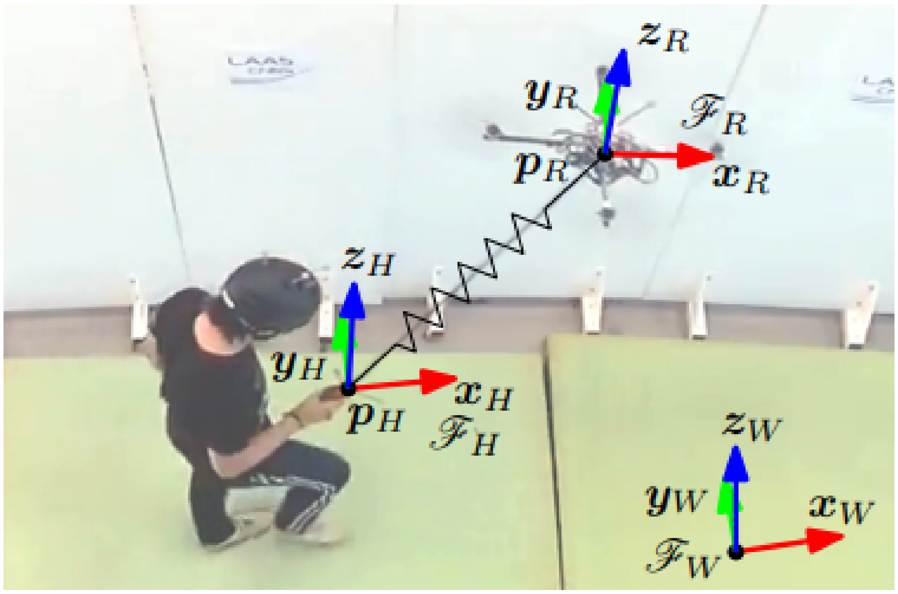
Force Based Control Of Tethered UAV

tags: `ResearchPaperNotes`



This paper deals with physical human robot interaction with a tethered UAV. Application to a force based human

We assume a inertial frame $\mathcal{F}_W = \{O_W, x_W, y_W, z_W\}$

where O_W is the arbitrary origin and $\{x_W, y_W, z_W\}$ are unit axes. Z_W is oriented in opposite direction to gravity vector.

$\mathcal{F}_H = \{O_H, x_H, y_H, z_H\}$ We also define a body frame rigidly attached to the handle. O_H is the origin of F_H and $\{x_H, y_H, z_H\}$ are unit axes.

The state of the human is then given by the position of O_H and its linear velocity defined by the vectors

$$p_H = [p_{H_x} \;\; p_{H_y} \;\; p_{H_z}]^T \in \mathbb{R}^3 \;\; and \;\; v_H = [v_{H_x} \;\; v_{H_y} \;\; v_{H_z}]^T$$

Respectively, both with respect to F_W(inertial frame of reference)

The human dynamics are approximated with the mass spring damper system. Impedance model has been used as a basis to develop human robot cooperative task.

We consider the human dynamics as

$m_h\dot{v}_h = -g_h - B_h v_h + f_c + f_g \; g_h = m g_h z_w$

m_h is equal to apparent mass B_h is equal to damping matrix f_c is equal to the cable force applied to the human at O_h

$f_c = [f_{c_x} \;\; f_{c_y} \;\; f_{c_z}]^T \in \mathbb{R}^3$

g_h is equal to insert eqn f_g is the ground reaction force such that it satisfies these conditions.

- $f_g^T x_W = f_g^T y_W = 0,$
- $f_g^T z_W > 0, and$
- $\dot{v}_H z_W = v_H^T z_W = 0 \;\; i.e., the \;\; human \;\; is \;\; constrained \;\; on \;\; the \;\; ground.$

Therefore the human is constrained on the ground.

