Underactuated off-center mass controller for steering flying vehicles

Kin Chang, Lin Li, Amirali Omidfar, Angel Jimenez

UCLA

Abstract. We aim to design an underactuated controller which is essentially a off-center spinning mass that is able to steer flying vehicles. A quadcopter is used to demonstrate the principle of such controller. By in-depth analysis of the system dynamics and results from this project, we believe such principle can be applied to modern rockets with little modification.

Keywords: Underactuated controller, steering flying vehicle, rocket control, robotics

1 Problem Statement

We aim to explore an alternative way to steer flying vehicles with underactuated controller. Taking the motivation from modern rocket control, we are going to implement such controller in a quadcopter to demonstrate such principle. We hope to extend such controller to steer rockets in a more cost and energy efficient manner.

2 Motivation

Modern Rocket uses 2 DOF revolute joint to turn the nozzle to directly control the direction of thrust. Challenges are it has to resist a very high temperature and the joint need a large amount of energy to keep the nozzle in a specific direction.

Instead, a precisely controlled off-center mass in the front of the rocket can create a torque that steers the Rocket.

3 Scope

In this project we will focus on the mathematical formulation and the design of the controller. We will build on a working quadcopter where all 4 propellers will provide the same constant thrust.

4 Detailed Context / Related work

4.1 Mathematical Model and Simulation

Complexity of Mathematical modeling of a quadcopter as an unmanned aerial vehicle with 4 rotors is shown in this article which can be applied to our mathematical modeling process.[6]

Quadcopters Dynamics (title of the article) defines and elaborates on dynamics and control of quadcopters. Useful point of this article is the simulation results author has done in Matlab. (Code is also given) which we may use as a reference to build our simulation. [2]

Modelling and control of quadcopter: Aerodynamical effects in quadcopters are discussed in details in this paper beside a very straightforward two dimensional matlab based simulation is given as well as good explanation on trajectory control of the drone which is of one our main goals to achieve. [5]

4.2 Quadcopter Control

Hybrid Control Algorithms Using complex controller for underactuated quadcopter flight system considering fuzzy logic and PID controller, complex controller may get us to our ideal controller since PID may not be our option. [7] This paper compare different controllers for drones and their similarities and differences. Especially good information is mentioned on PID and neural networks controller. This insight can help us decide what type of controller our system needs. [1]

4.3 Rocket Control

Gain a better understanding of how Thrust vectoring and gimbaled thruster systems work in rocket control In order to see how we can correlate our model to an actual rocket. [4] [3]

5 Tasks breakdown, potential challenges

1. Mathematical Formulation
   - Analysis of the system dynamics
   - How does a spinning mass create torque
   - How does the created torque affect the orientation of the system
   - The desired roll / pitch angle for system stability
   - The spinning mass dynamic and effect on system
2. Pick our components
   - Hackable Quadcopter (Crazyflie drone)
   - a motor with phase control adjustable to spin faster/slower in certain range ?
   - What mass to attach? What arm to connect motor and mass?

  - The mechanical structure to mount the controller on the Quadcopter
  - Microcontroller
  - IMU for sensor measurements
  - Wireless/Bluetooth module for communication
  - Battery

3. Simulation environment
   - Simulation in Matlab
   - State (orientation) Estimation
   - How does motor inputs generate torque and in turn affect the orientation
   - Controller simulation
   - How simulation apply to reality?

4. Hack the quadcopter
   - Be able to control the 4 propellers using our wireless module thru our microcontroller

5. Sensor Fusion
   - Configure the IMU, making use of accelerometer and gyroscope
   - Determine the rate of roll/pitch angle change

6. Control circuit for motor
   - make sure the motor can precisely manipulate the center of mass before mounting it on quadcopter
   - Design a test to show that the off-center mass can be

7. Putting it together
   - Integrate all our working components (wireless communication, motor pulse control, sensor fusion, simulation works)
   - Mount it on the quadcopter

8. Controller Design
   - Real experimental results should be available since we already built our system and mount it on quadcopter
   - controls the input to the motor and the propellers, by taking in state estimation and sensor measurements
   - Responsible to achieve the desired roll/pitch angle to steer the vehicle
   - Moreover, to stabilize the quadcopter from a moving position.

