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Three Axis Gimbal Design and Its Application

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Abstract **- Nowadays everyone is trying to record the moment everywhere and wants it to be perfect. Beyond resolution, there is a desire to get steady shots regardless of the environmental conditions. The gimbal stabilization system ensures a stable image by blocking motion-related vibrations before they are transferred to the camera lens axes. Thanks to the Three Axis Gimbal, perfect images can be achieved by minimizing the vibrations while jogging, climbing or coming down stairs, cycling, or using any kind of vehicle. In short, a three-axis gimbal can be integrated everywhere a fixed image is needed. It is envisaged that gimbal stabilization system will be needed in many scientific studies in the following periods.**

The aim of this study is to present the Three Axis Gimbal mechanism. Three separate brushless servo motors are installed on each axis for absorbing unwanted movements. The gimbal is also equipped with an inertial measurement unit consisting of a gyroscope and accelerometer close to the camera mount point. The general control system and PID controller are simulated by using MATLAB and the results are shown graphically.

Keywords **- Inertial Measurement Unit, Brushless Servo Motor, Gimbal System, PID Controller.**

I. INTRODUCTION

Gimbal is the system used to prevent the shaking, one of the biggest problems in video recordings. Figure 1 illustrates a simple block diagram of the gimbal assembly. There are two or three engines on the systems called as gimbal and they aim to prevent or eliminate vibration [1]. The basic logic of this system which can minimize the vibration in video recording devices is to create a reverse motion in the opposite direction of the vibration. This reverse motion is provided by the Inertial Measuring Unit (IMU) Sensor which is placed on the camera. The IMU Sensor detects the camera movements and reports motion to three brushless servo motors positioned in line with the camera lens. The sensor detects the relative position of the camera according to the ground. Based on the predetermined optimum position, it is detected how much the optimum position defined in each movement of the camera deteriorates. The main aim is to protect this optimum position. The information received from the sensor is processed on the electronic board and transmitted as a command to the brushless servo motors, which provide smooth motion. Thus, the brushless servo motor that produces the opposite movement of the camera allows to obtain a smooth image.

Thanks to the Three Axis Gimbal; a cameraman shooting on the baseline of the field in a football match can record smooth images while running in order not to miss the event; in unmanned armed vehicles used in the defense industry, cameras mounted at the barrel level can produce smooth images which helps to achieve accurate targeting, and perfect images can be obtained in many land and air shots as well [2].

In this study, a three-axis gimbal system which uses PID controller as the general control system is presented [3,4]. In the second chapter, the components of the moving platform system are detailed. In the third chapter, the filtering of the values read from the sensor, and the control system are referred. Finally, in the fourth chapter, proposals and conclusions are submitted.

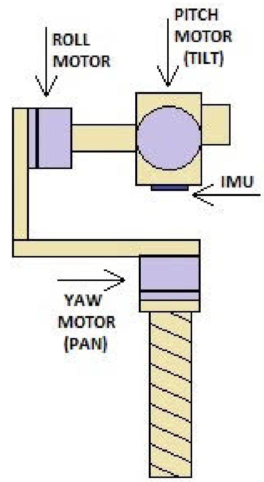

Figure 1: Gimbal block diagram.

II. MECHANICAL DESIGN

The frame carrying the system should be enduring enough to carry the camera and light enough to provide ease of use. Carbon fiber pipe is the material qualified for the conditions that we are looking for.

A six-axis IMU sensor card (which is often used in multicopter and robotic projects) which has a three-axis gyroscope and a three-axis angular accelerometer is often needed to detect camera movements. Thus, we can obtain the information such as orientation, speed, and position from a single unit.

The three axes mentioned in the Three-Axis Gimbal are shown in Figure 2. These three axes are called pitch, yaw, and roll, which carry the same name as the axes of the movement of a plane. In order to absorb the unwanted movements of these three axes, three separate brushless servo motors are mounted on these axes corresponding to the camera lens. The brushless servo motor mounted on the pitch axis absorbs the unwanted up-down movement of the camera lens, undesired right-left motion is absorbed by the brushless servo motor camera lens mounted on the yaw axis, and undesired rolling motion from one edge to the other is absorbed by the brushless servo motor mounted on the roll axis. The biaxial gimbal does not have yaw axis, so that the recorded videos are shakier than the three-axis gimbal. Because, there is no absorption in the sudden and involuntary turns towards right or left.

