3-Axis Active Camera Gimbal Stabilizer

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Objective

The purpose of this project is to implement a feedback control system for 3-axis camera gimbal stabilizer. The goal is to build an active stabilizer that is lightweight and useful for stabilizing a camera. The control system include MSP432 microcontroller, three MG996R servo motors, and one MPU9250 IMU sensor with 9 degree of freedom.
To achieve the above-mentioned goals, the project includes the following tasks:

1. Build an active stabilizer suited for controlling a gimbal stabilizer.
2. The system should be able to compensate for unintended motions in the pitch and roll axes to keep the camera level to a set reference plane.
3. Implement a complimentary filter to process a noisy signal.
4. The finished product should be handheld in the sense that it is relatively lightweight and easy to handle with one or two hands.

Control and System Overview

Figure 2 shows the CAD model of the 3-axis gimbal stabilizer designed for this project. The prototype was printed with PCA plastic and assembled with M3 bolts. Three MG996R servo motors are attached to the gimbal and are controlled with Texas Instrument's MSP432 microcontroller and powered by four AA batteries in series. On the small platform at a roll axis, a camera can be placed. The MPU9250 IMU sensor was placed on the handle to simplify the wires placement and to read only the intentional displacements.. An IMU sensor reads the angles yaw(ψ), pitch (ϕ), and roll(θ). To make the system as compact as possible, the mounting arms were designed to place the center of mass close to the midpoint of roll- and pitch- axis.