Condition for small medium sized aerial vehicles is as follows. inequality $f_c^T z_W < m_H g$

In our case, the human is not aware of the desired path. It blindly follows the external force applied by the robot through the cable. > The controller is designed so as to track any C^2 trajectory independent from external disturbances.

The close loop translational dynamics of the robot subject to the position controller is given as equation number 2.

$\dot{v}_R = u_R$

where u_R is the virtual input.

According to equation number 2, the platform is ==infinitely stable== with respect to the interaction forces.

The cable force produced at O_H on the handle is equation number 3 $f_c = t_c(||l_c||)l_c/||l_c||$

where $t_c(||l_c||)$represents the tension and $l_c = p_R - p_H$.

Force produced on the drone (O_R) is $-f_c$. Cable is considered to be of negligible mass and inertia.

$t_c(||l_c||)$ is given by eqn 4. represented as figure 2.

$$t_c(||l_c||) = \begin{cases} k_c(||l_c|| - \overline{l_c}) & \text{if } ||l_c|| - \overline{l_c} > 0 \\ 0 & \text{otherwise} \end{cases}$$

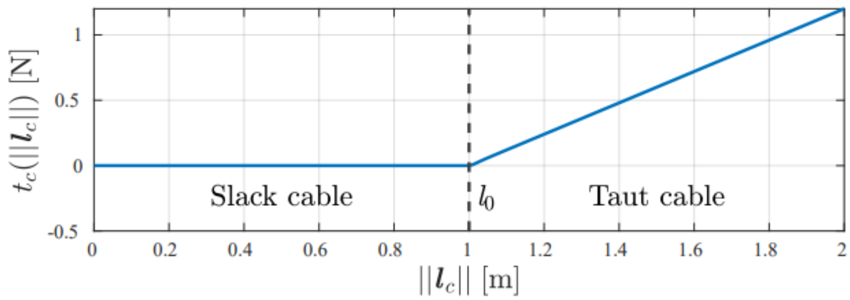


Fig. 2: Representation of $t_c(\|\boldsymbol{l}_c\|)$ as in (4).

where k_c is constant elastic coefficient.

> where tc can be any continous and differentiable monotonically increasing function. eqn 5

$t_c(||l_c||) \geq \epsilon||l_c|| + \gamma, \;\; if \;\; ||l_c|| - \overline{l_c} > 0$

Controller

Admittance Control Strategy Admittance is mass, stiffness and damping subjected to the measured external force acting on the robot. Robot control input uR is given by eqn 6 where mA is virtual inertia. M_A is $0.8I_3$ and B_A is $2.4I_3$ where I_3 is a $3*3$ identity matrix.

$u_R = M_A^{-1}(-B_A v_R - f_c + u_A)$

Virtual Inertia: As our model is based on spring mass damper system, in 3D we need to assume, 3 different masses in 3 different directions, mutually perpendicular to each other. As these masses do not exist in real time, they are considered as virtual masses connected to 3 different springs in respective directions.

In order to implement control law 6, state of the robot (p_R, v_R) and force applied by the cable f_c are required. These two can be computed with onboard sensors. We define the state vector as (state vector x) $x = [p_H^T \;\; v_H^T \;\; p_R^T \;\; v_R^T]^T$

To write the dynamics as x dot equal to f (x,uA) where eqn 7

$$\boldsymbol{f}(\boldsymbol{x}, \boldsymbol{u}_A) = \begin{bmatrix} \boldsymbol{v}_H \\ \frac{1}{m_H}\left(-\boldsymbol{g}_H - \boldsymbol{B}_H \boldsymbol{v}_H + \boldsymbol{f}_c + \boldsymbol{f}_g\right) \\ \boldsymbol{v}_R \\ \boldsymbol{M}_A^{-1}\left(-\boldsymbol{B}_A \boldsymbol{v}_R - \boldsymbol{f}_c + \boldsymbol{u}_A\right) \end{bmatrix}$$

fc is computed in eqn 3

To implement the control law, we only need a proportional feedback w.r.t robots position. eqn 8 $u_A = K_H e_R + f_c^r$

kH is proportional gain.

