



Bringing Advanced Sensor Functionality to Consumer, Embedded, and Industrial Applications

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Sensors play a key role in enabling modern electronics to more intelligently act within their environment. A cell phone, for example, uses sensors to detect when a user is holding the device to his or her ear so it can save power by turning off the display. Through sensor fusion technology, where data from multiple sensors is used in combination, even more advanced features can be enabled.

Sensors are popping up everywhere. A wide range of consumer electronics devices make extensive use of sensors, including smartphones, tablets, and gaming equipment. To capitalize upon the growing gaming market, set-top box vendors are beginning to integrate sensor-based gaming capabilities into their systems. Perhaps the largest growth sector for intelligent sensing is the Internet of Things. This market is focused on extending awareness and connectivity everywhere and includes everything from wearable devices such as pedometers and portable medical equipment to complex industrial systems that can self-monitor themselves and their environment.

The benefits of embedding sensors are apparent, but designing in sensors presents multiple challenges to OEMs. Some sensors must be continuously monitored, putting a load on the system's main applications processor. Data processing algorithms are often compute-intensive as well. Developers must minimize device size and power consumption. Finally, sensor design and algorithm development requires expertise an OEM may not have readily available in-house.

SENSOR HUBS

For many applications, a dedicated sensor hub provides a compact way to integrate sensor monitoring and analysis capabilities in a cost-effective manner that minimizes power consumption. As its name states, a sensor hub has the ability to accept inputs from multiple sensors such as accelerometers, gyroscopes, magnetometers, and pressure sensors. It also has an integrated MCU to handle real-time algorithm processing.

For existing systems, baseband and applications processors are power hungry components often called upon to do many tasks. Consider the use case of a cell phone running a video call with full video to the display while managing a cellular connection, streaming audio to a headset via Bluetooth, providing Wi-Fi hotspot capabilities to a tablet, and tracking the device's GPS location. In many instances, it is advantageous to offload the real-time monitoring of sensors for features like orientation positioning and drop detection away from

the applications processor to a more efficient sensor hub.

When the device isn't being actively used, it is valuable to power down the applications processor for intervals to save power. However, in order to detect use or measure movement (e.g., when someone picks up the device from a table or during use as a pedometer), the accelerometer needs to be continuously monitored. Here the sensor hub can manage the sensor data at an optimized low power rate while letting the main applications processor sleep. The impact of this power efficiency is especially noticeable for features like wake-on-approach where the device turns on when a person brings his or her hand close.

Additionally, in specialized applications that don't require the sophistication of a smartphone, the CPU integrated into the sensor hub may provide all the processing capabilities required. For example, a sensor hub like the KX23H from Kionix is built on the advanced computing capabilities of the ARM Cortex-M0 architecture. It offers the right level of processing performance to efficiently monitor multiple sensors and implement complex analysis algorithms. It also has enough headroom to perform all of the functionality required for a targeted application such as a pedometer or heart monitor without the need for an additional applications processor.

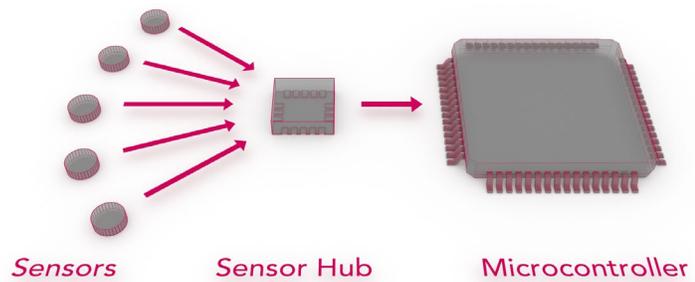


Figure 1

SENSOR FUSION

One of the primary benefits of using a sensor hub is the ability to perform what is known as sensor fusion. In its generic sense, sensor fusion refers to combining data from multiple sensors to yield information that cannot be captured by each sensor separately. A good example of sensor fusion is the use of two cameras to calculate the three-dimensional position of an object.

