Control Moment Gyroscope Platform Mk2

Introduction

Rotating a spacecraft (known as attitude) in space can only be achieved in three ways. Firstly thrusters (small rocket motors or thrusters) that are positioned at points around the spacecraft are briefly fired to rotate the spacecraft. This has the drawback of using some propellant which will eventually be used up. This clearly needs careful planning as any extra weight on a spacecraft by its very nature is inhibitively expensive. It also means that the thrusters are used when only necessary as it will reduce the spacecraft's life (assuming it can't be refuelled), or at huge cost (if it can be refuelled).

The second solution is to use a Control Moment Gyroscope (CMG) platform. This is one or more gyroscopes (spinning using an electric motor) that are forcibly rotated around an axis usually using a servo motor or similar means. The resulting gyroscope torque rotates the spacecraft. Up to 3 axes can be controlled this way. Extra gyroscopes can be used for redundancy. The benefits are clear; Provided the spacecraft has electrical power, by solar power for example, then the aircraft can rotate. With a CMG this can be gone on a regular basis to change the attitude of the spacecraft or simply used consistently to keep the spacecraft pointing in the same directional.

The third way is using reaction wheels. This is similar to the second because it uses a spinning mass, however rather rotating the gyroscope/flywheel while it is spinning causing precession, the flywheel is simply spun faster or slower. Just the act of spinning up the flywheel or slowing it down causes torque on the same axis as the spinning flywheel.

Control moment gyroscopes have been used with great effect on the international space station, Hubble space telescope and many other satellites.

Although most also used exclusively in space there is actually no reason they cannot be used for some interesting earth bound projects. For example it could be used to control the direction of aircraft, camera systems, direction of High altitude balloons, one/two wheel land vehicles or various robots.

This kit allows quickly allows you to Control Moment Gyroscopes begin to understand all the fundamentals.

Contents

Uses and benefits

- Useful for small satellites and microsats teaching
- Ideal for teaching students CMGs
- Allows numerous simulations, including CMG failure
- Unique uses in robotics
- Useful in the fields of Robotics, Aerospace, High altitude balloons and possibly photography
- Maybe of interest to niche market RC aircraft

Key features

- Supplied 4 electric powered Control moment gyroscopes
- Gyroscopes have internal BLDC style motors.
- Nema 17 Bipolar Stepper motors provide 45Ncm (64oz.in) of torque
- Steppers have native 1.8deg step angle
- Stepper controller is set to 1/4 step. Hence 0.45 step. Or 800 pulses per 360 degrees
- 3 or 4 gyroscopes can be used (more or less can be added/removed if needed)
- Gyroscopes can be placed at 15 degree angles on the platform.
- Simple gimbal allows movement in 3 axes (Pitch, Roll, Yaw) using SKF plain bearing.
- All gyroscopes have a stable RPM each having their own controller
- Each CMG is rotated using strong stepper motors. Provides precise small movements.
- Each CMG can be controlled independently
- High current switch mode power supplies are included
- Joystick supplied to control platform
- Joystick allows pitch, yaw and roll movements
- Controller is an Arduino (programmable using USB)
- Simple control software for the Arduino is supplied
- Software is supplied
- Gimballed stand for platform is included
- Provided source code includes single, double and triple Exponential Moving Average filters.
- DRV8834 stepper motor controller providing 1.5A continuously and 2A peak
- Arduino Uno include

Mk2 improvements

- Heavier, larger gyroscopes
- Structure is more rigid
- Servos replaced with much stronger, more precise stepper motors
- Much higher levels of torque can be provide
- Each gyroscope now has its own speed controller
- Gyroscope speeds are more stable
- Controller is now a widely used Arduino
- Now includes a stand
- Joystick included.

Power supply

Due to the BLDC motor controllers needing precise voltages for reliable starting, switch mode power supplies have been provided. They are either supply configured for 110v or 220-240v (default).

Connecting to a computer

Connect the Arduino using a USB cable. Download and install the Arduino IDE software from https://www.arduino.cc/ on your computer. Download the source code from http://www.gyroscope.com/images/CMG/CMGarduinocode.zip

When running the Arduino IDE use the serial console to view debug information from the Arduino as the CMG is running.

Note: the CMG platform will run without connection to a computer, although it does need power to the USB port.

Positioning everything

Place the power supply box and controller box next to one another. Position the CMG platform close to the boxes. The joystick box can be positioned nearby.

The cables from the controller box to the CMG platform are relatively short. They could be lengthened if you desire. If you require extra freedom of movement with the CMG platform, after initially familiarising yourself and using the CMG platform it is suggested using longer wires and suspending the wires from gantry above the CMG platform.

Before running for the first time - Overheating

The motors, controllers and wiring to spin the gyroscopes are over specified and should not get too warm. However during the development of the mk2 CMGs the initial design used smaller stepper motors. Although they had increased torque and precision to the Mk1 CMG, they didn't have enough torque for the larger gyroscopes. I decided to upgrade to larger stepper motors and requiring some metal parts to be redesigned and remade. These new stepper motors consume more power, roughly the maximum that the stepper motor controllers can provide (2 amps). Although this in itself is not a problem for the controllers, the PCB board design did not intend to have such amperage. As a result the wire and connectors (5 volt supply) was get rather hot after some use. At the last moment I decided to change the wiring to thicker wiring, design and change the PCB board to have thicker interconnects. The PCB board also has higher amperage connectors for the 5volt system.

