Dual-Axis Tilting Quadrotor Aircraft

An investigation into the overactuatedness thereof

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      - Results & Simulation Data: `https://github.com/nickvonklemp/results`

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Abstract

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The aim of this project is to design, simulate and control a novel quadrotor platform which can articulate all 6 Degrees of Freedom by vectoring the propellers' directional thrust. To achieve this the structure of the air-frame must redirect those thrust vectors to any desired orientation. This means it has to transform its configuration during flight, redirecting lift actuators whilst still maintaining stable attitude & position control in spite of such relative motion. In view of this required articulation the proposal is to add 2 (degrees) axes of extra actuation to each propeller. As a result each lift propeller can then be pitched or rolled relative to the body frame. This change, to what is an otherwise well understood and highly researched platform, produces an over-actuated control problem. Actuator allocation is the primary contribution of this paper with novel elements of non-linear (*state-space*) attitude control.

The structure of the dissertation first presents the design which the subsequent dynamics and control are derived with respect to. Following that, the kinematics associated with rigid bodies are derived. Any unique effects that could apply to the design like gyroscopic, inertial and aerodynamic responses are investigated and then incorporated into the dynamics. Position and control algorithms are first derived, then simulated and compared based on the plants' dynamics (*which include discretionary effects on the system*). The relative performance of the controllers are evaluated but regular performance metrics for attitude and position control are ill-suited for such a system. Some time is spent discussing the consequence of this and how the controllers are actually evaluated. Finally the design is built and tested using readily available RC components and conclusions drawn on the success or failure of the design.

The purpose of the investigation is the practicality and feasibility of such a design, most importantly whether the complexity of the mechanical design is a decent trade-off for the added degrees of control actuation. The outcome of the build is to ascertain if it's both economically (cost and control effort) feasible to use such a prototype to expand the range of a quadrotors' motion. The design and control treatment presented here are by no means optimal or the most exhaustive solutions, focus is placed on the system as a whole and not just one aspect of it.

This dissertation report is presented in a logical progression of concepts and information. In some cases the research and results were compiled differently from how they're listed.

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Appendix A

Standard Quadrotor Dynamics

Appendix B

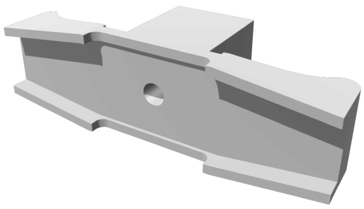
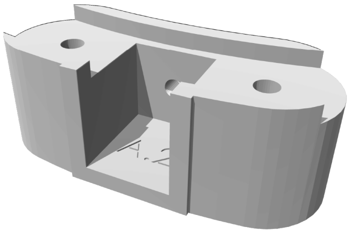
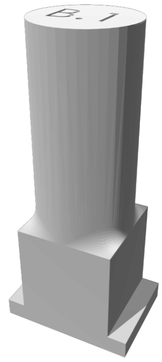
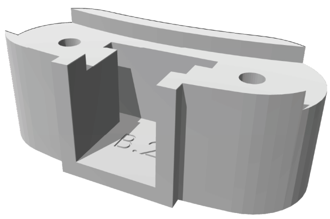
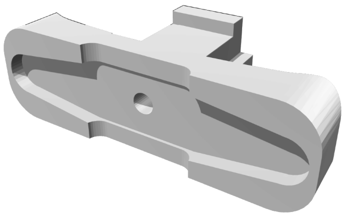
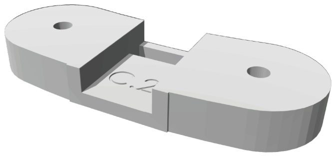
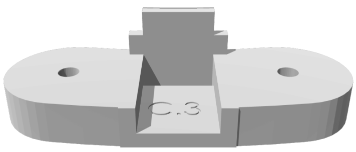
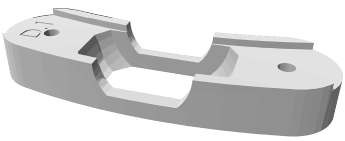
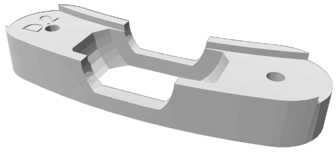
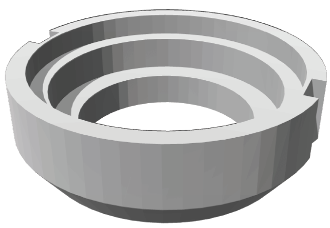
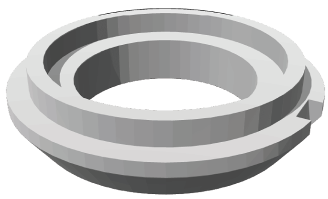
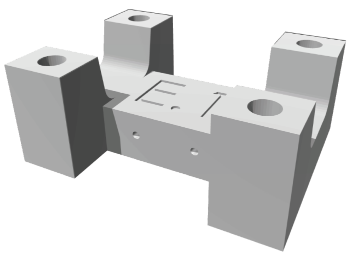
Design Bill of Materials