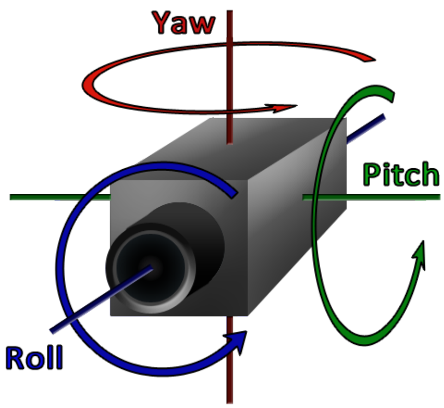

Figure 2: Gimbal axes.

Motors mounted in the line with the camera lens receive feedback from the sensor and are used to provide a rotational motion in the opposite direction of the movement to keep the camera lens steady. In this study, a brushless servo motor is preferred because of its ability to tolerate the fault quickly and smoothly.

III. SOFTWARE DESIGN

A. IMU Data Fusing

Gyros filter out accelerometer outputs to make a more accurate measurement. There are various algorithms for filtering. One of the most commonly used is the Kalman filter [5]. But it has a complicated algorithm. It makes a calculation by variable weighted average ratio and can use many different methods to calculate this ratio, but it is difficult to understand. The system works to predict new outputs by using previous outputs and measurements. In sum, the Kalman filter predicts the best value of the next output by monitoring the constantly changing inputs of the system. This filter is used in many areas such as image processing, orientation, motion tracking.

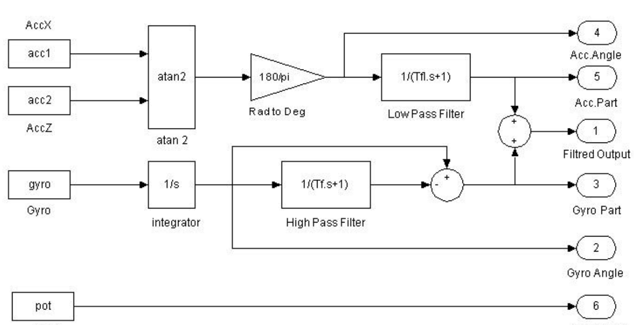

Figure 3: Complementary filter block diagram.

Block diagram of the Complementary Filter is illustrated in Figure 3. This filter is a method of taking averages of the reference data with a constant weighted average ratio [6]. It is the simplest algorithm. It is generally used for hobby purposes and in the applications to understand the operating logic. It simultaneously manages both high-pass and low-pass filters. Low pass filter filters high frequency signals (such as accelerometer in the case of vibration) and low frequency signals (such as gyroscope drift). By combining these filters with a complementary filter, a good signal can be obtained without the complications of the Kalman Filter.
Consequently, the Complementary Filter can be used instead of the Kalman Filter. Smoothing is better, and its algorithm is much simpler than Kalman. Therefore, The Complementary Filter is preferred in this study. An example of how the system is used with the Complementary Filter is shown in Figure 4. A graphical comparison between the signal filtered by the Complementary Filter and the true angle is shown in Figure 5.

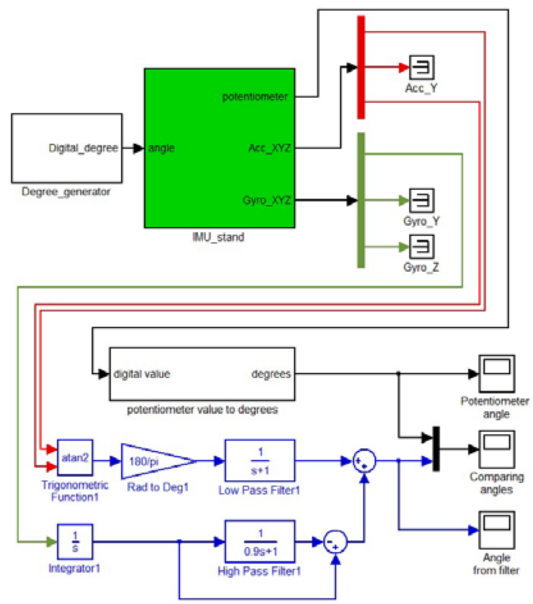

Figure 4: Complemenraty filter with IMU.

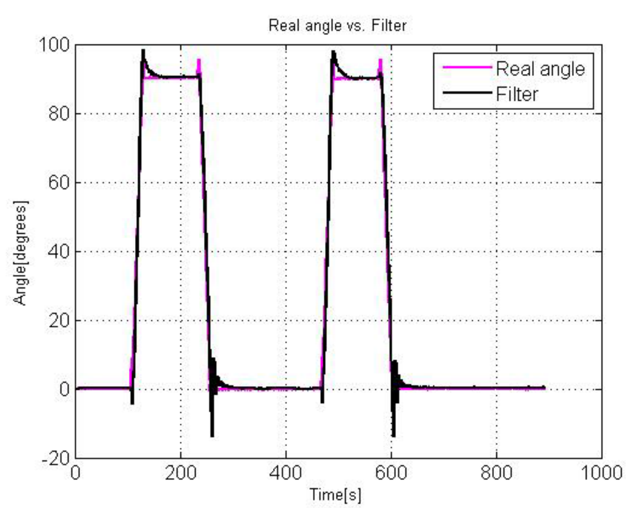

Figure 5: Complemenraty filter output and comparison of actual value.

