Cooperative Cable Transportation with Vision

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Abstract

The goal of this project is to take the the next step in allowing UAV's to transport heavy loads in the real world

1 Previous work

[1] Work done at penn on multiple robots with cables, experiments done in vicon, required high order derivative estimates
[2] Visual control of a payload with 2 quadrotors. No communication. LQR solution to put follower above tag. Uses tag on tail of leader to give the yaw of the payload, otherwise assume flat
[3] Mathematical explanation of how non-zero desired internal tension can be used in a communication free system to allow control of the attitude of a payload
[4] Controller used here with modifications to only use attainable derivatives. Only simulation
[5] Transportation of large objects with many hexrotors. Attachment via spherical joint (similar to a short cable). Communication free, each robot estimates the force on the payload and does an admittance controller. Heavy state machine use to reject disturbances. Quasi-static. Assumes flat. Yaw of the payload is based on following the leader
[6] Single robot with closed loop control using vision
[7] Whycode is a circular tag detector that includes a barcode in the middle for unique identification and yaw estimation
[8] How to merge visual estimates for multi robot control of a payload

2 Equations

2.1 Payload Errors

Subscript 0 refers to the payload

$$e_{x_0} = x_0 - x_{0_d}$$

$$e_{\dot{x}_0} = \dot{x}_0 - \dot{x}_{0_d}$$

$$e_{\int x_0} = \sum e_{x_0} dt$$

$$e_{R_0} = \frac{1}{2}(R_{0_d}^\top R_0 - R_0^\top R_{0_d})$$

$$e_{\Omega_0} = \Omega_0 - R_0^\top R_{0_d} \Omega_{0_d}$$

2.2 Payload Control Wrench

Linear component:

$$F_0 = m_0(-k_{p_x} e_{x_0} - k_{d_x} e_{\dot{x}_0} - k_{i_x} e_{\int x} + a_{0_d} + g e_3)$$

Untested Angular component:

$$M_0 = -k_{R_0} e_{R_0} - k_{\Omega_0} e_{x_0} + (R_0^\top R_{0_d} \Omega_{0_d})^\wedge J_0 R_0^\top R_{0_d} \Omega_{0_d} + J_0 R_0^\top R_{0_d} \dot{\Omega}_{0_d}$$

2.3 Payload Control Distribution

Define constant matrix P

$$P = \begin{bmatrix} I_{3x3} & \dots I_{3x3} \\ \hat{\rho_0} & \dots \hat{\rho_n} \end{bmatrix}$$

For 3 robots, $rank(p) = 6$ which allows for full linear and angular control of the payload
Next we calculate the "virtual desired control" μ for each cable

$$\begin{bmatrix} \mu_{0_d} \\ \dots \\ \mu_{n_d} \end{bmatrix} = diag[R_0, \dots, R_0] P^\top (P P^\top)^{-1} \begin{bmatrix} R_0^\top F_d \\ M_d \end{bmatrix}$$

2.4 Cable force input

The attachment point acceleraton is:

$$a_i = \ddot{x}_{0_d} + ge_3 + R_0\hat{\Omega}_0^2\rho_i - R_0\hat{\rho}_i\dot{\Omega}_0$$

The virtual control input is then mapped onto the cable direction: q_i

$$\mu_i = q_i q_i^\top \mu_{i_d}$$

And used to calculate the parallel component of control:

$$u_i^{\parallel} = \mu_i + m_i l_i \|\omega_i\|^2 q_i + m_i q_i q_i^\top a_i$$

Which we simplified to (for now)

$$u_i^{\parallel} = \mu_i + (m_i q_i q_i^\top a_i)$$

2.5 Cable Control

Now we need the quadrotor to move the cable to the desired direction

$$u_i^{\perp} = m_i l_i \hat{q}_i(-k_{p_q} e_q - k_{d_q} e_w - (q_i \cdot \omega_{i_d})\dot{q}_i - \hat{q}_i^2 \dot{\omega}_d) - m_i \hat{q}_i^2 a_i$$

Simplified to:

$$u_i^{\perp} = m_i l_i \hat{q}_i(-k_{p_q} e_q - k_{d_q} e_w) - m_i \hat{q}_i^2 a_i$$

2.6 Quadrotor attitude

Finally the components of u are combined and sent as the desired thrust to a standard attitude controller

$$u_i = u_i^{\parallel} + u_i^{\perp}$$

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