Motion Sensors Gaining Inertia with Popular Consumer Electronics

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Introduction

Inertial sensors are quickly becoming essential components in consumer electronics, enabling features that enhance the operation of an ever expanding list of products such as laptop computers, MP3 players, digital cameras, television remotes, game controllers and mobile phones. Enabling this trend are recent innovations in Micro-Electro-Mechanical Systems (MEMS) silicon sensors; in particular, accelerometers and gyroscopes. While these have commonly been used as industrial and automotive components, engineers are overcoming the obstacles that have prevented the introduction of motion sensors into handheld consumer products. Specifically, advances have been made that reduce cost, size and power consumption.

This paper discusses the use of inertial sensors in a few handheld applications, provides a brief technology overview of accelerometers and gyroscopes, and presents the advantages of using InvenSense's integrated dual-axis gyroscope as a standalone solution, or for supplementing multi-axis accelerometers for a more effective motion sensing solution.

Applications

For years, consumers have been reaping the benefits of MEMS inertial sensors in automotive applications for airbag deployment, dynamic stability control, rollover protection and GPS navigation. Now these sensors are showing up in a variety of handheld electronics. Here are just a few applications in which these sensors are being used:

Image and Video Stabilization

The slightest hand movements, especially when combined with zoom and slow shutter speeds, can make it impossible to take sharp pictures or stable video. Gyroscopes are becoming required components in compact digital cameras, video camcorders, telephoto lenses, and binoculars, for measuring and counteracting hand jitter by mechanically repositioning the lens or image sensor. In cameras, this produces crisp, high quality images. Image stabilization using gyros is quickly becoming a standard feature in digital still cameras and will be included in high resolution camera phones in the next several months.

Drop Protection

Recently IBM launched an active protection system for its laptops to protect the hard drive from damage due to a fall; other laptop designers quickly followed suit. Many of today's handheld products are starting to incorporate hard drives, including music players like iPods, digital cameras, and mobile phones. Because they are handheld, and more prone to jolts and drops, there is a higher risk of the drive failing and erasing stored data. Accelerometers are currently being used to prevent crashes by detecting free-fall. Once a fall is detected, the head of the disk drive is parked before the device hits the ground, ceasing read and write functions and keeping stored data safe. While accelerometers provide rapid detection of free-fall for an object that is not spinning, they can be easily deceived by one that is. As this market evolves, more intelligent drop sensing systems will be developed, incorporating gyroscopes to provide even faster detection of potential crashes.

Motion Control

There have been many recent press announcements about products, such as mobile phones and television remote controls that include motion sensors for navigating menus. As the core communications technology becomes increasingly compact, the size of a device is limited by the space required for its user interface. Use of hand motions, such as tilting left, right, forward and backward, can allow the device to be smaller by reducing the number of buttons that are necessary.

In phones, these sensors enable other applications, many of which have already been implemented, including automatic portrait or landscape image selection based on the phone's orientation, gesture-based dialing and text writing, interactive gaming where actual body motions are used, and a pedometer function tied to music for measuring distance while synchronizing with a musical "beat box".

In the next few years, as MEMS inertial sensors continue to become smaller, consume less power and decrease in price, applications and content for motion recognition will evolve to become a standard feature in a multitude of handheld consumer products.

Accelerometers

Accelerometers react to many types of movement, including linear and centripetal acceleration, gravity and vibration. Different algorithms can be used to extract measurements of tilt, position, vibration, shock and free-fall. Today, inexpensive accelerometers are abundant from many suppliers; these were the first MEMS components used in consumer electronics to provide basic motion recognition capabilities. Because of their range of uses and low cost, engineers usually consider accelerometers first when designing a motion sensing device; however, experienced designers understand that being sensitive to so many inputs has serious consequences. Typically, only one of these inputs is desired at a time, but accelerometers deliver the sum of all of them. Extracting a single piece of information is often impossible without the addition of other sensors.

While there are a variety of types of accelerometers, the most common design for handheld consumer applications uses differential capacitance transducers. The design of this type of accelerometer typically includes a suspended proof mass whose motion responds to a force exerted on it in a particular direction. The displacement is measured to determine acceleration and is delivered as an analog signal. The output is then externally converted into a digital signal, which is used to compute the appropriate application input and response (Figure 1).

