J. Shibley 2021-05-29

Rocket Guidance System: Writings

Purpose:

The purpose of the "Rocket Guidance System" is to create an electromechanical control system that is capable of stabilizing and guiding a mid-power rocket. Furthermore, an indigneous launcher is created to facilitate the testing of the aforementioned guidance system.

Reference:

D'Arcy, Chris. "Project 30. Long Independent Study Project." ICS4U-E DER Projects,
http://darcy.rsgc.on.ca/ACES/TEI4M/2021/ISPs.html#LongISP.

2020-2021 ICS4U-E; DER Projects
darcy.rsgc.on.ca/ACES/TEI4M/2021/ISPs.html#LongISP

MPU6050 Gyroscope / Accelerometer Datasheet
invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf

HD-1160A Servo Motor Datasheet
pololu.com/file/0J318/HD-1160A.pdf

Fundamentals of Naval Weapons Systems: Chapter 15. Guidance and Control
https://fas.org/man/dod-101/navy/docs/fun/part15.htm

Theory:

The concept of a guidance, navigation, and control (GNC) system has existed since the dawn of modern rocketry in the 1920s. Despite the massive technological advancement since then, the basic concept still remains the same. Every rocket guidance system consists of two main sections; the attitude control system and the flight path control system. The attitude control system functions to keep the rocket on the desired attitude on the ordered flight path by controlling the pitch, roll, and yaw. The attitude control system operates as an auto-pilot, damping out fluctuations that tend to deflect the rocket from its ordered flight path. The flight path control system processes the flight path necessary and generates the orders for the attitude control system to maintain that path.

GNC systems are based on the principle of feedback. The GNC system makes corrective adjustments of the rocket's control surfaces when a guidance error is present. The guidance system will also adjust the control surfaces to stabilize it in roll, pitch, and yaw. Then, guidance and stabilization corrections are combined, and the result is applied as a single correction to the control system.

The heart of any inertial guidance system are a series of accelerometers that will detect any change in the vehicle's motion. An accelerometer is a device that measures acceleration. If the acceleration along the fore and aft axis were constant, the speed of the rocket at any instant could be determined simply by multiplying the acceleration by the elapsed time. However, the acceleration may change considerably over a period of time. Under these conditions, integration is necessary to determine the speed.

Procedure:

There are three main sections to the "Rocket Guidance System": the test rocket, the guidance system housing, and the guidance system itself. The test rocket also known as the "Flight Test Platform" is a reusable, modular, mid-power rocket that serves as a test bed for the guidance system. It consists of two 14" BT-80 body segments connected through an internal coupler. The engine mount in the lower of the body segments can safely house E, F, or G rocket engines. A black polymer coating is applied to areas under large amounts of stress to increase structural integrity. A reflective orange paint is applied to certain sections to indicate areas of high heat and to increase visibility.

The guidance system housing is constructed out of 3D printed PLA and is comprised of 5 subsections: Nose Cone, Nose Cone Retention Plate, Servo / Gyroscope Mount, Electronics Housing, and Rear Plate. The nose cone is 11cm tall and maintains a parabolic shape to reduce instabilities near the canards. At the rear of the Nose cone is a 30mm ISO thread to screw it into the nose cone retention plate. The nose cone retention plate connects the nose cone to the rest of the housing and increases the strength of the servo / gyroscope mount. The servo / gyroscope mount keeps the servos firmly in place whilst allowing their wires to pass through the bottom plate. It also retains the MPU6050 gyroscope directly inline with the centres of mass and thrust. Thus, increasing accuracy of its readings. The electronics housing contains all further electronics and their respective connections, such as the ATmega328p (Arduino Nano), power regulator, and lithium ion battery. The rear plate holds the aforementioned electronics in and protects them from the exhaust gasses of the rocket engine. Furthermore, there is a reinforced loop on the external side of the plate for the primary 2m parachute to attach to the guidance system.

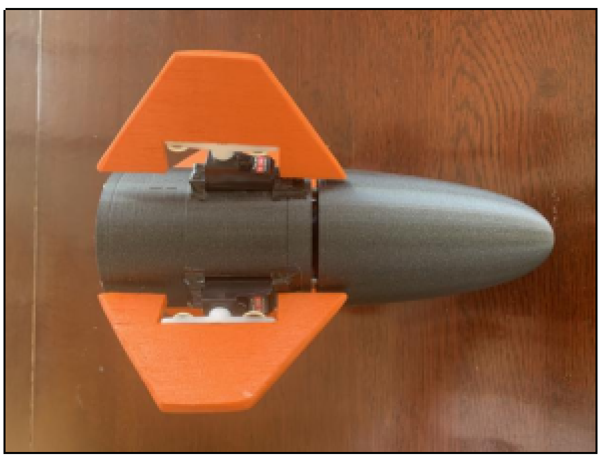
The guidance system consists of three main components: MPU6050 Gyroscope, Arduino Nano, and Servo Motors. The MPU6050 is one of the most capable motion processors available on the market today. It combines a MEMS 3-axis gyroscope and a 3-axis accelerometer on the IC with an onboard Digital Motion Processor that can process complex 9-axis MotionFusion algorithms. Thus, solving the cross-axis alignment errors that have plagued digital motion processors for decades. The MPU6050 measures its gyroscope and accelerometer and computes the current angle in relation to the ground. This data is then sent to the Arduino Nano for further processing. Upon receiving the current angle Arduino Nano compares it to the desired angle of the flight path modeled by a function of angle vs. time and outputs the necessary angle required to maintain the flight path to the 4 servo motors. However, in order for the rocket to truly stabilize, the angle must be exaggerated by 10% to achieve angular acceleration. The 4 servo motors can control pitch yaw and roll through various alignments. All electrical components are connected to a power header. Originally, this header was designed to be connected to a Lithium Ion battery. However, COVID supply issues render that impractical. Thus, the power is supplied through a regulated 9V battery or 5V power supply until a Lithium ion battery is acquired.

