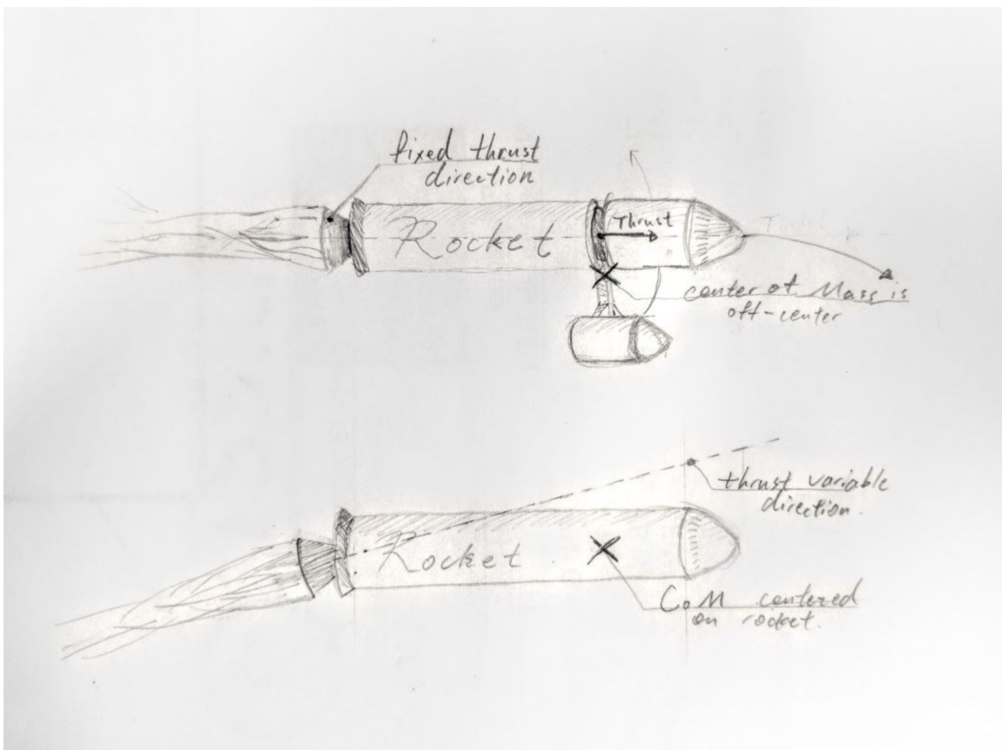
Big picture

Rockets without a control system are inherently unstable, so most rockets have a control mechanism in the form of gimbaled rocket engines, vernier rockets, or jet vanes. All rocket active control methods currently require more than 1 DOF. For example, gimbaled rocket engines require at least 2 actuators, and can move in a cone. In other cases, extra rocket engines (vernier) are attached to the rocket, etc. This adds additional weight to the rocket. The goal of our research is to explore the possibility of underactuated control methods, which have a smaller DOF, with the goal of sacrificing some control for less weight and more range.

These types of control problems are typically solved through mathematical modeling and simulation, followed by a real demonstration.

If a suitable method of control is found, it may lead to ways of saving weight or cost when constructing rockets for certain uses.



Top Image: our proposed control system uses an off center spinning mass to offset the Center of Mass from the line of thrust to achieve torque

Bottom Image: a standard gimbaled rocket engine offsets the line of thrust from the CoM to create torque.

Our approach emphasizes avoiding high gain feedback loop control in order to exploit the dynamics of our systems instead of canceling it with fully actuated control. In doing so, we hope to increase the efficiency, robustness, and agility.

The main idea here is to focus on controlling only one variable which would effectively modify the <u>center of gravity</u> of our system to gain the ideal trajectory.

To simplify the modeling process, we would use a quadcopter assuming it returns the same dynamic response as rocket. Our approach will be to derive the mathematical model of our quadcopter with spinning mass attached first. Once the model is verified in simulation environment we shall continue with physical implementation.

Specific Project Scope:

We want to explore the properties of a control system that steers a rocket using a rotating off-center mass by shifting the rocket's center of mass with respect to the line of thrust. A demonstration that such a control system works may encourage other researchers to come up with better ideas of underactuated control of rockets.

We will first write down mathematical models for the rocket and mass system, then explore its stability in simulation. We will use either Python or Matlab for this purpose. If the simulation yields satisfactory results, we will also try to experimentally demonstrate the viability of the controller by building an analogous fixed thrust system with a spinning mass, using a quadcopter.

If this method of control is effective, it may encourage other researchers to investigate other underactuated methods of control.

Background/ Related Work/ References

- Fundamentals needed to understand my problem and to reach a solution
    - Rigid body dynamics
    - State Space Control
    - Awareness of most other major kinds of control algorithms
    - Rocket performance parameters vs quadcopter performance parameters
- I have not found any related work on using off center masses to steer rockets, however I can use famous papers to learn good practice for designing controllers for attached rigid bodies.
- References:
    - http://cambridgerocket.sourceforge.net/AerodynamicCoefficients.pdf
    - Box, Simon. Estimating the dynamic and aerodynamic parameters of passively controlled high power rockets for flight simulation
        - learning about rocket parameters used in industry.
    - R. Sumathi, Pitch and Yaw Attitude Control of a Rocket Engine Using Hybrid Fuzzy-PID Controller
        - In this article the control of a rocket is derived, and simulated in simulink, this will serve as a good comparison between standard control and my control method.

