Quadcopter Load Suspension

Clement Cantil, Zane Meyer, Roger Wienaah

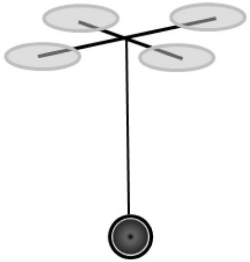
Motivation

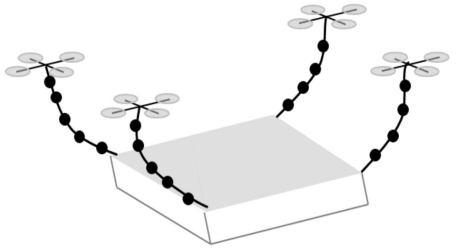
- UAV payload transportation receiving a lot of attention from military and industry.
- Difficulty in stabilizing UAVs with suspended payloads due to the underactuated nature of the system.
- Need for robust control systems
- Our motivation is use this project to explore pybullet

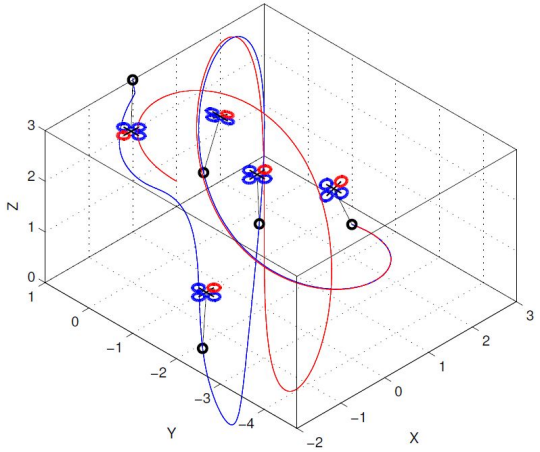


Relevant Prior Work: Problem Modeling

- Single UAV [5] vs Multiple UAV systems [7]
- Taut Cable Model [5] vs Flexible Cable Model [6]
- Quadcopter trajectory tracking [1] vs Load trajectory tracking [5]







Relevant Prior Work: Controllers

- Cascaded PID Controller [1]
- Feedforward-Feedback adaptive control (Notch Filter + LQG) [2]
- Reinforcement Learning [3]
- Model Predictive Control [4]

Lesson Learned: Don’t Trust Conference Papers (entirely)

- Not all papers in good journals / conferences are accurate:
  - Paper: Quad-rotor Lifting-Transporting Cable-Suspended Payloads Control, Alothman et al, 2015
  - Publisher: IEEE, 21st International Conference on Automation and Computing (ICAC)

- Paper proposed a linear model that was uncontrollable
  - We didn’t think to check it until we couldn’t reproduce their results.
- Wasted time and energy trying to implement their proposed model

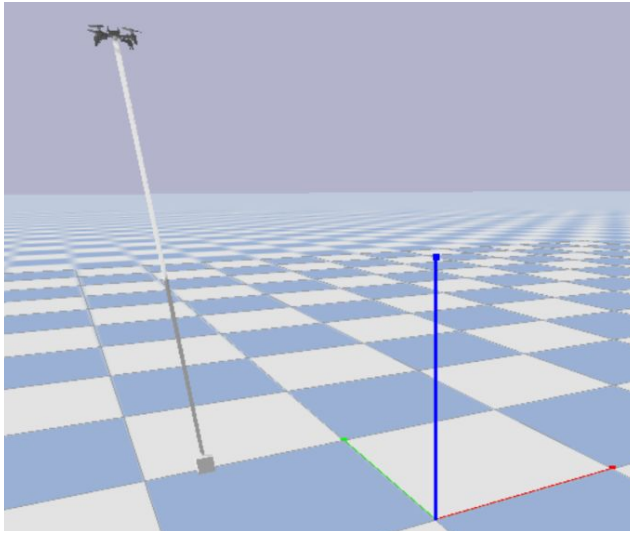
Our Model

Single UAV

Quadcopter Load Balancing

Taut cable model

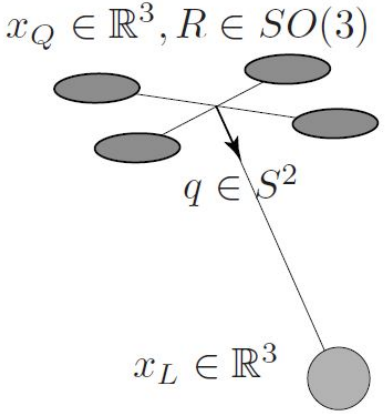
URDF



Dynamical Model of UAV with suspended load

System has 8 DOF with 4 degree underactuation.

