

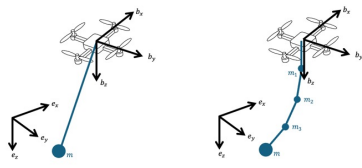
Track 18 : ASME International Undergraduate Research and Design Expo

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Poster U56

Project Objectives and Goals

- Create a control system that accurately model the behavior of a RTMUAV
- Modeling slack to taut and taut to slack behavior of the tethered UAV dynamics



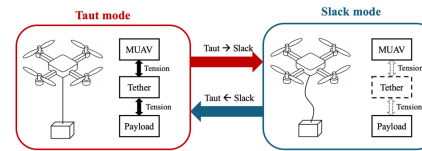
[1] Diagram representing modeling of quadrotor

Numerical Equations and Procedures

- Dynamics governing equations:

<p>Taut State</p> $\dot{x}_Q = v_Q \quad (1)$ $\dot{v}_Q = \frac{fR_{e3}}{m_Q} + \frac{T_Q q}{m_Q} - g e_3 \quad (2)$ $\dot{x}_L = v_L \quad (3)$ $\dot{v}_L = -\frac{T_L q}{m_L} - g e_3 \quad (4)$ $\dot{q} = \omega \times q \quad (5)$ $\dot{\omega} = -\frac{q \times f R_{e3}}{m_Q I} \quad (6)$ $\dot{R} = R \hat{\Omega} \quad (7)$ $\dot{\Omega} = J_Q^{-1} (M - \Omega \times J_Q \Omega) \quad (8)$	<p>Slack State</p> $\dot{x}_Q = v_Q \quad (9)$ $\dot{v}_Q = \frac{fR_{e3}}{m_Q} - g e_3 \quad (10)$ $\dot{x}_L = v_L \quad (11)$ $\dot{v}_L = -g e_3 \quad (12)$ $\dot{q} = \omega \times q \quad (13)$ $\dot{\omega} = 0 \quad (14)$ $\dot{R} = R \hat{\Omega} \quad (15)$ $\dot{\Omega} = J_Q^{-1} (M - \Omega \times J_Q \Omega) \quad (16)$
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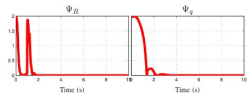
- State switch modeling:
 - Compares distance between UAV and payload to tether length to determine state
- Differentiation techniques:
 - Used Simulink to remove algebraic loops
 - Integrated ode45 solver for the system



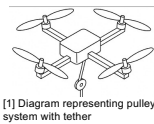
[1] Diagram depicting differences between taut and slack.

Background

- Multirotor unmanned aerial vehicles (MUAVs)
 - Highly adaptable
 - Compact and agile
- Tethered MUAVs
 - Tether can reach difficult to access areas
 - Many Applications:
 - Payload transportation
 - Environmental monitoring
 - Search and rescue
 - Sensor deployment
 - Many benefits over:
 - Gripper arm
 - Ground-linked systems
- Geometric Controller
 - Removes the singularities caused when using local coordinates
 - Allows for global convergence in the differentially-flat hybrid system of the UAV and payload
- Reference Papers
 - Presented results on both an unretractable and retractable tether
 - Replaced many analytical derivatives with nominal values in controller
 - Used only minimal jerk trajectories
 - Never tested slack and taut transitions, only included theoretical equations



[2] Shows multiple peaks in configuration error due to nominal values used in calculating derivatives in calculations



[1] Diagram representing pulley system with tether

Data and Results

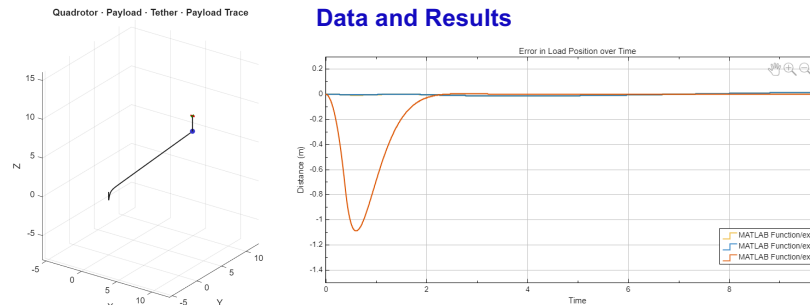
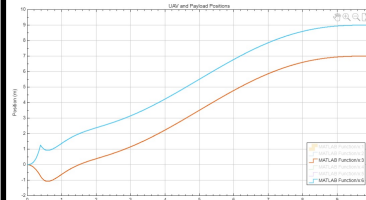


Image showing the trajectory taken by the payload to get to the desired location



Graph recording the z position of the UAV and the payload

- Initial setup:
 - Started with hovering UAV with payload right beneath
 - Time: 10 seconds
 - Target position of payload: (7,7,7)
 - Quadrotor attitude set to a constant
 - Constant tether length of 2 meters
- Minimal jerk trajectory was used in generating desired positions
- Large initial error due to slack condition of the tether
 - Can visibly observe the peak in quadrotor position symbolizing the switch to taut

Conclusions

- Relatively fast running simulation
- Need to test more complex trajectories to more thoroughly verify the timing of the simulation
- If need be, complexity of certain controller calculations can be reduced to lower time take to run
- Accurately simulated a slack to taut state switch in the simulation
 - By starting the simulation from slack the initial drop of the payload allowed for a test of this condition
- Errors reached one peak and reduced from there on with no further large oscillations in error
 - Analytical derivation of certain derivatives helped to reduce error

Future Studies / Recommendations

- Integrating retractable tether into controller
 - Introduces pulley torque, length change, and small pulley dynamics into the model
 - Vastly greater accessibility
 - Allows for both a use of changes in UAV position as well as tether length for aggressive maneuvers
- Non-minimal jerk trajectories
 - Required in high stress environments
 - Allow for more adaptable routing
- Create 2 axis testbed for the UAV and tethered payload to verify simulation results
- Study the effect of the aerodynamics of payload into controller calculations

Acknowledgments

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References

- [1] Handrick, D., Eckenrode, M., & Lee, J. (2025). Review of Tethered Unmanned Aerial Vehicles: Building Versatile and Robust Tethered Multirotor UAV System. *Dynamics*, 5(2), 17. <https://doi.org/10.3390/dynamics5020017>
- [2] Sreenath, K., Taeyoung Lee, & Kumar, V. (2013). Geometric control and differential flatness of a quadrotor UAV with a cable-suspended load. 52nd IEEE Conference on Decision and Control. <https://doi.org/10.1109/cdc.2013.6760219>