ^{B}\vec{F}_T + {}^{B}\vec{F}_g + {}^{B}\vec{F}_w = 0$$

$$\begin{bmatrix} 0 \\ 0 \\ -F_T \end{bmatrix} + m\underbrace{\begin{bmatrix} ^{B}a_x \\ ^{B}a_y \\ ^{B}a_z \end{bmatrix}}_{\text{IMU data}} + {}^{B}\vec{F}_w = 0$$

$$\Rightarrow \; ^{B}\vec{F}_w = \begin{bmatrix} -{}^{B}a_x \\ -{}^{B}a_y \\ F_T - {}^{B}a_z \end{bmatrix}$$

We found wind estimate in Body-Frame

estimate ...

What if no equilibrium?:

$$ {}^{B}\vec{F} = m\left({}^{B}\vec{\omega} \times {}^{B}\vec{v} + \dot{\vec{v}} \right) $$

$$ {}^{B}\vec{F}_T + {}^{B}\vec{F}_g + {}^{B}\vec{F}_w = m\left({}^{B}\vec{\omega} \times {}^{B}\vec{v} + \dot{\vec{v}} \right) $$

$\begin{bmatrix} 0 \\ 0 \\ -u_4 \end{bmatrix}$ — Thrust control input

$Q^T_{est} \begin{bmatrix} 0 \\ 0 \\ -9.81 \end{bmatrix} m$ — State estimation

${}^{B}\vec{F}_w$: ?

${}^{B}\vec{\omega}$: IMU data

${}^{B}\vec{v}$: State estimatn

$\dot{\vec{v}}$: IMU data? (acceleratn)

$$ \boxed{ {}^{B}\vec{F}_{w_{est}} = m\left({}^{B}\vec{\omega}_{IMU} \times {}^{B}\vec{v}_{est} + {}^{B}\dot{\vec{v}}_{IMU} \right) - \begin{bmatrix} 0 \\ 0 \\ -u_4 \end{bmatrix} - Q^T_{est} \begin{bmatrix} 0 \\ 0 \\ -(9.81)m \end{bmatrix} } $$

Estimated Wind vector in Body frame

- Sensors
- EKF2
- Control Data
- Truth

Find required orientation from Wind estimate:

(this orientation is different from current Q_{est})

$$ {}^{B}\vec{F}_T + {}^{B}\vec{F}_g + \underbrace{\boxed{{}^{B}\hat{F}_w}}_{\text{(estimated)}} = 0 $$

THIS EQ^N IS WRONG BECAUSE WE FOUND WIND IN BODY FRAME OF NON-EQUILIBRIUM ORIENTATION.

$\therefore$ FIND WIND IN WORLD FRAME BECAUSE THAT COORDINATE REPRESENTATION WOULD BE ABSOLUTEY TRUE REGARDLESS OF "EQUILIBRIUM" OR "NON-EQUILIBRIUM" ORIENTATION ORIENTATION

$$ Q_{sp}^{T}\,{}^{W}\vec{F}_T + {}^{B}\vec{F}_g + \boxed{Q_{sp}^{T}\,{}^{W}\vec{F}_{w_{est}}} = 0 $$

$$ \left({}^{W}\vec{F}_{w_{est}} = Q_{est}\,{}^{B}\vec{F}_{w_{est}} \right) $$

(from above)

the orientat^n that will satisfy equilibrium under current Wind vector estimate ${}^{B}\hat{F}_{w_{est}}$

$$ \Rightarrow Q_{sp}\left(Q_{sp}^{T}\,{}^{W}\vec{F}_T + {}^{B}\vec{F}_g + Q_{sp}^{T}\,{}^{W}\vec{F}_{w_{est}} \right) = 0 $$

$$ \Rightarrow {}^{W}\vec{F}_T + Q_{sp}\,{}^{B}\vec{F}_g + {}^{W}\vec{F}_{w_{est}} = 0 $$

$$ \Rightarrow {}^{W}\vec{F}_T + {}^{W}\vec{F}_g + {}^{W}\vec{F}_{w_{est}} = 0 $$