Quadrotor and load positions: $x_Q = x_L - lq, \ (1)$



Equations of motion (Lagrange method):

$$\mathcal{L} = \mathcal{T} - \mathcal{U}, \text{ where } \mathcal{T} : TQ \to \mathbb{R} \text{ and } \mathcal{U} : Q \to \mathbb{R}$$

$$\mathcal{T} = \frac{1}{2} m_Q v_Q \cdot v_Q + \frac{1}{2} m_L v_L \cdot v_L + \frac{1}{2} \langle \hat{\Omega}, \widehat{J_Q \Omega} \rangle, \quad (2)$$

$$\mathcal{U} = m_Q g e_3 \cdot x_Q + m_L g e_3 \cdot x_L, \quad (3)$$

Satisfies, Lagrange d'Alembert principle;

$$\delta \int_0^\tau \mathcal{L} \, dt + \int_0^\tau \left(\langle W_1, \hat{M} \rangle + W_2 \cdot f R e_3 \right) \, dt = 0, \quad (4)$$

Dynamical Model of UAV with suspended load

$$\dot{x}_L = v_L, \tag{5}$$

$$(m_Q + m_L)(\dot{v}_L + ge_3) = (q \cdot fRe_3 - m_Q l(\dot{q} \cdot \dot{q}))q, \tag{6}$$

$$\dot{q} = \omega \times q, \tag{7}$$

$$m_Q l\ \dot{\omega} = -q \times fRe_3, \tag{8}$$

$$\dot{R} = R\hat{\Omega}, \tag{9}$$

$$J_Q\dot{\Omega} + \Omega \times J_Q\Omega = M. \tag{10}$$

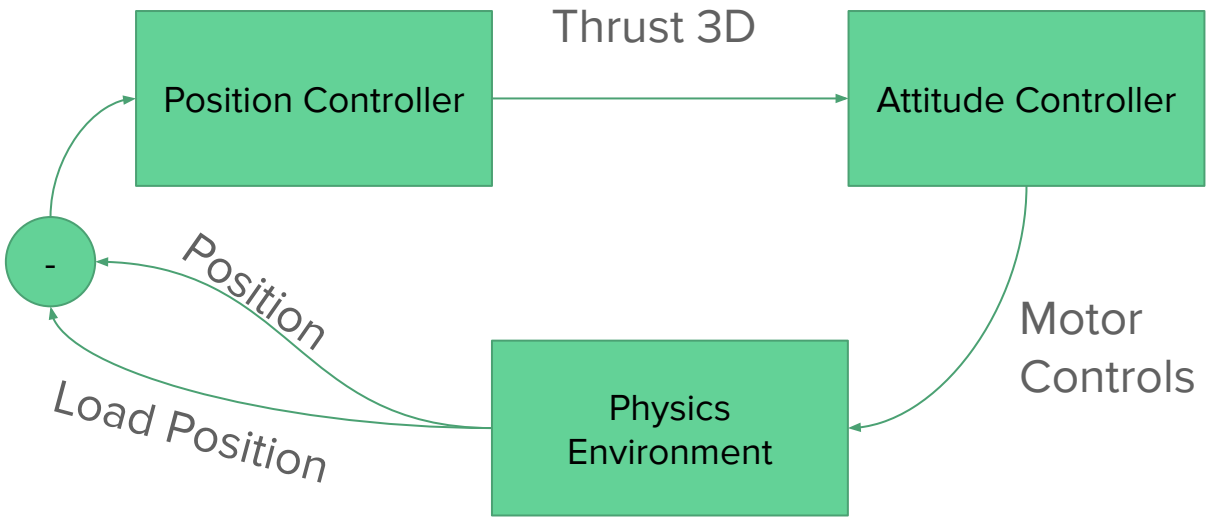
Above dynamics can be written in the standard form: $\dot{X}_n = f_n(X_n) + g_n(X_n)u$

Where, $X_n = \{x_L, q, R, v_L, \omega, \Omega\}$ is the state and u = $\{f, M\}$ the input to the system

Updated Question:

With a swinging load, can we just stabilize the load so that we don’t crash?

