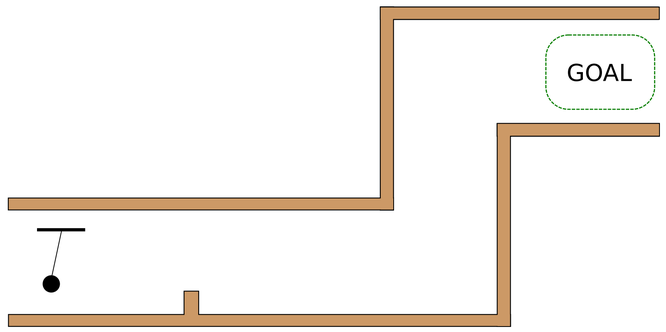
Trajectory Planning for a Quadrotor UAV with Suspended Payload

JB Ubbink, JAA Engelbrecht

Stellenbosch University

Introduction

The ability to transport payloads transform Unmanned Aerial Vehicles (UAVs), from primarily monitoring and surveillance machines, to versatile machines able to assist in rescue missions, deliveries and construction. This research project focuses on navigating and controlling a quadrotor UAV, with a suspended payload, autonomously through a confined environment.



The quadrotor with a suspended payload is shown at an initial position and is tasked to autonomously navigate to the goal region while avoiding the boundaries. The flight control system and trajectory planning algorithm work in conjunction to solve the task:

- The trajectory planning algorithm determines the desired action sequence applied to the flight control system.
- The flight control system ensures that the quadrotor UAV follows the desired trajectory.

Aim

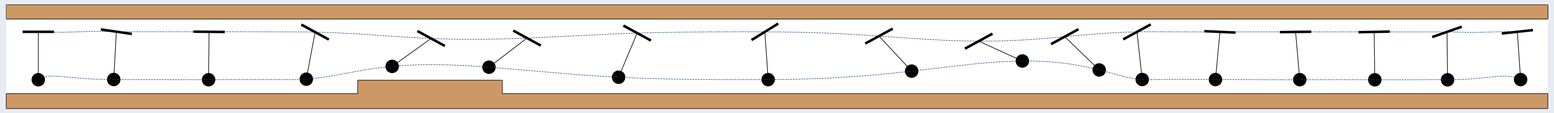
Autonomously navigate a quadrotor UAV, with a suspended payload, through a confined environment, by making use of feedback control systems and trajectory planning algorithms.

Objectives

- Derive a mathematical model of the system.
- Implement and design a flight control system.
- Minimise payload swing.
- Plan a trajectory through a confined environment.
- Verify performance through simulation.

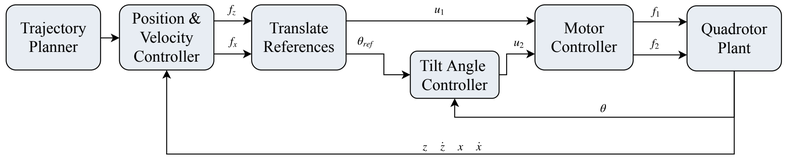
Obstacle Avoidance

An obstacle avoidance action sequence is defined to enable the quadrotor with suspended payload to fit through a confined space. The distance between the obstacle and the ceiling is less than the height of the quadrotor with suspended payload.



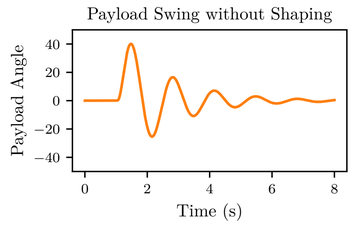
Flight Control System

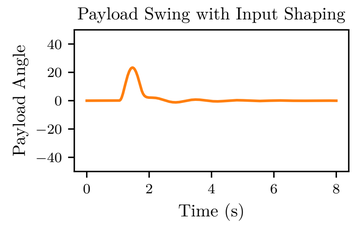
A flight control system is needed for stable and controlled flight. An inner-loop control system is designed to control the tilt angle of the quadrotor. Two outer-loop controllers are implemented to control the position and the velocity of the quadrotor. The outer-loop controllers supply reference commands to the inner-loop system.



Minimise Payload Swing

Input shaping, an open-loop method to reduce the oscillations of a response, is implemented to reduce the swing of the payload while controlling the quadrotor.

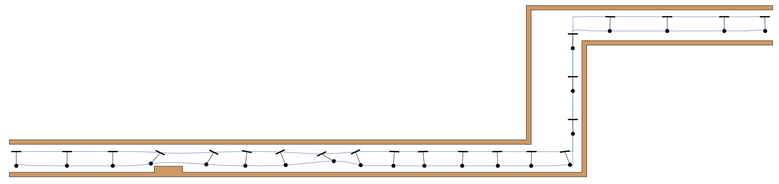




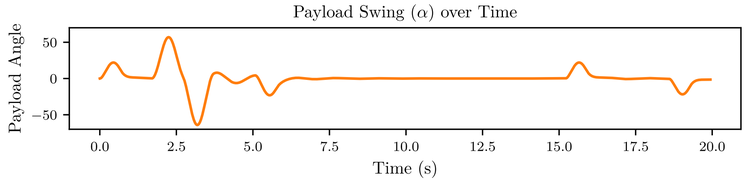
The figure on the left shows the payload response if a velocity step command is applied to the velocity controller. When the reference command is shaped by the input shaper, and the response can be observed in the figure on the right. The payload swing is significantly reduced when the reference signal is modified.

Trajectory Planning

The A* Algorithm, an algorithm that is widely used in path finding and graph traversal, is implemented to plan trajectories for the quadrotor with suspended payload. The search algorithm applies a combination of velocity and force commands, to a simulated model of the plant, to calculate the state of the next node. The action space and cost functions are chosen to force the planning algorithm to implement input shaping manoeuvres to reduce the payload swing.



The trajectory planning algorithm was tasked to plan a path through a verification environment. The successful path through the environment is illustrated above. The controlled payload swing is shown below.



Conclusion

This project has successfully reached the original project aim of autonomously navigating the quadrotor payload system, through a confined space consisting of horizontal and vertical tunnels, by making use of feedback control systems and trajectory planning algorithms.