Expanding the Functionality of Mobile Applications with Magnetic Gyroscopes

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Being able to determine a device's position and movement is becoming a standard feature in many portable systems. Systems such as cell phones and tablets use the 6-axis data from accelerometers and magnetometers to enable key functions that make consumer electronics interfaces easier and more intuitive to use.

Next-generation devices are moving to 9-axis sensor fusion employing gyroscopic capabilities to further improve the user experience. For example, a health monitor can track users more accurately when it can differentiate between activities like walking, swimming, and running. Gyroscopic data also enables new interface capabilities, such as gesture recognition, where a user can flick his or her wrist to bring up the display.

Many consumer electronics devices can benefit from 9-axis sensor fusion (see Figure 1). For example, cell phones, gaming systems, health monitors, and wearable electronics could implement high value- added functions such as three-dimension gesture recognition, relative positioning to other users, and motion tracking. To achieve this, devices need 9-axis sensor data and the ability to process it efficiently.

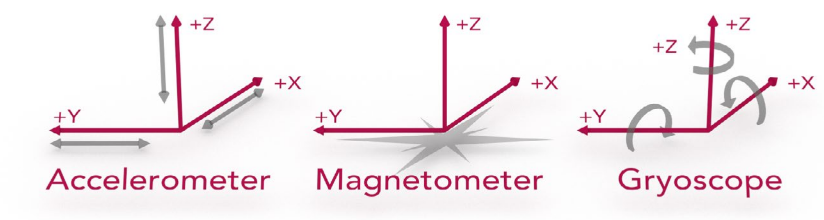

Figure 1

Note that many of these systems do not require the same level of precision that a fighter jet needs to stay in flight. Rather, they need a cost-effective 9-axis sensor fusion implementation that matches the needs of consumer applications to improve the user experience. With the availability of new MagGyros, such as the KMX62G from Kionix, developers can use 6-axis sensors (accelerometer + magnetometer) to provide the equivalent of 9-axis output (accelerometer + magnetometer + gyroscope) while reducing energy consumption by as much as 90%.

9-AXIS SENSOR FUSION

Using 9-axis sensor fusion—data from an accelerometer, magnetometer, and gyroscope—systems can accurately position themselves in the world, including inclination and orientation as well as changes in position and rotation (see Figure 2). Effectively, sensor fusion uses multiple sensors to fill in the blind spots of individual sensors.

Accelerometers

An accelerometer measures acceleration in 3 axes. It is important to note that gravity is a form of acceleration, and so an object at rest still has a downward acceleration. This fact enables an accelerometer to determine how a system is oriented relative to “down.”

This information can also be used to determine how level a system is. Many handheld and portable devices use orientation to adjust the display to match how the user is holding the device. Devices commonly using this functionality include cell phones, tablets, and laptops.

Another unique feature of an accelerometer is the ability to tell if a device has been dropped. For example, when a laptop is resting on a table, it detects 1 G. However, if the laptop is knocked off the table, it will detect 0 G as it falls to the floor (similar to how zero-gravity is simulated by putting a plane into freefall). This enables a system to detect if it is falling and at imminent risk of collision. In the case of a laptop, the system can proactively park the hard drive head in a safe position to prevent damage to the drive or data.

Many other uses have been developed for accelerometers, including increasing power efficiency. Consider that a fitness tracker that has not moved in a few minutes is likely not being used. The device can then power itself down. This simple use case can substantially improve battery life across a wide range of applications.

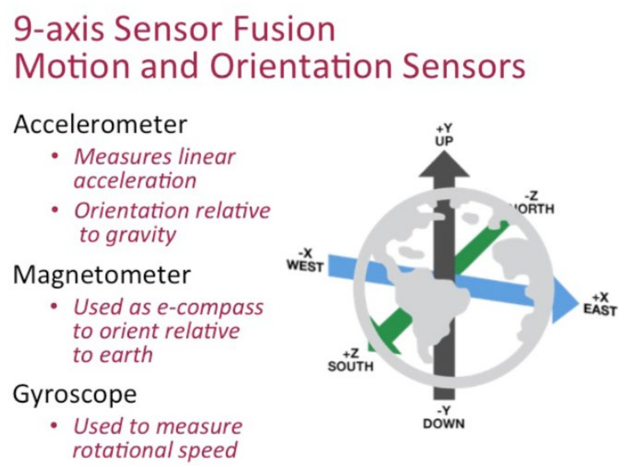

Figure 2

Magnetometers

A magnetometer measures magnetic fields. It can be used in a compass to identify the Earth’s magnetic field. By analyzing the magnitude, direction and rate of change of the detected field, a magnetometer can be used to find the direction of magnetic north.