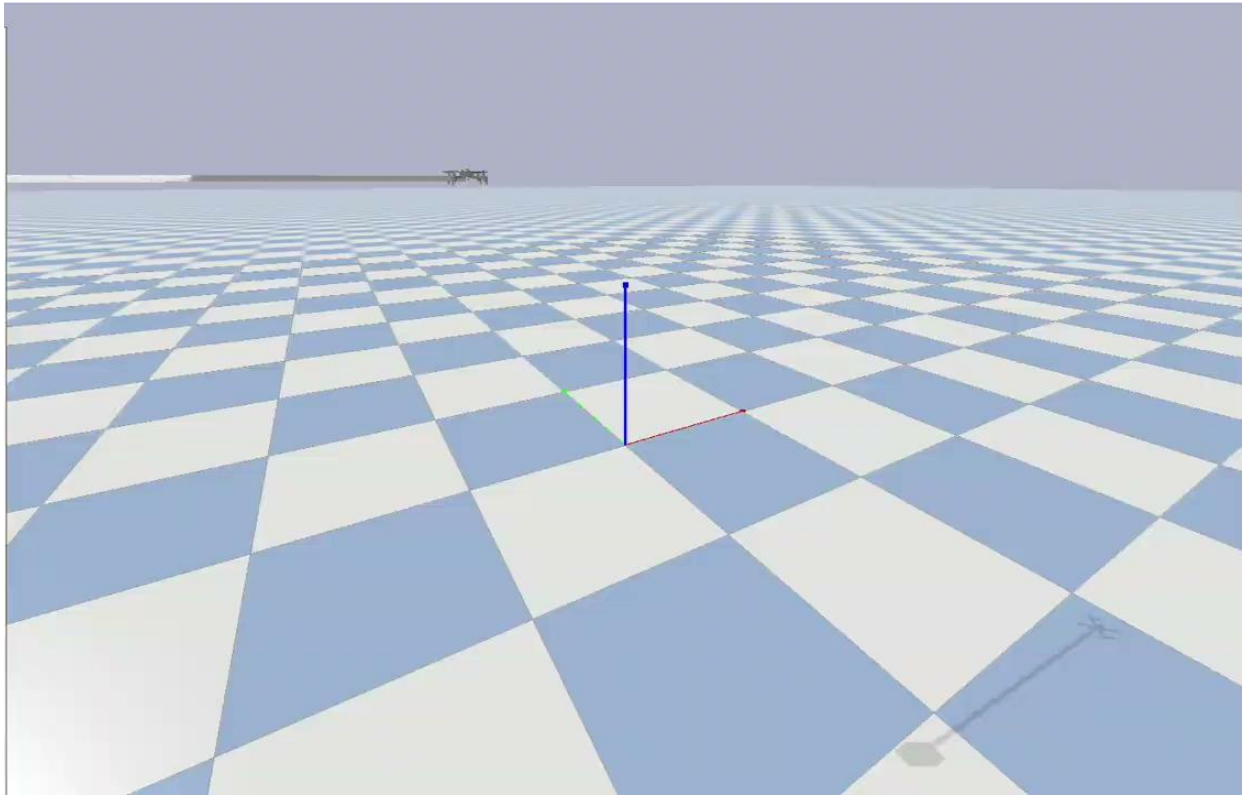
PID Controller(s) Design



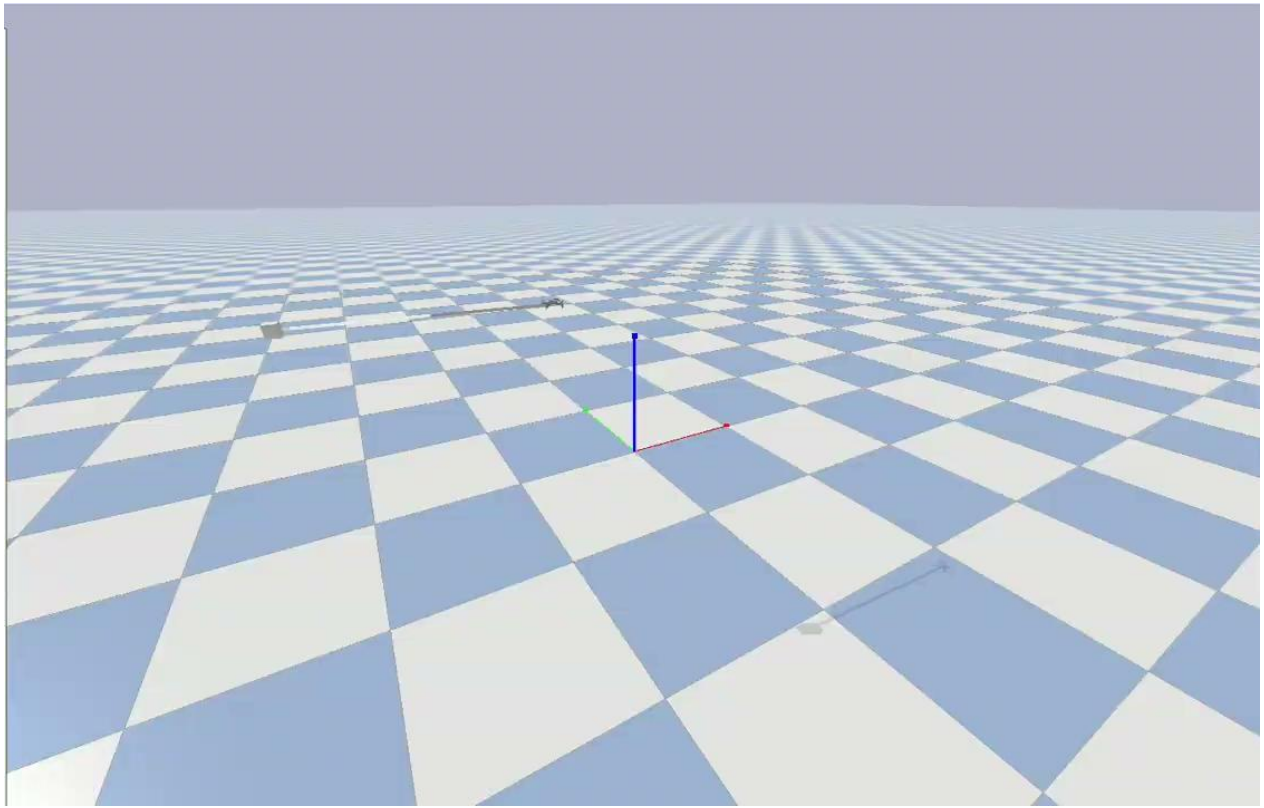
Pos	P	I	D
X	0.4	0.05	0.2
Y	0.4	0.05	0.2
Z	1.25	0.05	0.5