B. Controller Design

Although there are a variety of modern techniques for controlling gimbal systems, PID controllers are preferred because of their low cost, ease of implementation and high performance.

The block diagram in Figure 6 is a feedback mechanism controller commonly used in PID (Proportional-Integral-Derivative) industrial control systems. In 1942, Ziegler and Nichols presented two classical methods for determining the parameters of the PID controller [7]. These methods are still widely used in the original form or in some modifications. The methods are based on determining some properties of the process dynamics.

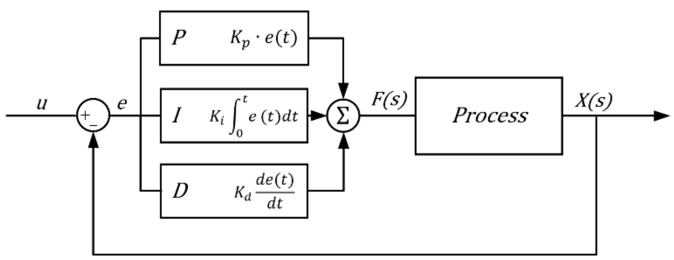

Figure 6: PID block schema.

The PID control system continuously calculates the error value as the difference between the desired value and the measured process variable. The controller tries to minimize the error over time. In doing so, sets a new value (determined by a weighted sum) for a control variable, such as power fed to a control valve, a dashpot, or a heating element.

Transfer function of PID controller:

$$G(s) = K_P + \frac{K_i}{s} + K_d . s \quad (1)$$

K_P : proportional gain,
K_i : integral gain,
K_d : derivative gain,

As shown in Table 1, the proportional gain (Kp) reduces the rise time and the steady-state error (but never removes it). The integral gain (Ki) removes the steady-state error but can worsen the transient response. Derivative gain (Kd) increases the stability of the system, reduces overshoot and improves the transient response.

Table 1 : Effect of PID gains on system

Controller Response	Rise Time	Overshoot	Settlement Time	S-S Error
K_p	Decreases	Increases	Changes Slightly	Decreases
K_i	Decreases	Increases	Increases	Removes
K_d	Changes Slightly	Decreases	Decreases	Changes Slightly

Figure 7 shows the PID controller designed with MATLAB Simulink, where all controller coefficients are set. The program is started and the necessary parameters are obtained by PID tuning [8]. Once Simulink is running, we can see the signal shown in Figure 8.

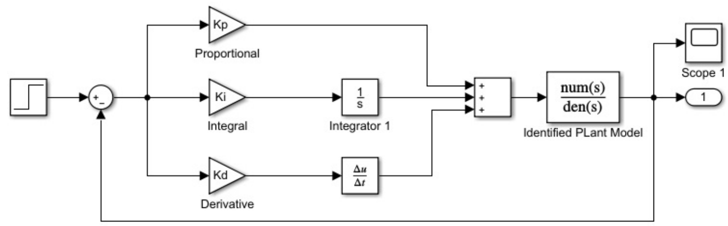

Figure 7: Design of PID control system in MATLAB Simulink.

Figure 8: Output signal in case of PID

IV. CONCLUSION AND RECOMMENDATION

In this study, three-axis gimbal system is introduced. Under the title of mechanical design, the basic elements of the gimbal system are introduced. Under the software design title, gimbal control system, sensors and sensor information filtering are mentioned. PID control is used to stabilize three axes of this platform model. The PID control system is simulated in the MATLAB / Simulink environment and the results are shown in the diagram. PID control is often preferred because of its high performance, but control methods such as PI, PI2, optimal control, and compensator can also be used in two-axis and three-axis gimbal systems. Brushless servo motors are used in the system as motion providers. Step motor or servo motor may be preferred instead of brushless servo motor. The error signal is detected by using the IMU sensor while the Complementary Filter is preferred for sensor filtering. Besides Complementary and Kalman filters; the Mahony Madwick Filter, which is used to calculate the quaternion with the information received from the sensor, may also be preferred. This system is being implemented and it is targeted to be used in military applications carried out within our company.

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