As a standalone sensor, however, a magnetometer is typically unable to identify the direction of magnetic north. A traditional compass uses a magnetic rod with a bearing that restricts the rod to align in one dimension; proper leveling of the housing allows the user to best align the rod with magnetic north. In an electronic magnetometer, 3-axis of sensing is used to compute the direction and magnitude of the magnetic field. Any tilt between the magnetometer axes and the measured signal will cause error in the reported direction of the field.

A handheld device can use both an accelerometer and magnetometer to determine magnetic north. This is achieved by identifying the tilt of the device using the accelerometer and using this information to supplement the reading from the magnetometer.

Gyroscopes

An accelerometer at rest on a desk can sense that the device is at rest. However, if you rotate the system with the accelerometer at the center of the rotation, the accelerometer will not be able to detect the movement. This is effectively a blind spot for the accelerometer. If the system has access to a gyroscope, the gyroscope can detect the rotation.

Unfortunately, implementing gyroscopic technology is difficult to justify for many applications. Of the three types of sensors, gyroscopes are the largest and most expensive. Although the sensor provides useful information, too often the cost, size, and/or power consumption of a physical gyroscope exceeds the value it represents. For these reasons, developers have often had to limit position and orientation functionality to the 6-axis data provided by an accelerometer plus magnetometer.

THE KMX62G MAGGYRO

Today, advances in software algorithms and low-noise, low-latency sensors make it possible to simulate gyroscopic output using data from only an accelerometer and magnetometer. This is the approach used in MagGyros, where the system computes a device's rotational direction and speed based on knowledge of its previous position. In other words, when a system can track orientation over time, it can extrapolate rotational data.

To enable developers to bring gyroscopic capabilities to a wide range of new applications, Kionix offers the KMX62G MagGyro. The KMX62G takes Kionix's KMX62 accelerometor/magnetometer and enhances it with industry-leading sensor fusion software and auto- calibration algorithms (see Figure 3). This makes the KMX62G more than just an accelerometor/magnetometer. It is the industry's first highly accurate gyroscopic emulator, providing 9-axis positioning capabilities.

Figure 3

Power	Package and Interface	Performance Characteristics	Embedded Functionality	Algorithms	Other
•Scalable power consumption <=1μA standby •**Accel only power <=150μA, mag/accel power <= 395μA** •**9-axis output with total power consumption of 940μA**[1] •**1.7-3.6V Vdd**	•3x3x0.95mm •LGA package •16-pin •9-Axis output[2] •Digital I^2C up to 3.4MHz •**Communication down to 1.2V**	•User selectable ± 2g, 4g, 8g, **16g** accel range •±1200μT mag range •Superior offset stability •Up to **16-bit** resolution •Excellent combination of thermal, shock, and reflow performance	•384 bytes FIFO/ FILO buffer with watermarking •Digital high-pass filter outputs •Internal voltage regulator •Accel self-test •**Mag self-test**	•User-configurable motion wake-up function •**Magnet field change detection and notification** •**Freefall detection**	•Synthesized gyro output[2] •Magnetometer algorithms for auto-calibration and MI rejection •**Dynamically adjustable power and noise values for optimized system performance**

[1] Includes power consumed by atmel atuc128l4u operating at 48 mhz executing at 3mips to produce gyro output
[2] via sensor fusion software

THE KMX62G OFFERS SEVERAL KEY BENEFITS TO OEMS

- **THE RIGHT LEVEL OF ACCURACY:** Because it estimates rather than directly measures rotational speed, the accuracy of a MagGyro is not as high as that of a physical gyroscope. However, gyroscopic accuracy comes into play most often when distance is involved, such as when flying a plane: being off by one degree over 100 miles can put you far off course. Close activities such as gesture recognition, on the other hand, can tolerate relatively large errors. Thus, consumer electronics applications focused on the user experience do not require the scientific levels of accuracy of a physical gyroscope.
- **POWER:** A physical gyroscope is always resonating, which means it continuously draws power. Typically, a physical gyroscope operates at 2.5 V or greater and consumes 4000 to 7000 µA (see Figure 4). Note that this is for the gyroscope alone.

  With the KMX62G MagGyro, the accelerometer + magnetometer sensors consume 450 µA. Even when the power required for the microcontroller executing the software algorithms is taken into account (~500 µA), the entire MagGyro operation is less than 1000 µA. Thus, the KMX62G achieves 5X to 10X better energy efficiency compared to a physical gyroscope.