Att	P	I	D
X	70	50	50
Y	70	50	50
Z	6e4	500	12e3

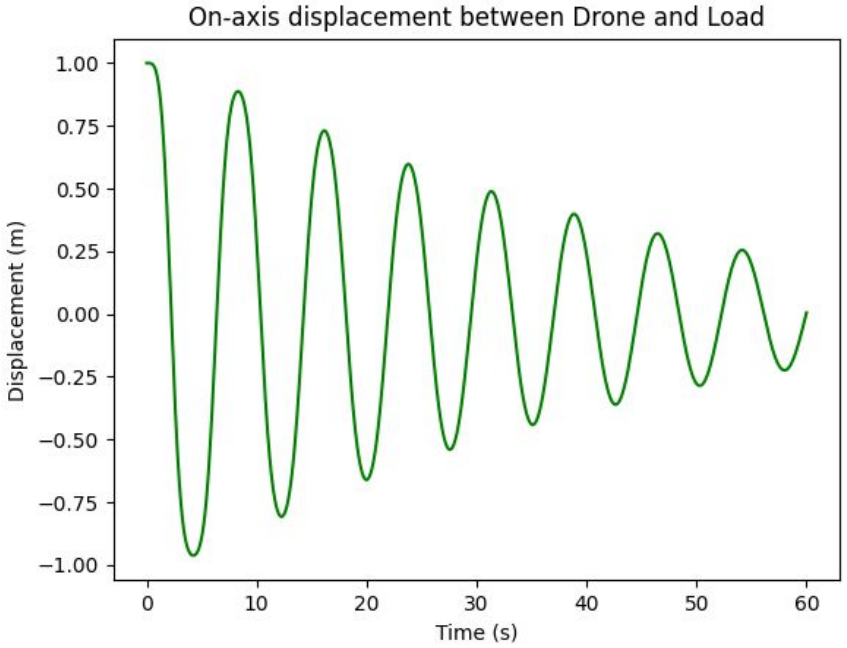
Simulation: Without PID controllers



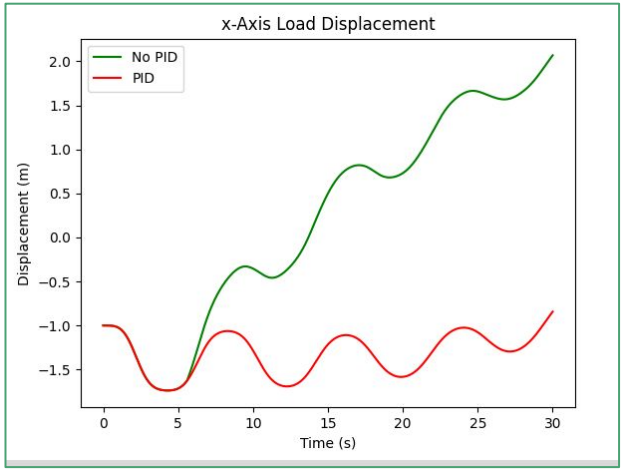
Simulation: With both PID controllers

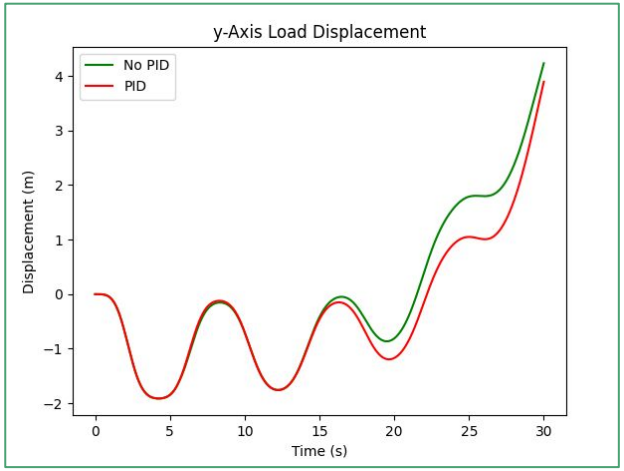


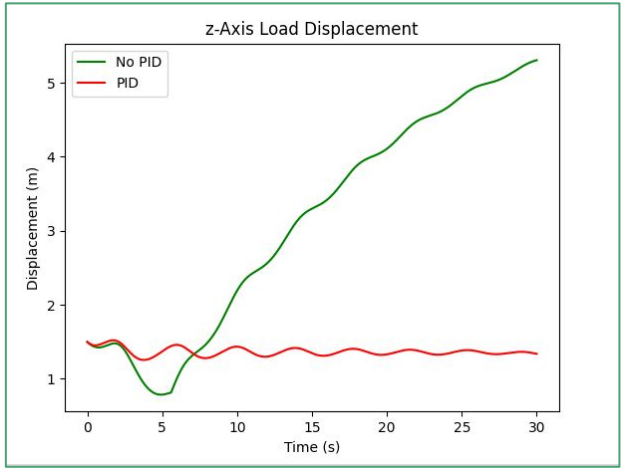
Results


On-axis displacement between Drone and Load
Displacement (m)
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0
10
20
30
40
50
60
Time (s)

Results


x-Axis Load Displacement
No PID
PID
Displacement (m)
Time (s)


y-Axis Load Displacement
No PID
PID
Displacement (m)
Time (s)


z-Axis Load Displacement
No PID
PID
Displacement (m)
Time (s)

Conclusion

- Designed a PID controller to stabilize a suspended load
- Learned a new simulator (i.e., Pybullet)
- Stay away from bad papers

THANK YOU

Questions ?

References

1. X. Huo, J. Chen, Q. Liu and X. He, "Vibration Elimination for Quadrotor Slung System Based on Input Shaping and Double Closed-loop Control," 2019 12th Asian Control Conference (ASCC), Kitakyushu, Japan, 2019, pp. 492-497.
