Autonomous parachute

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Rencontre AID
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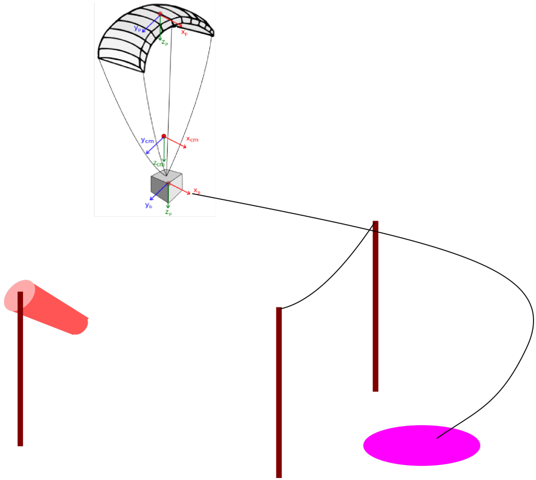
https://youtu.be/eqOGpQ0qoel

Reach a target

System: $\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{w}, \mathbf{u})$
Sensors: $\mathbf{y} = \mathbf{g}(\mathbf{x})$
Input: $\mathbf{u}$
Perturbation: $\mathbf{w}$
Controller: $\mathbf{u} = \mathbf{r}(\mathbf{y})$
Target: $\mathbb{T}$
Obstacles: $\mathbb{O}$
Initial set: $\mathbb{X}_0$


y_p
z_p
x_p
y_{cm}
x_{cm}
z_{cm}
y_b
z_p
x_p

Experiment with Eole [1]

youtu.be/L04n5RVhgAc

Model

δ_s →

δ_a →

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix} = \mathbf{v}_{gnd} = \mathbf{R}_B^I \, . \, \mathbf{v}_{cm} + \mathbf{v}_w$$

$$\begin{pmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} 1 & tan(\theta)sin(\phi) & tan(\theta)cos(\phi) \\ 0 & cos(\phi) & -sin(\phi) \\ 0 & \frac{sin(\phi)}{cos(\theta)} & \frac{cos(\phi)}{cos(\theta)} \end{pmatrix} . \boldsymbol{\omega}$$

$$\begin{aligned}
(mI_3 + M_F)\,\dot{\mathbf{v}}_{cm} = {} & \tfrac{1}{2}\rho S_p||\mathbf{v}_p||(C_{L_0} + C_{L\alpha}\alpha_p)\begin{pmatrix} \mathbf{v}_{p_z} \\ 0 \\ -\mathbf{v}_{p_x} \end{pmatrix} - \tfrac{1}{2}\rho S_p||\mathbf{v}_p||(C_{D_0} + C_{D\alpha 2}\alpha_p^2)\mathbf{v}_p \\
& + \begin{pmatrix} (C_{L_{\delta_a}}\mathbf{v}_{p_z} - C_{D_{\delta_a}}\mathbf{v}_{p_x})sign(\delta_a) & C_{L_{\delta_s}}\mathbf{v}_{p_z} - C_{D_{\delta_s}}\mathbf{v}_{p_x} \\ -C_{D_{\delta_a}}\mathbf{v}_{p_y}sign(\delta_a) & -C_{D_{\delta_s}}\mathbf{v}_{p_y} \\ (-C_{L_{\delta_a}}\mathbf{v}_{p_x} - C_{D_{\delta_a}}\mathbf{v}_{p_z})sign(\delta_a) & -C_{L_{\delta_s}}\mathbf{v}_{p_x} - C_{D_{\delta_s}}\mathbf{v}_{p_z} \end{pmatrix}\begin{pmatrix} \delta_a \\ \delta_s \end{pmatrix} \\
& - \tfrac{1}{2}\rho S_b||\mathbf{v}_b||(C_{D_0} + C_{D\alpha 2}\alpha_d^2)\mathbf{v}_b - \mathbf{Ad}(\boldsymbol{\omega}).M_F.\mathbf{v}_p + mg\begin{pmatrix} -sin(\theta) \\ sin(\phi)cos(\theta) \\ cos(\phi)cos(\theta) \end{pmatrix} \\
& - m\mathbf{Ad}(\boldsymbol{\omega}) \, . \, \mathbf{v}_{cm}
\end{aligned}$$