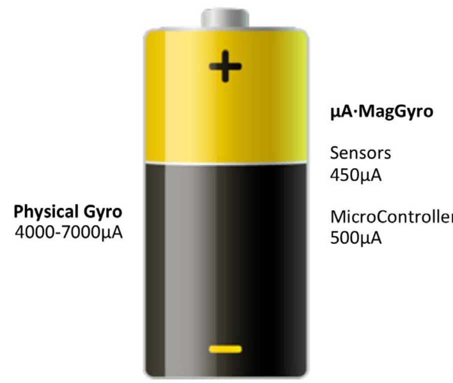

Figure 4

- **START UP TIME:** Because they consume so much power, systems often turn off the gyroscope as often as they can. However, a physical gyroscope can take between 50 and 100ms for the output to stabilize. Thus, a power-efficient implementation with a physical gyroscope results in slow responsiveness that can negatively impact the user experience.

  From startup, the KMX62G takes approximately 15-20ms to start outputting 9-axis data. This arises from the need to collect first samples and process them. Once the data pipeline has been established, this delay effectively goes away. However, for many applications, the low energy draw of the KMX62G enables the device to be running most of the time, eliminating any start up delay for those applications or use cases where this matters.
- **COST:** The KMX62G can be implemented for substantially less cost than an equivalent 9-axis solution with a physical gyroscope. It provides an excellent intermediate solution between not having a physical gyroscope and offering features based on 9-axis positioning.

PERFORMANCE AND QUALITY

The performance of a MagGyro is highly dependent upon the quality of its components. Consider that in order to simulate a gyroscope, the MagGyro algorithms use the sensor data from both an accelerometer and magnetometer. Noise in either sensor will quickly erode the accuracy of the gyroscopic calculations. In addition, the same sensor data is then used in sensor fusion algorithms to compute 9-axis positioning. This means the error from these sensors may be compounded. Thus, low noise performance in both the accelerometer and magnetometer is essential to achieving accuracy.

Synchronization between the sensors is also critical. If the reading for the accelerometer is associated with a reading from the magnetometer captured at a different time, an error can result in the MagGyro output. Designing a tight circuit to ensure accurate synchronization of these sensors can be difficult when using external components. To simplify design, many designers prefer to eliminate synchronization issues by using a single component like the KMX62G that combines the accelerometer and magnetometer together. In addition, the latency of magnetometers can vary depending on their underlying technology. The magnetometer in the KMX62 has one of the lowest latencies on the market. This enables the accurate synchronization of data between the accelerometer and magnetometer and results in high performance of Kionix's MagGyro solution.

The final piece of the KMX62G MagGyro is the software implementation of the simulated gyroscopic algorithms. There are numerous functions that make up these algorithms, and the quality of the implementation determines the system's overall performance and, in consequence, the user experience. These algorithms are implemented on a host processor or sensor hub. An Application Programming Interface (API) is provided to simplify product design. Supported platforms include Qualcomm's Snapdragon and Atmel's AVR UC3 and ARM-based SAM D20. The KMX62G is also certified for Windows 8 and 8.1.

Accurate MagGyro algorithms are fairly complex in their implementation. For example, averaging of signals reduces noise. However, averaging takes time, impacting latency and responsiveness. To maximize accuracy, Kionix utilizes adaptive software that dynamically adjusts averaging. When the system is moving quickly and small errors aren't as noticeable, averaging is reduced to improve responsiveness. Similarly, when movements are smaller and responsiveness is less important, averaging is increased to improve accuracy. This provides an optimal user experience based on how the system is currently being used.

This focus on human use cases is part of the value Kionix offers with its KMX62G MagGyro. It excels in human perception and user experience applications. It does this by trading off a little of its performance and in return enhances the user's experience. By designing its algorithms for a high quality experience, Kionix enables the KMX62G to bring new functionality cost-effectively to a whole new realm of applications.

One other factor to consider when evaluating sensor fusion algorithms is the data processing requirements. Key metrics to consider are MIPS, code space, and RAM space. Algorithms that consume too many system resources can actually add cost to the system. If they place too much of a load on the host processor or sensor hub, they may even impact the primary function of the device and degrade the overall user experience. In terms of software loading, the MagGyro algorithm requires less than 3 MIPS. It can run on systems with as little as 128 KBytes of Flash and 32 KBytes of RAM. This is all that is needed for sensor calibration, magnetic anomaly rejection, sensor fusion and synthetic gyroscope calculations. This is a reasonable load for the value of being able to provide 9-axis data including gyroscopic functionality.

With the availability of the KMX62G MagGyro, there is now a cost-effective option for next-generation consumer electronics systems that can benefit from gyroscopic capabilities. By trading off an appropriate level of performance, the KMX62G offers lower cost, higher power efficiency, and a smaller footprint compared to systems based on physical gyroscopes.■