Goals/Deliverables/Tasks

Goal: 1) explore controller viability. 2) if it works, explore its speed, oscillations (damping), accuracy, stability, and bandwidth

- **Goal:** computer simulation
    - derive dynamical equations for the rocket + mass
    - design controller so that rocket can turn and travel in a relatively straight trajectory.
- **Goal:** experimental demonstration with passively stabilized quadcopter
    - build a system that has similar dynamics to a passively stabilized rocket (so rocket flying with air)
    - using kinect for state estimation, attempt to demonstrate the controller that (hopefully) succeeded in software.

Week 2 (7/2 M):
Goals:
- Learn most of the prerequisites
- familiarize with the field of control theory (what is optimal control, etc?)

Deliverables: none
Tasks:
- read “Attitude control of small scale rockets” for Journal Club (SUSP)
- read Ch. 11 in Marion and Thornton (Rigid Body Dynamics)
- read Ch. 11 - 12 in Ogata, “Modern Control Engineering”
    - Analysis of control systems in State Space
    - Design of control system in state space
    - Lyapunov Stability Analysis and Quadratic Optimal Control
- read wikipedia page on control theory

Week 3 (7/9 M):
Goals:
- familiarize with **python**
- start deriving mathematical model

Deliverables:
- copied rigid body simulation (with modifications to make it more relevant)
- maybe some self motivated exercise from the rigid body simulation course

Tasks:
- read Rigid Body Simulation (Course Notes) Part I and II
- read Ch. 13 in Ogata, “Modern Control Engineering”: Lyapunov Stability Analysis and Quadratic Optimal Control
- recreate a rigid body simulation somewhere online to practice python

Week 4 (7/16 M):
Goals:
- finish mathematical model
- start & finish computer simulation of system with no controller

Deliverables: completed mathematical model
Tasks:
- write simulation, and show what happens when the mass is stationary or spinning really fast, to build some intuition about system dynamics.

Week 5 (7/23 M):
Goals: gather and organize results (SUSP)
- work on computer simulation with controller

Deliverables: controller simulation attempt #1
Tasks:
- review notes on all the types of control in control theory, and attempt one of the types of controllers.

Week 6 (7/30 M):
Goals: draw conclusions (SUSP)
- work on computer simulation with controller
- draw conclusions and work on poster (SUSP)

Deliverables: controller simulation attempt #2
Tasks:
- review notes and attempt another type

Week 7 (8/6 M):
Goals:
- finish computer simulation with controller
- work on poster (SUSP)

Deliverables: remastered controller simulation (#1 or #2)
Tasks:
- collect data on the better controller, and prepare poster.
- make as much of the SUSP poster as possible.

Week 8 (8/13 M):
Goals: **or paper**
- hack the quadcopter
- finish poster (SUSP)

Deliverables: poster for SUSP
Tasks:
- finish SUSP poster

Week 9 (8/20 M):
Goals:
- hack the quadcopter

Deliverables: undetermined
Tasks: undetermined

Week 10 (8/27 M):
Goals:
- hack the quadcopter

Deliverables: undetermined
Tasks: undetermined

SUSP Timeline

1. Familiarize yourself with lab culture. are there weekly lab meetings and presentations? what is expected of you? how do you get help when stuck?
2. **establish perspective of the scientific question** finalize your scientific question and start thinking about what data you will be collecting to answer it, with alternative plans in case plans fail.
    a. what has been done in the past,
    b. what is the research field lacking or limited in knowledge or technology,
    c. what is your approach to the problem or what do you want to test.
    d. how will your approach overcome the previously mentioned limitations of your research field
    e. what equipment will you use and how do they work?
    f. what protocols will you be following, and what data do you expect to collect at the end of each protocol
3. **start data collection and set up backup plans** learn the lab techniques that will give you most efficient yield of preliminary results
    a. what convincing qualitative data will you be collecting (pictures? videos?)
    b. how will you obtain quantitative data (graphs, scatter plots, histograms)
    c. what alternative methods can you perform in case you cannot obtain any results? How will you change your experimental design.
4. **Evaluate experimental plan of action** start thinking about how you will present your data on your poster
    a. methods summary: draw a pictorial flowchart of your plan of action, including special equipment, and the type of result they should bring about to substantiate your hypothesis
    b. describe what results you obtained from each method
5. **Gather and organize results** refine experiments to yield presentable convincing data. begin drawing conclusions of those data, and tie them back to the hypotheses.
6. **draw conclusions** looking at all of your data as a whole, what can you definitively say with respect to your initial hypotheses? what are the real world impacts of this work?
    a. for any funders who are sponsoring your project, write 1-2 sentences about the organization,what they do, and other things they fund.
    b. what experiments could be done for your project to further bolster your data?
    c. at the end of this work, what is the contribution to the research field
    d. how can you or someone expand upon your research to allow the field to progress
7. and 8 **add final touches and present your results** integrate feedback into a finalized poster, including las graphs/tables/figures/conclusions. practice all presentations
    a. rehearse presentations
    b. final project summary