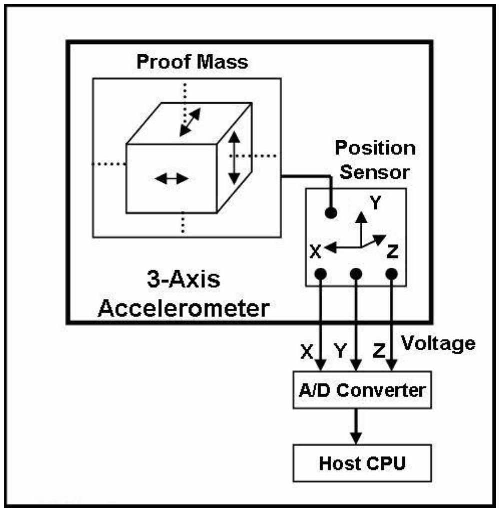

Figure 1

Limitations

While accelerometers provide basic motion sensing for simple applications, there are limitations that affect their operation and performance in more complex applications.

Linear Movement

Accelerometers sense linear motion by measuring the shift in the proof mass when a force is applied. This output can be integrated once to provide velocity, and again for position.

However, when the accelerometer is stationary and an axis of the accelerometer is vertical relative to the Earth, the output of that axis is not zero; instead, it will be one *g*, due to the displacement of the proof mass by gravity. When the accelerometer is rotated 90 degrees with the sensitive axis horizontal to the earth, the output will be zero. Tilting the accelerometer at an angle will result in a measurement of gravity along each axis, related to the tilt of the device. In each of these cases, the accelerometer is stationary, but is producing an output indistinguishable from the actual dynamic motion.

When used as a linear acceleration sensor in navigation systems or user interfaces, the corruption of the signal due to gravity is devastating. When the output signal is integrated twice to provide linear position, the final error due to gravity will be amplified. This error can be corrected using gyroscopes and well known algorithms.

In more advanced systems, the accelerometer and gyroscope are first combined to retrieve tilt. The offset due to gravity can then be calculated, and subtracted from the accelerometer; whatever is left is uncorrupted linear acceleration.

Tilt

In applications where the accelerometer is used as a tilt sensor, other algorithms will attempt to isolate the signal due to gravity and use that as an orientation reference. However, this signal can only be isolated when the accelerometer is motionless; when there is movement, the output will be corrupted by linear and centripetal accelerations. This makes any tilt-based user interfaces or games extremely unstable. A common compromise is to low-pass filter the accelerometer to isolate tilt. This makes a correct assumption that, in human movement, linear accelerations will be transient, and can be filtered out. Unfortunately, it also makes the incorrect assumption that tilting movements are all slow, and as a result faster changes in orientation will also be filtered out. A low-pass filtered accelerometer makes an extremely poor tilt sensor for user interface control.

A better solution is to combine the accelerometer with a gyroscope; this provides a rapid, accurate, high bandwidth tilt sensor. For applications in which dynamic tilt is desired, but the fixed reference of gravity is not necessary, gyroscopes can be used without accelerometers.

GYROSCOPE

Gyroscopes, also called angular rate sensors, measure how quickly an object rotates. This rate of rotation can be measured along any of the three axes, shown in Figure 2: X (roll), Y (pitch) and Z (yaw).

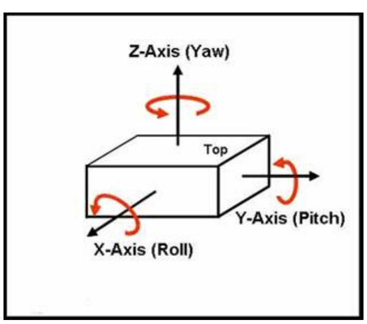

Figure 2

The output of a gyro is a voltage proportional to the angular rate of rotation measured in millivolts per degree per second. As with accelerometers, this output is externally converted to a digital signal, which is used to compute and process the appropriate application input and response.

Until the recent release of InvenSense's integrated dual-axis gyroscope, discussed below, all other gyroscopes were single axis and were specific for measuring rotation along an axis parallel to the circuit board, or an axis perpendicular to it. The former is referred to as an "X-axis" gyro, but can easily be a Y-axis gyro when mounted along that axis. Use of an X-axis gyro has been popular for measuring hand motion for image stabilization in digital cameras. In this case, two gyros, mounted perpendicular to each other, are required to measure hand jitter along the X and Y axes. While this is effective, the use of two gyros along with their many corresponding external components results in a space-consuming and costly solution for small handheld devices. A Z-axis gyro can be used to measure the rate of rotation around an axis perpendicular to the circuit board. By mounting a Z-axis gyro on its side, it may also be used to measure the X or Y axis. However, Z-axis gyros have not been popular for measuring X and Y rotation in handheld products due to size limitations and manufacturing costs and design complexities associated with sideways mounting.