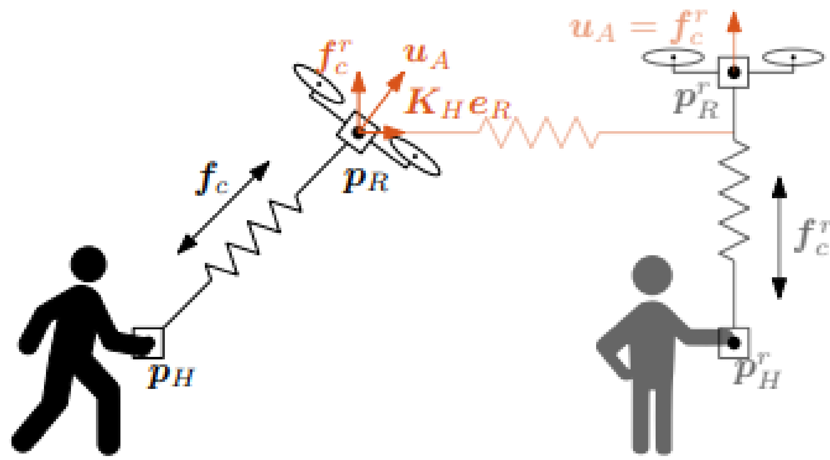
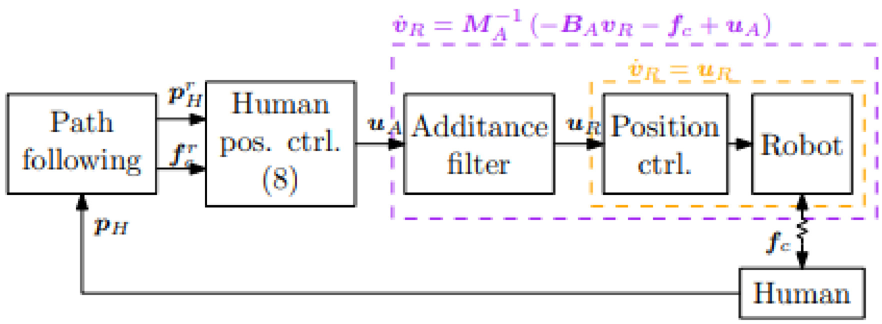


Fig 3

fcr is constant forcing input. (desired cable force)

Block diagram of the overall control method is shown here fig 4



Considering system 7, under the control law 8 we finally get the dynamics as eqn number 11 and the control law as eqn 16.

$$\boldsymbol{f}(\boldsymbol{x}) = \begin{bmatrix} \boldsymbol{v}_H \\ \frac{1}{m_H}(-\boldsymbol{g}_H - \boldsymbol{B}_H \boldsymbol{v}_H + \boldsymbol{f}_c + \boldsymbol{f}_g) \\ \boldsymbol{v}_R \\ \boldsymbol{M}_A^{-1}(-\boldsymbol{B}_A \boldsymbol{v}_R - \boldsymbol{f}_c + \boldsymbol{K}_H \boldsymbol{e}_R + \boldsymbol{f}_c^r) \end{bmatrix}. \quad (11)$$

$$\begin{bmatrix} p^r_{Rx} \\ p^r_{Ry} \\ p_{Rz} \end{bmatrix} + \begin{bmatrix} p_{Hx} \\ p_{Hy} \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \frac{f_z}{k_c} + \bar{l}_c \end{bmatrix}. \tag{16}$$

Our system is output strictly passive.

- $\bar{l}_c = 1[m]$, $negligible \ \ mass(lessthan 10[g])$
- $p_{d_H}(0) = [-2 \ \ -0.5 \ \ 0]^T$
- $p_{d_H}(1) = [2 \ \ 0 \ \ 0]^T$