9. End-to-End testing
10. Documentation

6 Project plan

6.1 Major Milestones

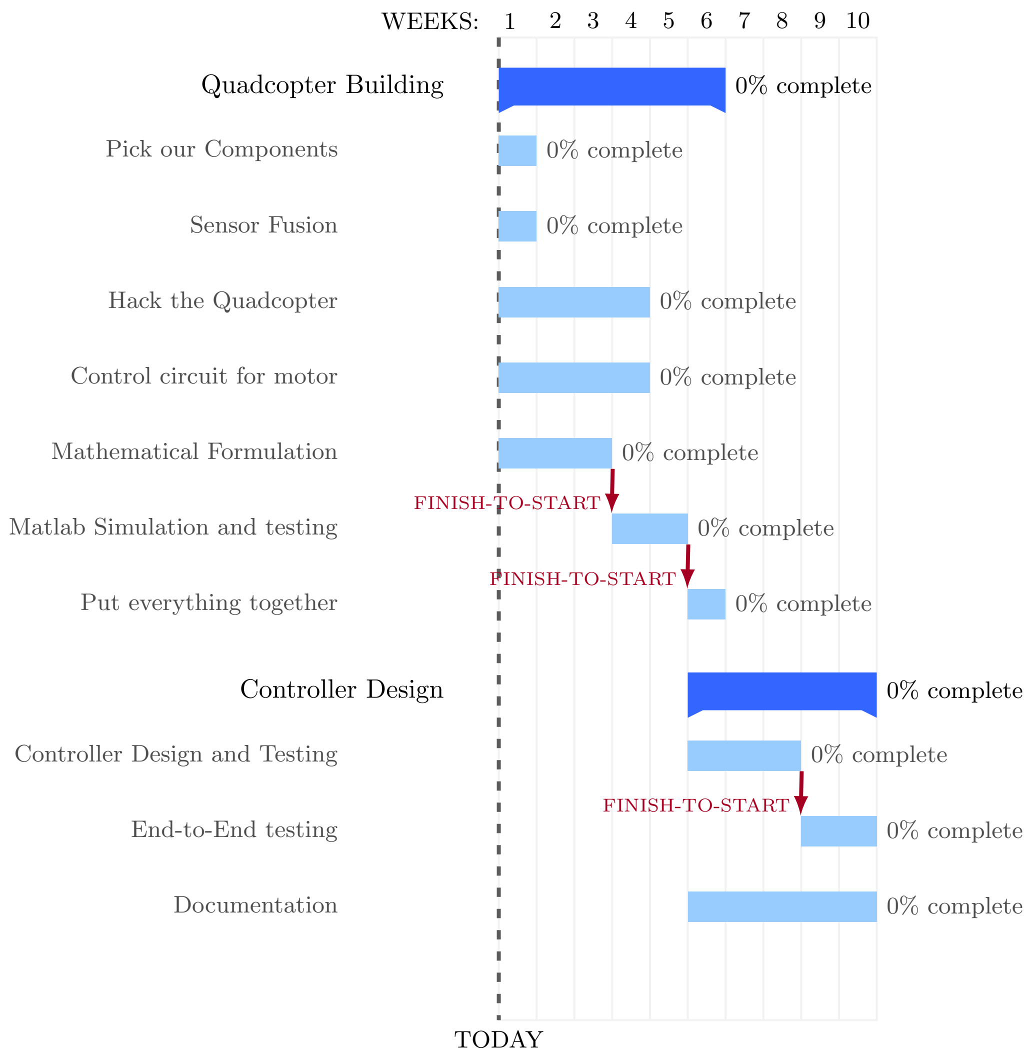
Milestone	Demonstration
Pick our components	Reason choosing these parts
Hack the quadcopter	Controll the quadcopter with Arduino code
Mathematcial Formulation	Show our mathematical model
Sensor Fusion	Demonstrate angle change / vector graph
Control circuit for motor	Test: falling on desire side
Develop Matlab Simulation	Show simulation graph
Putting everything together	Show our modified quadcopter: video demo?
Controller Design	Show how quadcopter reacts with different controllers
End-to-end testing	Gather experimental results that supports our conclusion
Documentation	Document all our work