The code that the Arduino runs is built off of three custom libraries. The first of the libraries, Fastwire, serves as a replacement for the preexisting “Wire” Arduino library. The replacement was needed because the original wire library transmission speed is 4MHz, far too slow for time-sensitive mechanics. To solve this problem, the fastwire library runs at the maximum speed the Arduino can handle, and it adds several quality of life improvements such as onboard debouncing. The custom I^2C library adds additional functions to simplify reading and writing from numerous registers. Finally, the MPU6050 library adds functions to easily initialize, control, and read from the MPU. Thus, it also stores the registers and predefines required to interface with the MPU. The main loop functions as follows:
First, the four servo motors are initialized to pins 3, 5, 6, and 9. Then, the MPU6050 is initialized. In the loop, the arduino receives the 6 axis from the MPU, of which only the acceleration will be used. However, because the DMP is enabled on the MPU, the “acceleration” values are actually the angles between the current position and gravity. The angle for the servos is calculated through adding or subtracting the angle off of centre from the current path angle. From there, the pitch and yaw servos receive their new angle. Every 10ms, the path angle is updated following the imputed function. In conclusion, the rocket will follow the path by accounting for any discrepancies or disturbances in the rocket’s motion.

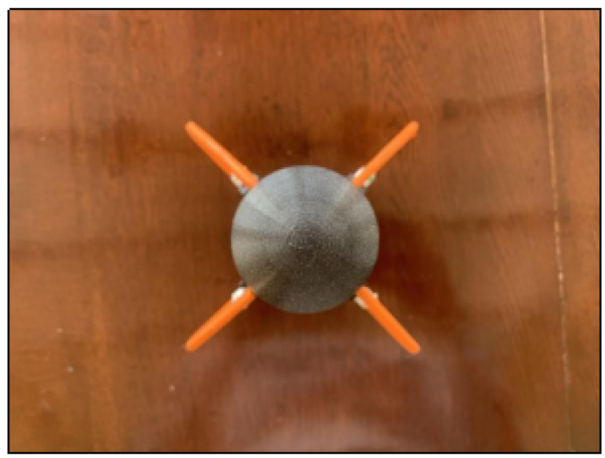
Media:

Guidance System (Complete)

Flight Test Platform (Complete)

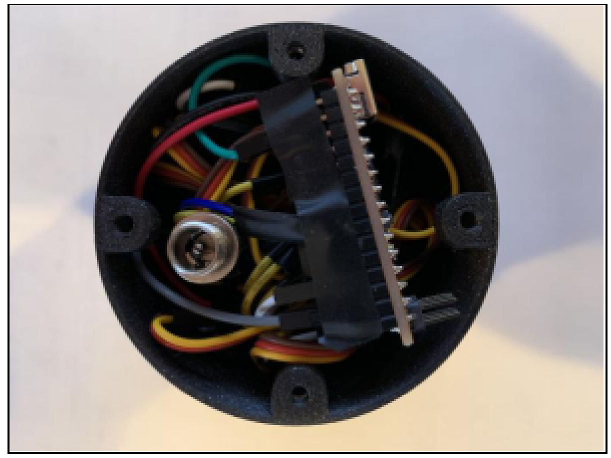


Guidance System (Side)



Guidance System (Front)

Guidance System Internals (Top)



Guidance System Internals (Bottom)

Complete Project

Project In Action:

https://youtu.be/Jd08QXdUqzw

Code:

The Fastwire, SHiBI2C, and SHiBMPU6050 Libraries are too large to fit into this document. Thus, they can be found on the corresponding GitHub for this project:

https://github.com/SpaceShib/SHiBRocketGuidanceSystem

Reflection:

I see this project as the perfect bridge between my time in the ACES program and my future. It allowed me to combine my future profession, Aerospace Engineering, with the knowledge that I have gained over the last 3 years. I could not have completed this project without Joseph Vretenar as he helped me learn FUSION360 and printed off the housing for me. For those skills, I am truly thankful. This project was not without its difficulties, as COVID through a massive wrench into my acquisition of parts. In the end, it was all solvable with only minor setbacks and a few compromises.

As this is my final project, I feel like I need to reflect on the past 3 years…

These last years have been the best of my life and a lot of this was because of hardware. It has completely changed who I am. I am now more resourceful, independent, productive, and creative than I ever saw myself becoming in a million years. The ACES community has always been there for me, through thick and thin. In the DES, nothing ever went wrong there were only setbacks. In the DES, the world was at peace, for all that mattered was hardware and its community. And in the DES lived some of the best guys that I have ever met. From the late nights to the early mornings, they were always there, tinkering away, chatting and laughing. Life was perfect there.

I need to mention a few people who I can single out for completely changing my life:

Tim Morland: for teaching me what it was to be an ACE, a Georgian, and for giving me the first taste into engineering back in Grade 9.

Daniel Raymond: for making me the kind of man I am today and always pushing me to shoot for the stars.

And Chris D'Arcy: for facilitating the greatest 3 years of my life. I will never forget what he has done for me. All the hours spent teaching me, I forever in his debt. One day, I will look down upon the earth and remember how far I have come, and how it all started because of one man and his course.

Thank You Gentlemen,

J. Shibley