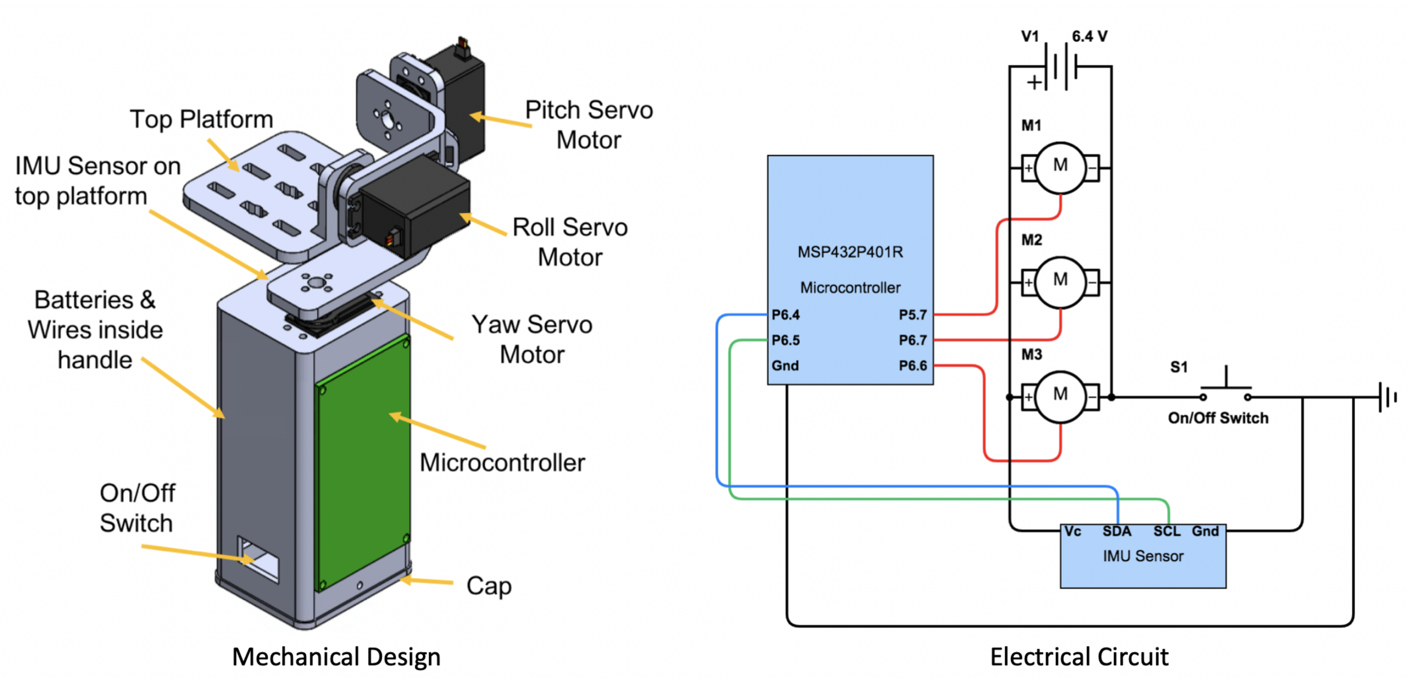

Fig. 1: Mechanical and electrical design of 3-axis gimbal system

The full schematic for how the motor drivers were plugged in can be seen in Figure 2. The IMU sensor sends data to the master microcontroller which then processes the data continuously which in turns generates commands for the three servo motors as seen in the block diagram in Figure 3.

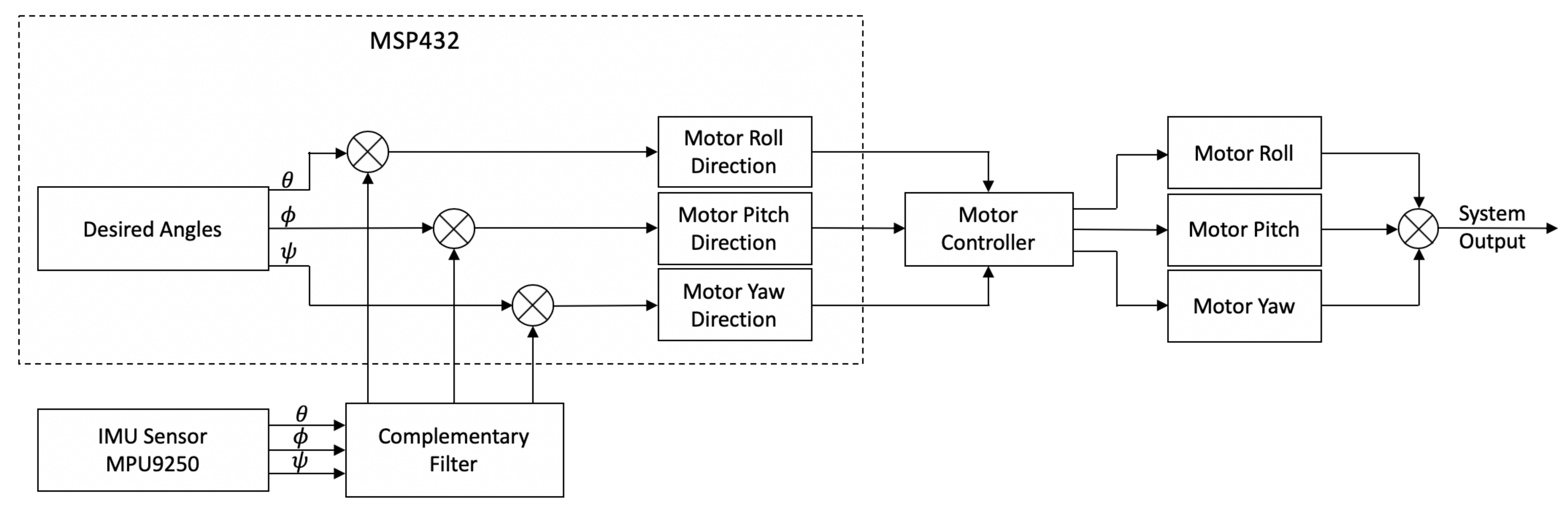

Fig. 2: Block diagram of the complete system

Sensor Fusion

Complementary filter is used to combine noisy accelerometer readings and time-varying biased gyroscope reading to obtain an estimate that better corresponds to the real world. In the frequency- and time- domain, complementary filter can be described by:

$$\theta(s) = \frac{1}{1+\tau s}A(s) + \frac{\tau s}{1+\tau s}\frac{1}{s}(s) \tag{1}$$

$$\theta(k) = \alpha(\theta(k-1) + \omega(k)h) + (1-\alpha)a(k) \tag{2}$$

where $\alpha = \tau/(\tau + T)$ and T is sampling time, $A(s)$ is the frequency domain representation of accelerometer signal, $B(s)$ is the gyroscope signal, $\theta(s)$ is the orientation with respect to inertial frame and τ is the time constant of each filter.
The filter does not work directly with the raw sensor data. Some processing has been done before the filtering. In order to obtain an Euler angle from the accelerometer trigonometry has to be used, as shown is Equation (3). The gyroscope data also has to processed to get an earth frame representation, see Equation (4).