InvenSense's Dual-Axis Gyroscope

MEMS technology has allowed gyroscopes to shrink to small sizes acceptable for handheld devices. Recent patented advances by InvenSense in MEMS technology used to develop a novel gyroscope architecture have resulted in the world's first, ultra compact, dual-axis gyroscope with integrated electronics designed specifically for mobile applications.

The design of a gyroscope is inherently more challenging than a MEMS accelerometer due to the need for generating oscillating or resonating mechanical motion with minimal off-axis motion. This is reflected by only a few manufacturers offering production-ready miniature gyroscopes for handheld products and numerous manufacturers offering accelerometers.

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Technology

InvenSense spearheaded the development of a third-generation MEMS gyro technology that overcomes the current technology constraints to meet the strict needs of mass market consumer electronics. The company's robust gyroscope platform takes advantage of major innovations in MEMS design and fabrication, integrated circuit design and wafer-scale packaging to achieve the world's smallest, lowest-cost, dual-axis gyro for the motion sensing market.

InvenSense's MEMS gyro is designed to simultaneously sense both the rate of rotation in-plane about the X and Y axes, by using two bulk silicon elements with unique vibrating mass configurations resulting in a guaranteed-by-design vibration rejection and high cross-axis isolation.

InvenSense's gyroscope includes the integrated electronics necessary for application-ready functionality. It incorporates X- and Y-axis low-pass filters, pins for user definable high-pass filters, user controlled integrated switches for resetting the high-pass filters and an EEPROM for on-chip factory calibration of the sensor. Factory trimmed scale factors eliminate the need for external active components and end-user calibration.

Advantages

InvenSense's gyroscopes have numerous features and performance advantages over competing gyroscopes for handheld products.

Size

With handheld products integrating more features and shrinking in size, eliminating components and decreasing component sizes are a constant focus of manufacturers. The most popular gyro solution for motion sensing in a handheld product today consists of two single-axis gyros in addition to numerous required external components. InvenSense's first gyroscope is available in a tiny 6x6x1.5 mm, QFN package or as Known Good Die (KGD) and integrates many external components resulting in a footprint that is over 5X smaller than the competition.

System Integration

Four of the so-called "six degrees of freedom" in inertial sensing are well served by commercially available 3-axis accelerometers and Z-axis gyroscopes. However, the last two degrees of freedom, X and Y rotation, have eluded a cost-effective solution until now.

InvenSense is unique in its ability to integrate other system components with the silicon die of the gyro to produce single chip system-in-package (SIP) solutions for addition space and cost savings. In addition, InvenSense is capable of producing an inertial measurement unit (IMU) that incorporates all six degrees of freedom on a single silicon die. This means tremendous flexibility and opportunities for companies engaged in designing ever smaller consumer products packed with increasing functionality and intelligence.

Reliability

Other gyro devices use piezo-type designs that are highly susceptible to shock, vibration, temperature and humidity. InvenSense's gyroscopes use bulk silicon technology which is significantly more robust and inherently more resistant to such problems.

Cost

InvenSense's gyroscope architecture integrates many of the typical external components used by today's piezo-type gyroscopes. This combined with using proprietary wafer-scale packaging along with silicon MEMS, results in InvenSense having the most cost-competitive dual-axis gyro solution for the consumer electronics market.

Complete Motion Sensing Solution

Gyroscopes and accelerometers are already widely used together in military and commercial applications for GPS navigation and stability control systems in spacecraft, airplanes, missiles and automobiles. Gyros provide precise rotation measurements and supplement the accelerometer by filtering out the noise caused by gravity. As applications for handheld products become more intelligent in the near future, the need for a 6-axis solution utilizing a gyro will become necessary.

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Use of InvenSense's gyro, with its size, reliability, and cost advantages, in conjunction with a low-cost three axis accelerometer, will provide the best solution for the handheld market.

Conclusion

MEMS technology innovation continues to drive and enable new components that are smaller, more reliable, efficient, and lower in cost, benefiting consumers with a wide variety of new products and applications. This is especially true for motion sensors in handheld products. InvenSense's patented MEMS and dual-axis gyro technology positions it to be one of the leading drivers and suppliers of motion sensors for current and next generation mobile applications.

About the Authors

Daniel Goehl is the Director of Sales for InvenSense Inc. He has held senior level sales and marketing management positions at several successful startup companies selling into the wireless market. He has a degree in Economics from the University of Illinois.

David Sachs is a Systems Application Engineer at InvenSense. He has designed many gyroscope-based systems at InvenSense and MIT's Media Lab. His work ranges from low-level algorithmic development and multi-sensor fusion of gyroscopes, accelerometers, and magnetic field sensors, to complete motion-sensing systems including image stabilization systems, user interfaces, and gaming devices. He has a MS from MIT, and a BA from Oberlin College.