$$\begin{aligned}
(\mathbf{J} + I_F)\,\dot{\boldsymbol{\omega}} = {} & \tfrac{1}{2}\rho S_p||\mathbf{v}_p||^2\begin{pmatrix} C_{l_p}b^2\frac{p}{2||\mathbf{v}_p||} + C_{l_\phi}b\phi \\ C_{m_q}c^2\frac{q}{2||\mathbf{v}_p||} + C_{m_0}c + C_{m_\alpha}c\alpha_p \\ C_{n_r}b^2\frac{r}{2||\mathbf{v}_p||} \end{pmatrix} + \tfrac{1}{2}\rho S_p||\mathbf{v}_p||^2\begin{pmatrix} C_{l_{\delta_a}}\frac{b}{t} & 0 \\ 0 & 0 \\ C_{n_{\delta_a}}\frac{b}{t} & 0 \end{pmatrix}\begin{pmatrix} \delta_a \\ \delta_s \end{pmatrix} \\
& - \mathbf{Ad}(\omega).I_F.\,\omega - \mathbf{Ad}(\mathbf{v}_p).M_F.\mathbf{v}_p + \mathbf{Ad}(\mathbf{X}_{gp})\Big[\tfrac{1}{2}\rho S_p||\mathbf{v}_p||(C_{L_0} + C_{L\alpha}\alpha_p)\begin{pmatrix} \mathbf{v}_{p_z} \\ 0 \\ -\mathbf{v}_{p_x} \end{pmatrix} \\
& - \tfrac{1}{2}\rho S_p||\mathbf{v}_p||(C_{D_0} + C_{D\alpha 2}\alpha_p^2)\mathbf{v}_p + \begin{pmatrix} (C_{L_{\delta_a}}\mathbf{v}_{p_z} - C_{D_{\delta_a}}\mathbf{v}_{p_x})sign(\delta_a) & C_{L_{\delta_s}}\mathbf{v}_{p_z} - C_{D_{\delta_s}}\mathbf{v}_{p_x} \\ -C_{D_{\delta_a}}\mathbf{v}_{p_y}sign(\delta_a) & -C_{D_{\delta_s}}\mathbf{v}_{p_y} \\ (-C_{L_{\delta_a}}\mathbf{v}_{p_x} - C_{D_{\delta_a}}\mathbf{v}_{p_z})sign(\delta_a) & -C_{L_{\delta_s}}\mathbf{v}_{p_x} - C_{D_{\delta_s}}\mathbf{v}_{p_z} \end{pmatrix}\begin{pmatrix} \delta_a \\ \delta_s \end{pmatrix} \\
& - M_F.\dot{\mathbf{v}}_{cm} - \mathbf{Ad}(\boldsymbol{\omega}).M_F.\mathbf{v}_p\Big] + \mathbf{Ad}(\mathbf{X}_{gb})\Big[-\tfrac{1}{2}\rho S_b||\mathbf{v}_b||(C_{D_0} + C_{D\alpha 2}\alpha_d^2)\mathbf{v}_b\Big] \\
& - \mathbf{Ad}(\mathbf{v}_p).M_F.\mathbf{v}_p - \mathbf{Ad}(\boldsymbol{\omega}) \, . \, (\mathbf{J} + I_F) \, . \, \omega
\end{aligned}$$

Dubins car

$$\begin{cases} \dot{x}_1 & = & \cos x_3 + w_1 \\ \dot{x}_2 & = & \sin x_3 + w_2 \\ \dot{x}_3 & = & u \end{cases}$$

Controller

Error we want to cancel [2][3]:

$$e = x_3 + \text{atan} x_2.$$

Thus

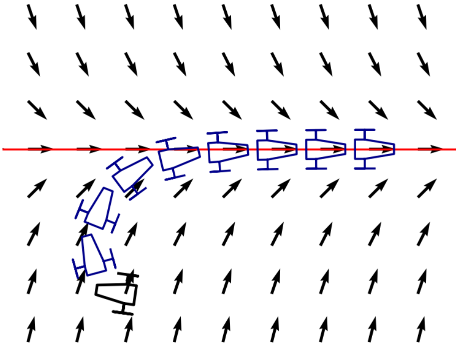
$$\dot{e} = \dot{x}_3 + \frac{\dot{x}_2}{1+x_2^2} = u + \frac{\sin x_3}{1+x_2^2}.$$

We want

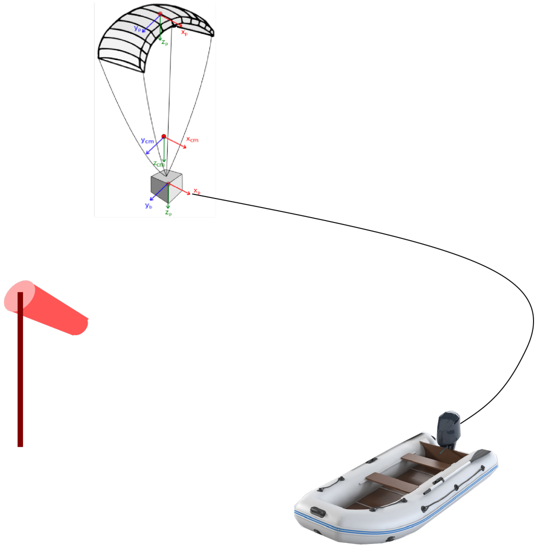
$$\dot{e} + e = 0.$$

We get:

$$u = -x_3 - \mathsf{atan} x_2 - \frac{\sin x_3}{1+x_2^2}$$



Next step


y_p
x_p
z_p
y_{cm}
x_{cm}
z_{cm}
x_p
y_b
z_p

How to guarantee that if the parachute starts in the region $\mathbb{X}_0$, it will reach the target $\mathbb{T}$ for all perturbation $\mathbf{w} \in \mathbb{W}$

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M. Le Gallic, J. Tillet, L. Jaulin, and F. Le Bars.
Tight Slalom Control for Sailboat Robots.
In Sophia Schillai and Nicholas Townsend, editors, *Robotic Sailing 2018*, pages 87–93, 2018.

L. Jaulin.
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ISTE editions, 2015.