$$\phi = \arctan\frac{a_x}{\sqrt{a_y^2 + a_z^2}}; \theta = \arctan\frac{-a_y}{\sqrt{a_x^2 + a_z^2}} \tag{3}$$

$$\begin{bmatrix}\dot{\phi}\\ \dot{\theta}\\ \dot{\psi}\end{bmatrix} = \begin{bmatrix}1 & \sin\phi\tan\theta & \cos\phi\tan\theta\\ 0 & \cos\phi & -\sin\phi\\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta}\end{bmatrix}\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} \tag{4}$$

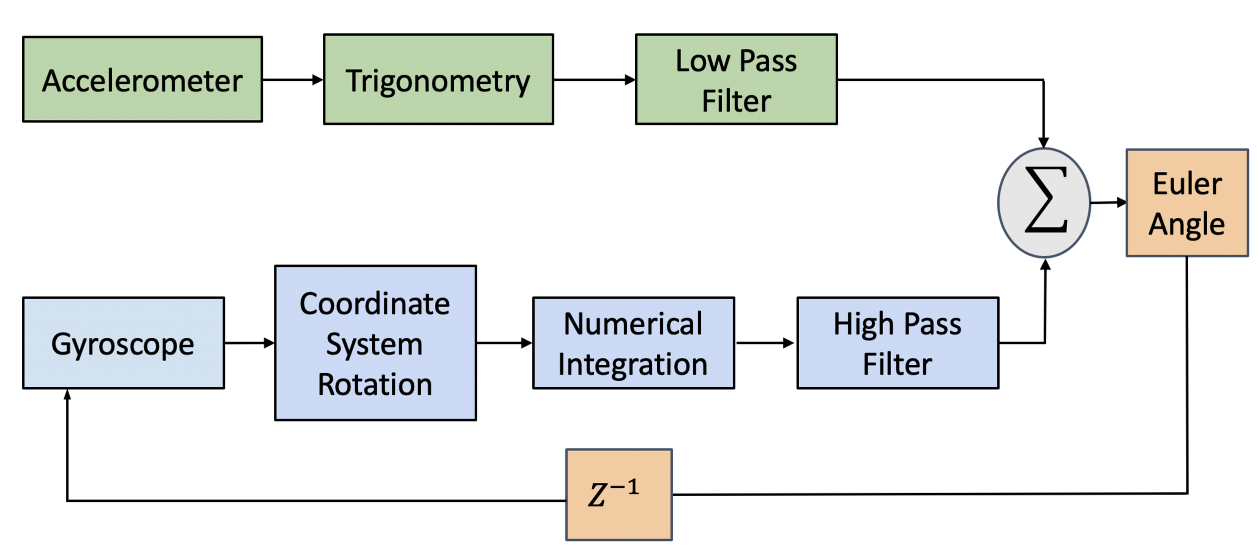

Fig. 3: Block diagram of the complementary filter, including raw data processing

Conclusion

Figure 4 highlights the noisy accelerometer data and the drift from the gyroscope data. The drift from the gyroscope data is caused by an integration error and occurs even though the bias is zero. The drift is a result of accumulating white noise of the integration reading.