B.1 Parts List

Part Name	Amount Used	Unit Weight[g]
Electronics		
SPRacing F3 Deluxe Flight Controller	1	6
OrangeRx 615X 2.4 GHz 6CH Receiver	1	9.8
Signal Converter SBUS-PPM-PWM	1	5.0
STLink-V2 Debugger	1	N/A
RotorStar Super Mini S-BEC 10A	1	30
128x96" OLED Display	1	N/A
XBee-Pro S1	2	N/A
HobbyWing XRotor 15A Opto ESC	4	10.5
OrangeRX RPM Sensor	4	6
HobbyKing Multi-Rotor Power Distribution Board	1	7.6
Motors		
Corona DS-339MG	8	32
Turnigy DST-700KV Brushlesss DC	4	65
Frame Components		
APM Flight Controller Damping Platform	1	16
HobbyKing SK450 Replacement Arm (2 pcs)	2	N/A
SK450 Extended Landing Skid	1	93
Alloy Servo Arm (FUTABA)	8	N/A
10X18X6 Radial Ball Bearing	8	N/A
80g Damping Ball	32	N/A
Plastic Retainers for Damping Balls	32	N/A
3/5mm Aluminum Prop Adapter	4	N/A
6x4.5 Gemfam 3-Blade Propeller	4	N/A
M3 6mm Hex Nylon Spacer	8	N/A
M3 16mm Hex Nylon Spacer	32	N/A
M3 25mm Nylon Screw	128	N/A
M2.5x10mm Socket Head Cap Screw	36	N/A
M2.5x25mm Socket Head Cap Screw	20	N/A
M2.5 A-Lok Nut	16	N/A

Table B.1: Parts List

B.2 3D Printed Parts

Custom Printed CAD Designs		
 **Figure B.1:** Part A.1	 **Figure B.2:** Part A.2	 **Figure B.3:** Part B.1
 **Figure B.4:** Part B.2	 **Figure B.5:** Part C.1	 **Figure B.6:** Part C.2
 **Figure B.7:** Part C.3	 **Figure B.8:** Part D.1	 **Figure B.9:** Part D.2
 **Figure B.10:** Part D.3	 **Figure B.11:** Part D.4	 **Figure B.12:** Part E.1

B.3 Lasercut Components

B.4 Assembly

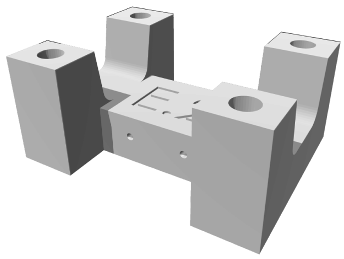


Figure B.13: Part E.2

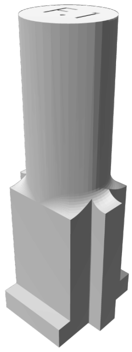


Figure B.14: Part F.1

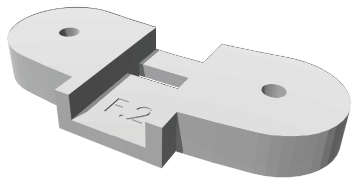


Figure B.15: Part F.2

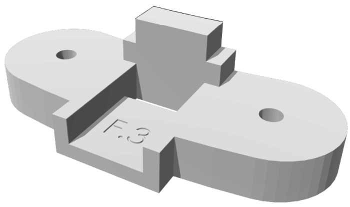


Figure B.16: Part F.3

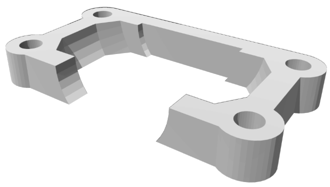


Figure B.17: Part G.1

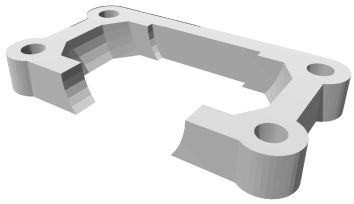


Figure B.18: Part G.2

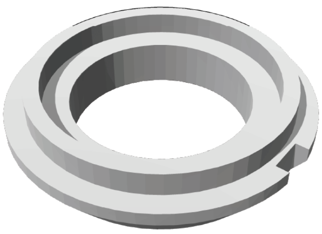


Figure B.19: Part G.3

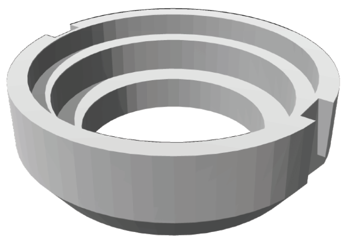


Figure B.20: Part G.4

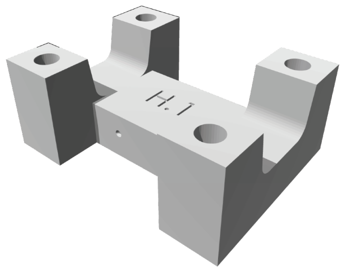


Figure B.21: Part H.1

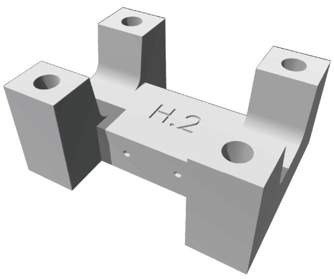


Figure B.22: Part H.2

Appendix C

System ID Test Data

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