Bi-Directional Tilting Quadrotor

An investigation into the overactuatedness thereof

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Abstract

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The aim of this thesis is to design, simulate and control a novel quadrotor platform which can articulate all 6 Degrees of Freedom by vectoring thrust produced by the lift propellers. To achieve this the airframes' structure needs to be able to be changed dynamically during flight, namely adding 2 additional axes of actuation about which each lift propeller can be rotated. The introduction of such actuation to what is otherwise a well understood platform results in an over-actuated control problem. The allocation of actuator priority is the primary contribution of this paper with novel elements of non-linear control treatment for UAV airspace platforms.

A high fidelity simulation environment was constructed which incorporated all known non-linearities associated with airspace bodies. The effects unique to the proposed design were investigated and incorporated too. After which control algorithms where developed and compared, the affects which discretization would have on the system were included in this comparison. The relative performance of the controllers was evaluated on standard performance metrics of attitude and position controllers. Finally the design built and tested using readily available Radio-Control components.

The purpose of the investigation is the practicality of such a platform and weather the added complexity of the mechanical system is a decent compromise for the improved degrees of control actuation. As a result the outcome of the build is weather its' both feasible and practical to build such a prototype. The design and control treatment proposed here are by no means the most optimal solution as focus is placed on the system as a whole and not just one aspect of it.

Acknowledgements

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 A Brief Background to the Study

Currently the most popular topic for control and automation research is the quadrotor UAV, specifically the control thereof. Much work has been done on quadrotors and their attitude control, specifically control around a stable trim point, at the inertial frames origin, to which the control algorithm always tends to. The highly coupled non-linear dynamics for a bodies linear and angular motions arise as a result of gyroscopic torques and Coriolis accelerations. Such affects are elegantly linearized around the origin when they can be approximated to 0, decoupling the system and allowing for traditional SISO control techniques to be applied.

As every quadrotor based research paper will tell you, the current interest in them is as a result of the recent spur in availability of MEMS systems and low-cost ARM based microprocessors to perform complicated control calculations and state estimation. This led to development and expansion in the field and introduction of a large huge of hobbyist solutions, from professionally made units to DIY kits with room for modification. A rapidly growing enthusiast community was borne out of this progression which was no longer open only to those willing spend lots of money on their pass times.

The avenues for potential applications of both fixed wing and VTOL UAVs is expansive and the quadrotor configuration provides a mechanically simple and low cost platform on which to test advanced aerospace control algorithms. Considering that commercial drone usage is such an emerging sector; especially in Southern Africa following the revision of aviation laws which have legalized the use of UAVs for commercial application, any research into a non-trivial aspect of the field is extremely valuable.

Large scale quadrotor, hexrotor and even octorotor UAVs are a popular intermediate choice for aerial cinematography. Whilst still expensive, the cost of a commercial drone like the SteadiDrone Maverik [1] is far less than the cost of chartering a helicopter to achieve the same panoramic aerial scenes. Another interesting application for UAVs is in the agricultural sector, introducing crop dusting drones instead of the traditional bi-planes which perform the same job. One difficulty which hinders the progress of the commercial drone sector is that of inertia, specifically when scaling up any vehicle, its performance is adversely affected, due to the increased mass inertial effect.

1.2 Research Questions & Hypotheses

The difficulty with a quadrotors' control is that fundamentally it's under-actuated, having only 4 controllable inputs (each propellers rotational speed and hence lift force) available to manipulate all

6 degrees of freedom (linear X-Y-Z position and angular Pitch, ϕ, Roll, θ and Yaw, ψ rotations). The resulting solution is to control the perpendicular heave thrust, $\vec{T}$, and angular torques about each axis, $[\tau_\phi \ \tau_\theta \ \tau_\psi]^T$. So the attitude control problem of a quadrotor is a zero set point problem as any other attempt to track attitude is inherently unstable.

1.3 Significance of Study

1.4 Other Applications of Proposed Investigation

1.5 Scope and Limitations

1.5.1 Subsection

Bibliography

[1] steadidrone.com.