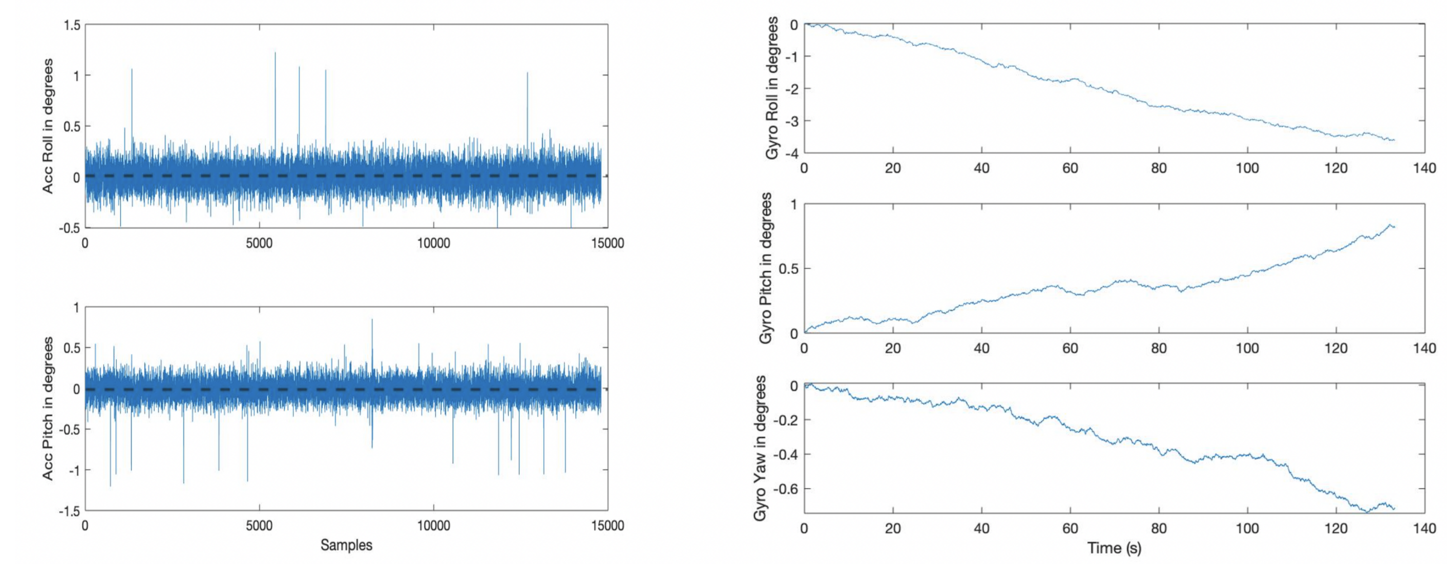

Fig. 4: Accelerometer Noise and Gyroscope Drift

By implementing the sensor fusion algorithm, the data from the gyroscope and accelerometer are merged into one signal by giving the signals different weights, according to Equation 6. For the complementary filter, the weight of the accelerometer data was set to 6% and the gyroscope was set to 94% to obtain a smooth and filtered signal as can be seen in Figure 5

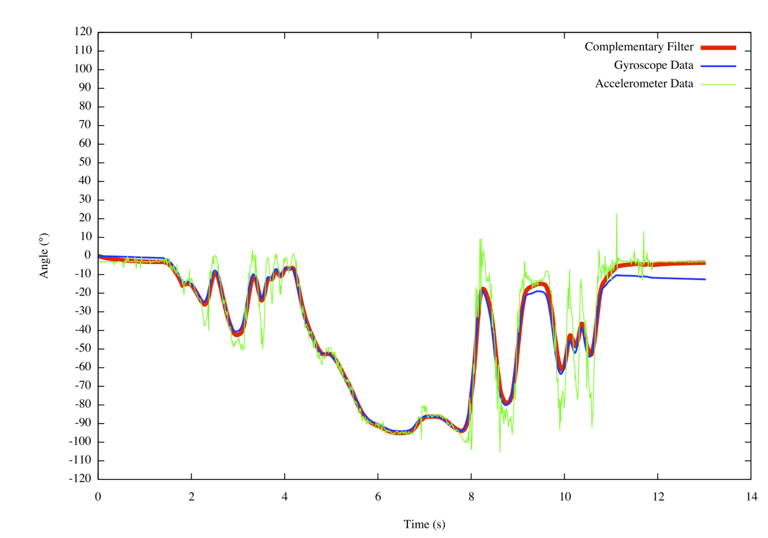

Fig. 5: Block diagram of the complementary filter, including raw data processing

List of Improvements

1. Use Quaternion instead of Euler Angles to represent roll, pitch, and yaw orientation.
2. For yaw axis, fuse gyroscope readings with magnetometer readings to get rid of time-varying drift
3. Replace servo motors with brushless DC motors for better speed and performance.
4. Stabilize for the coupled motion by taking inverse kinematics into account.