6.2 Weekly Plan

Week	Task
1	Fundamental of quadcopter and drone specs
2	Derive equation and hack quadcopter
3	Code system in Matlab and build OSCM
4	Test OSCM and correct model
5	Determine controller model and complete OSCM
6	Improve controller model and add sensor fusion
7	Test drone + OSCM + start PCB design
8	Test drone + OSCM + Finish the PCB design
9	End to End testing + video demo

Table 1. Weekly Plan

6.3 Gantt Chart



7 Expected Conclusion

We would like to conclude that an off center spinning mass is able to steer the quadcopter using the system's dynamic; and that such principle can be apply on rockets for more effective way of stering a rocket.

References

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Planning sheet – Team: **Parsley**

Week 1:

Task	Deliverable	Score allocation	Score achieved
Understanding the fundamental of drone flight and off center spinning mass	Show the mathematical Derivations/Equations	4 /10	
Identify the drone specifications	Show the resources to use/control/program the drone and being able to work with the drone	5 /10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 2:

Task	Deliverable	Score allocation	Score achieved
Deriving required equations to describe our flight system and start working on the simulation model	Show the mathematical Derivations/Equations and explain how our flight system works	4 /10	
Hack the Drone controller (use ps4 controller for driving the drone)	Demo on controlling the drone with PS4 controller	5/10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 3:

Task	Deliverable	Score allocation	Score achieved
Code the system using mathematical model	Demo of our system run in the simulation environment	4 /10	
FInd the proper material to be used for the OCSM motor and start building the prototype	Show the material picked and the progress in building the prototype	5 /10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 4:

Task	Deliverable	Score allocation	Score achieved
Have the OCSM prototype ready and testing it OCSM =off center spinning mass	Show the demo on OCSM prototype	4 /10	
Calibrate and correct the model based on the data got from running simulation	Show the modifications added to our previous mathematical modeling	5 /10	
Documentation	Show the recorded progress and write up	1/10	
Total		10/10	/10

Week 5:

Task	Deliverable	Score allocation	Score achieved
Derive the right controller model to implement on the drone	Show and explain the derived model	4 /10	
Complete OCSM module which will be attached to our drone	Demo on prepared and built OCSM module	5 /10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 6:

Task	Deliverable	Score allocation	Score achieved
Improve the controller model based on data collected and simulation data	Show and describe the controller model improvements	4 /10	
Implement the sensor fusion adding our required sensors or using the sensors on the drone	Do a live demo with drone and show the collected data from the sensors on the drone	5/10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 7:

Task	Deliverable	Score allocation	Score achieved
Testing the model with drone+OCSM module attached (1)	Share the test results and outputs	4/10	
Start designing the PCB	Show the schematics and board file	5/10	
Documentation	Show the recorded progress and write up	1/10	
Total		10/10	/10

Week 8:

Task	Deliverable	Score allocation	Score achieved
Testing the model with drone+OCSM module attached (2)	Share the test results and outputs	4 /10	
Finish the PCB Design	Show and explain the prepared finished board	5 /10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 9:

Task	Deliverable	Score allocation	Score achieved
End to end testing and final corrections	Share any change and modification to our system based on end to end testing	4 /10	
Capture a video demo	Share the recorded demo	5 /10	
Documentation	Show the recorded progress and write up	1 /10	
Total		10/10	/10

Week 10:

Task	Deliverable	Score allocation	Score achieved
Any minor details forgotten or /not taken care	show how we fixed the errors and unexpected problems happened during the process of working on the project	8 /10	
Documentation	Show the recorded progress and write up	2/10	
Total		10/10	/10

Finals week:

Task	Deliverable	Score allocation	Score achieved
Final Presentation	Present our project	10 /10	
Record and add any final change to our documentation	Final paper on our project results	/10	
		/10	
		/10	
Total		10/10	/10