This should resolve the problem. HOWEVER I strong advice keeping an eye on the temperature of the wires. Always stay in attendance of the platform when running. Keep away from anything combustible.

Mechanical Configuration

First you will need to decide how many CMG units you want and how they are positioned. A good starting point is 4 units equally spaced apart (90 degrees) on the carbon fibre composite platform. You will also need to decide at what angle the CMG needed to be position. This usually would be at either 90 degrees to the platform or 45 degrees. The angle will need to correspond to the software that you write. The aluminium section of the CMG allows you to position the CMGs in 15 degree positions. To change simply unscrew the 3 screw either side (total of 6 screws) position as you want and then put the screws back in place.

A T10 torx screw is used for most of the screws on the platform.

Hot components

The stepper motor controllers (white PCB boards) do get very hot under normal operation. Chip temperatures range from 100C to just under 200C. This appears to be normal.

The boards are DRV8834 boards and you can find more about them here
https://www.pololu.com/product/2134

The number of steps is set to ¼ steps. The current can be limited using/turning the variable resistor on the board. You can find out more able setting this by visiting the link above.

Check for loose screws

It is important to check that screws do not loosen and tighten if needed. This can occur over time due to the vibrations from the gyroscopes.

Manually moving the stepper motors into position

Each of the 4 CMGs do not have absolute position e.g. after turning off-on they won't know there position. Once turned on you will need to centre stepper motors. This usually means all facing the same direction. You will need to use quite a bit of force to turn the motors.

Spinning up the gyroscopes

Once power is supplied there is a short delay. The joystick is calibrated. It is important not to more the joystick for the first few seconds while this occurs.

Then each gyroscope is spun up one by one. The start-up procedure may seem a little odd. Essentially a gyroscope is very briefly spun then idled, then started again. The gyroscope should then reach full speed. The other gyroscopes are then started in the same way.

This is due to the very nature of sensor-less BLDC motors. At low speeds the controllers cannot detect the positioning of the rotors/motors due to the back-emf not producing a high enough voltage at low rpms. This is why sensor-less BLDC motors always jump quickly to 500 or 100rpm.

Off-the-shelf BLDC motor controllers don't expect large heavy weights attached to the motors and timeout/error when they can't detect the back-emf/position. An initial start, then idle get the gyroscope turn and on the second start this is enough to get the gyroscope to the required speed for the controller to operate normally.

If you happen to find a gyroscopes failing to start. Identify which way the gyroscopes are trying to spin. Then spin each gyroscope by hand as the start procedure occurs. This initial spinning should be enough to get everything running.

The Arduino controls the speed of the gyroscopes by sending a PWM (effectively giving an analogue) signal to each BLDC controller. You could change the RPM of the gyroscopes by changing the PWM signal. However be aware you may have to change the start-up procedure and timings.

It is very likely that a quicker start up sequence can be found. You may want to fiddle with the timing s and power settings.

Software

The code is already preloaded onto the Arduino. You can view and edit the code from the Arduino IDE software. These are all the files:

CMG.ino
AccelStepper.h
AccelStepper.cpp
filter.h
MultiStepper.cpp
MultiStepper.h

The code does the following things.

1) Filters the signal from the joystick and calibrates the joystick to the centre position
2) The BLDC motors are started in sequence one after another. Each one is briefly started to get it spinning. Power is stop then restarted to obtain higher speeds. Power is then cut again and restart at a 'cruising' speed. This is done to avoid timeouts on the BLDC controllers.
3) Once the motors are spinning the joystick is then checked for movements and the stepper motors moved according to the movements.

Specifications

Stepper Specifications

- Nema 17 Bipolar Stepper motors provide 45Ncm (64oz.in) of torque
- Steppers have native 1.8deg step angle
- Stepper controller is set to 1/4 step. Hence 0.45 step. Or 800 pulses per 360 degrees
- 5 volt supply switch mode power supply
- Amps is 1 to 2 (peak)
- With fast movements the torque from the gyroscopes can overcome the stepper (this only occurs in extreme cases with fast movements).

Motor Specifications

- 24 volt supply switch mode power supply
- BLDC (brushless DC) motor design
- Max motor wattage 150 watts (never used)
- 1080Kv (1080~ rpm per volt)
- Controller throttles power using PWM on each phase
- Controller accepts analogue (PWM) signal from Arduino for speed control.

Future wish list of upgrades

- Dynamically balanced gyroscopes
- Custom BLDC controllers with more elegant handling of start-up and Digital RPM control.
- Updated software with close-loop style feedback with the platform
- Long wires (need to test longer wires works).
- Joystick with connector (rather than fixed wire). Or maybe Bluetooth joystick.
- Anti-vibration washers on screws
- Homing of the stepper motors (with mechanical stop)

Feedback and support

I welcome any feedback customers have. I intend to slowly make improvements to the software and some aspects of the design. If you need any support please contact me on support@gyroscope.com