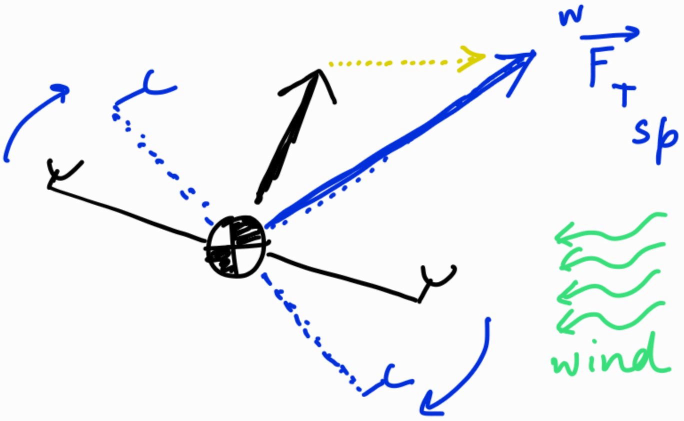
$$ {}^{w}\vec{F}_T + m\begin{bmatrix}0\\0\\-9.81\end{bmatrix} + {}^{w}\vec{F}_{w_{est}} = 0 $$

(?)

Need

$$ {}^{w}\vec{F}_{T_{sp}} = -\,{}^{w}\vec{F}_{w_{est}} - m\begin{bmatrix}0\\0\\-9.81\end{bmatrix} $$

"Target Thrust"
or "Thrust Setpoint"
in World Frame



Target
Current

<u>Option - 1</u>: We could execute Mover-Thrust update from PX4 (need to check)

<u>Option - 2</u>: We could execute "<u>Find orientation from Thrust Setpoint</u>" from PX4

/mc_pos_control

OPTION-2

$$^{W}\vec{Z}_{body} = -\frac{^{W}\vec{F}_{T_{sp}}}{\left\| ^{W}\vec{F}_{T_{sp}} \right\|}$$

↳ /PositionControl
↳ /ControlMath.cpp
(Line 70-120)

→ normalize $\left(^{W}\vec{Z}_{body} \right)$

→ $\vec{y}_{dummy} = \begin{bmatrix} -\sin(\psi_{sp}) \\ \cos\psi_{sp} \\ 0.0 \end{bmatrix}$

In PX4, this ψ_{sp} comes from user input

This means px4 assumes world frame to be N-E-Down

→ $^{W}\vec{x}_{body} = \vec{y}_{dummy} \times {}^{W}\vec{Z}_{body}$

→ normalize $\left(^{W}\vec{x}_{body} \right)$

→ sanity check for upside-down case

→ $^{W}\vec{y}_{body} = {}^{W}\vec{Z}_{body} \times {}^{W}\vec{x}_{body}$

→ normalize $\left(^{W}\vec{y}_{body} \right)$

→ $\boxed{R_{sp} = \begin{bmatrix} ^{W}\vec{x}_{body} & ^{W}\vec{y}_{body} & ^{W}\vec{Z}_{body} \end{bmatrix}}$

Q_{sp}

Non-Linear Controller

Linearization

↳ Find quaternion q_{sp} from Q_{sp}

↳ $$\begin{bmatrix} \vec{r}_{sp} \\ q_{sp} \\ 0 \\ 0 \\ \hdashline {}^{w}w_x \\ {}^{w}w_y \\ {}^{w}w_z \end{bmatrix}$$

recent estimates of wind velocities

can be used as a linearization point for counteracting against wind.

Augmented State-Disturbance vector $\begin{bmatrix} \Delta x \\ \hdashline \Delta d \end{bmatrix}$

An alternative way to find Orientat^n Q_{sp} from recent wind-estimate:

OPTION-3

$$\underbrace{{}^{W}\vec{F}_T}_{(?)} + \begin{bmatrix}0\\0\\-9.81\end{bmatrix} + \underbrace{{}^{W}\vec{F}_{W_{est}}}_{\checkmark} = 0$$

$$\underbrace{\left(Q\,{}^{B}\vec{F}_T\right)}_{\begin{array}{c} \text{①} \\ \text{②} \\ \text{③} \end{array}\begin{bmatrix} ? & & ? \\ ? & ? & ? \\ ? & & ? \end{bmatrix}_{3\times3}\begin{bmatrix}0\\0\\-{}^{B}F_T\end{bmatrix}} = -\left\{m\begin{bmatrix}0\\0\\-9.81\end{bmatrix} + {}^{W}\vec{F}_{W_{est}}\right\}$$

