

## Accelerometers and Gyroscopes

### Introduction

In space navigation, tracking a device's position requires sensors to measure its velocity and orientation. Accelerometer sensors, which is designed to measure the acceleration and tilt, and gyroscope sensors, which is to measure angular velocity and orientation, are used in different devices including smartphones, gaming consoles, crafts, robots for motion monitoring, position tracking, etc. Many people combine the two sensors to create an inertial measurement unit (IMU) for more accurate position detection. This technical review summarizes some commercially available IMU sensors, explains the underlying technology, and provides methods of implementation for ideal operation.

### Commercial Applications of IMU sensors

Due to demanding requirements on knowledge of exact position, an IMU is needed rather than accelerometers or gyroscopes alone. A 6 degrees of freedom IMU digital combo board provided by Sparkfun is currently a good choice. This board offers users the ability to select acceleration ranges, the upper and lower limits of what the accelerometer can measure, stretching from  $\pm 2g$  (acceleration of gravity) to  $\pm 16g$  [1]. The maximum angular velocity the gyro can measure is 2000 degrees per second [2], which is a very large range among IMUs. Besides, 6 degrees of freedom means that both the accelerometer and gyros can sense three possible axes (x, y, and z). With this board, almost all human motions can be sensitively detected. Additionally, its tiny size benefits small devices plus a 3.3VDC power requirement, which is lower than most IMUs on the catalog list [3]. This IMU board sells for \$39.95 [3].

Another competing design is the triple axis accelerometer and gyro breakout – MPU-6050, also designed by Sparkfun. Compared to the combo board, the MPU-6050 not only has the same selectable ranges for the accelerometer, but its gyroscope also has a full-scale range with the minimum  $\pm 250$  degrees per second (dps) and maximum  $\pm 2000$  dps [4]. A gyroscope can get the best possible sensitivity by making sure that its maximum range exceeds expecting measurements but not much greater than that. Same as the combo board, MPU-6050 is a combination of a 3-axis gyroscope and a 3-axis accelerometer together with an onboard digital motion processor capable of processing complex 9-axis algorithms [5]. Moreover, MPU-6050 features a temperature sensor, which is very useful when compensating for drift. A 2.3 – 3.4 VCD power requirement adds one more advantage for this design [3].

### Technology of Accelerometers and Gyroscopes

### *Accelerometers*

Some accelerometers use the piezoelectric effect [6]. They contain microscopic crystal structures that get stressed by accelerative forces, which outputs electrical charge and then causes a voltage to be generated. Another way to do it is by sensing charges in capacitance [6]. Accelerometers contain capacitive plates internally. There is a capacitance between two plates with a certain distance. If an accelerative force moves one plate relative to the other one, the capacitance between them changes. Then add some circuitry to convert from capacitance change to voltage change, and the acceleration can be determined.

### *Gyroscopes*

Precession is a change in the orientation of the rotational axis of rotating bodies. When a force is applied to the shaft of a spinning gyroscope, the gyroscope will start rotating around a secondary axis in a direction perpendicular to the applied force [7]. Gyroscope sensors can detect these gyroscope precession movements and convert them into a voltage that a processor in a device can utilize to determine orientation based on changes in angular velocity. The way microelectromechanical system (MEMS) gyroscope detects angular velocity is by measuring a small amount of resonating mass shifted inside the gyroscope sensor as the angular velocity changes [8]. This movement is converted into very low-current electrical signals that can be amplified and read by a host microcontroller.

## **Implementation of Accelerometers and Gyroscopes**

The primary hardware connections to use accelerometer and gyroscopes are communication interface and power. Accelerometers can communicate over an analog, digital or pulse-width modulated connection interface [6]. Accelerometers with an analog interface can show accelerations through voltage levels. An analog to digital conversion on a microcontroller can be used to read these values. Compared to analog accelerometers, digital accelerometers are more expensive because they tend to have more functionality. They can either communicate over serial peripheral interface (SPI) or I<sup>2</sup>C communication protocols. However, accelerometers with digital interface is less susceptible to noise than analog ones. Pulse-width modulation (PWM) accelerometers are the least commonly used among three. They output data over PWM output square waves with a fixed period, but the duty cycle will vary with changes in accelerations [6]. Same as accelerometers, gyroscopes have an either analog or digital communication interface. According to [8], one limitation of a digital interface of gyroscopes is max sample rate. I<sup>2</sup>C has a maximum sample rate of 400Hz. SPI, on the other hand, can have a much higher sample rate [8]. Accelerometers and gyroscopes are generally low power devices. With micro or milli-amp current range, 5V or less supply voltage, and power saving or sleep modes, accelerometers and gyroscopes are well suited for battery powered applications.

## References

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