2. J. F. Slabber and H. W. Jordaan, "Vision-Based Control of an Unknown Suspended Payload with a Multirotor," 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Prague, Czech Republic, 2021, pp. 4875-4880, doi: 10.1109/IROS51168.2021.9636648.
3. Faust, A.; Palunko, I.; Cruz, P.; Fierro, R.; Tapia, L. Automated aerial suspended cargo delivery through reinforcement learning. Artif. Intell. 2017, 247, 381–398
4. Urbina-Brito, N.; Guerrero-Sánchez, M.E.; Valencia-Palomo, G.; Hernández-González, O.; López-Estrada, F.R.; Hoyo-Montaño, J.A. A predictive control strategy for aerial payload transportation with an unmanned aerial vehicle. Mathematics 2021, 9, 1822.
5. Sreenath, Koushil, Nathan Michael, and Vijay Kumar. "Trajectory generation and control of a quadrotor with a cable-suspended load-a differentially-flat hybrid system." 2013 IEEE international conference on robotics and automation. IEEE, 2013.
6. Bisgaard, Morten, Jan Dimon Bendtsen, and Anders la Cour-Harbo. "Modeling of generic slung load system." Journal of guidance, control, and dynamics 32.2 (2009): 573-585.
7. Michael, Nathan, Jonathan Fink, and Vijay Kumar. "Cooperative manipulation and transportation with aerial robots." Autonomous Robots 30 (2011): 73-86.