~~4 unknowns → $\psi, \theta, \phi, {}^{B}F_T$~~

~~3 equations → ①, ②, ③~~

↳ (I) ONE WAY OF LOOKING AT THIS:

* IF WE ROTATE ABOUT ROLL & PITCH AXES FIRST, WE HAVE THE SAME THRUST VECTOR $\vec{F}_T$, FOR ALL YAW ANGLES *

↳ II BY Z-Y-X CONVENTION,
$(\psi)\ (\theta)\ (\phi)$

$$\left({}^{W}\vec{x} = Q\,{}^{B}\vec{x} \right)$$

$$Q = \begin{bmatrix} C_\psi C_\theta & -S_\psi C_\theta & S_\theta \\ \begin{pmatrix} C_\psi S_\theta S_\phi \\ + S_\psi C_\phi + 0 \end{pmatrix} & \begin{pmatrix} -S_\psi S_\theta S_\phi \\ + C_\psi C_\phi \end{pmatrix} & -C_\theta S_\phi \\ \begin{pmatrix} -C_\psi S_\theta C_\phi \\ + S_\psi S_\phi \end{pmatrix} & \begin{pmatrix} S_\psi S_\theta C_\phi \\ + C_\psi S_\phi \end{pmatrix} & C_\theta C_\phi \end{bmatrix}$$

$$\therefore \left(Q\,{}^{B}\vec{F}_T \right) = -\left\{ m \begin{bmatrix} 0 \\ 0 \\ -9.81 \end{bmatrix} + {}^{W}\vec{F}_{W_{ext}} \right\}$$

$$\begin{bmatrix} (\ ) & (\ ) & \sin(\theta) \\ (\ ) & (\ ) & -\cos(\theta)\sin(\phi) \end{bmatrix} \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} (\ ) & (\ ) & -\cos(\theta)\sin(\phi) \\ (\ ) & (\ ) & \cos(\theta)\cos(\phi) \end{bmatrix} \begin{bmatrix} \\ -{}^{B}F_{T} \end{bmatrix}$$

$$= -\begin{bmatrix} 0 \\ 0 \\ -mg \end{bmatrix} - {}^{W}\vec{F}_{w_{est}}$$

$$\Rightarrow \boxed{\begin{bmatrix} \sin(\theta)\left(-{}^{B}F_{T}\right) \\ -\cos(\theta)\sin(\phi)\left(-{}^{B}F_{T}\right) \\ \cos(\theta)\cos(\phi)\left(-{}^{B}F_{T}\right) \end{bmatrix} = -{}^{W}\vec{F}_{g} - {}^{W}\vec{F}_{w_{est}}}$$

☆ [NOTE: YAW TERM (ψ) DOES NOT APPEAR IN EQ^{N}]

This is illustrated above...

Solving this will lead to θ_{sb} & ϕ_{sb} but not ψ_{sb}

(Pitch) (Roll) (Yaw)

$\therefore$ ψ_{sp} needs to be specified from somewhere (PX4 uses Yaw-Stick input)

$$\sin(\theta)\ \left(-{}^{B}F_T\right) = -{}^{W}F_{wind_x}$$

$$-\cos(\theta)\sin(\phi)\left(-{}^{B}F_T\right) = -{}^{W}F_{wind_y}$$

$$\cos(\theta)\cos(\phi)\left(-{}^{B}F_T\right) = -mg - {}^{W}F_{wind_z}$$

${}^{B}F_T$ is the Thrust Control Input.

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* Check the complexity of both options for deployment

	OPTION - 2	OPTION - 3
Assign a value	4	
x, +, ÷, -		3+1+1
cross Product	2	
vec-normalize	3	
$\tan^{-1}()$		1+1

(solve)

(fill Rotatn Matrix)

→ Assign ψ_{sp} (fill Rotatn matrix)

→ • cos θ
cos ϕ
cos ψ

• sin θ
sin ϕ
sin ψ

→ Fill all terms in Rot Matrix

→ Normalize Rot-Mat.

(seems too tedious!)