One way of looking at the "1+1>2" result of sensor fusion is to realize that every sensor has its blind spots. Consider the challenge of measuring motion or change in orientation. When an accelerometer is laying flat on a table at rest, the effect of gravity causes an acceleration to be detected in the Z direction with no force on the X- or Y-axes. If the accelerometer is tipped, the acceleration due to gravity is distributed on the X- and Y-axes as well, allowing one to measure motion and orientation. However, if the accelerometer is placed back on the table and then rotated while still remaining flat on the table, the acceleration due to gravity always acts fully on the Z-axis, while the acceleration on the X- and

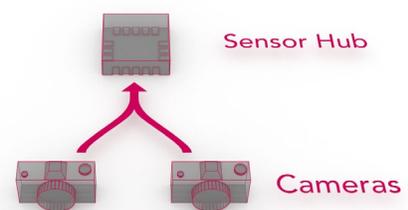


Figure 2

Y-axes remain at zero. Thus the outputs remain the same and there is no indication of motion or change in orientation. In this situation, the accelerometer has a blind spot. The addition of data from gyroscope or magnetometer would allow one to compensate for this blind spot and identify the device's motion and orientation.

Another example of how sensors can complement each other is an eCompass application. For a traditional compass, the magnetic rod is aligned with the earth's magnetic field, and the user inherently levels the housing to obtain a stable reading for magnetic north. In an electronic compass, the signal is typically detected on three orthogonal magnetic sensing elements, and slight variations in tilt or level significantly alter the readings on the three axes and hence the interpretation of direction. An accelerometer is used to measure the tilt relative to gravity and so paired with a magnetometer the two can accurately compute magnetic north.

One form of sensor fusion that is commonly used in portable devices is known as nine-axis sensor fusion. Nine-axis sensor fusion combines the tri-axis data from three different sensors—accelerometer, magnetometer, and gyroscope—to accurately determine a device's orientation and motion in 3-D space. In this way, the blind spots of each sensor are filled in using information from the other sensors. Nine-axis sensor fusion brings value to consumers by providing a level of functionality that enables devices to accurately track themselves in 3-D space. With this accuracy, many new features can be introduced such remote control pointing devices and augmented reality displays.

THE KX23H SENSOR HUB

To help OEMs introduce advanced sensor functionality to consumer, embedded, and industrial designs, Kionix offers the KX23H sensor hub (Figure 3). Key features of the KX23H include:

- **HIGH PERFORMANCE**—Built on a 32-bit ARM Cortex-M0 core running at 32MHz, the KX23H offloads real-time sensor fusion algorithms from a system's main applications processor.
- **ON-CHIP ACCELEROMETER**—Based on Kionix's highest performance design, the accelerator integrated into the KX23H provides 16-bit resolution with a 256-byte FIFO/FILO buffer and very low power consumption down to 1uA. It also features FlexSet Performance Optimization, allowing dynamic adjustment of power and noise parameters to match the state and activity of the device.
- **POWER EFFICIENCY**—In sleep mode, the ARM core consumes only 2.5uA. It also offers an efficient operational power of 1.5mA @ 32kHz and just 6mA @ 32MHz.



Figure 3

- **OPTIMAL LEVEL OF INTEGRATION**—Designed for sensor monitoring and processing, the KX23H doesn't integrate the extraneous capabilities of a general-purpose processor, like a USB port or large memory banks that add unnecessary cost and reduce power efficiency. In addition, because the accelerometer and Cortex-M0 are paired, they can work more efficiently than a CPU with an external accelerometer.
- **SMALLER FOOTPRINT**—The KX23H offers a great deal of functionality in a small 3mm x 3mm x 0.9mm package.

OVERCOMING THE CHALLENGE OF SOFTWARE

Traditionally, OEMs have had to design sensor algorithms from scratch or port generic code to their chosen applications processor. This means OEMs are responsible for developing, testing, and verifying their own monitoring and analysis algorithms. This presents a challenge for many OEMs that don't have their own design resources or in-house expertise. This is typical for many companies in the IoT space that are still emerging and don't have the volumes to justify internal algorithm development. The ability to partner with an expert and offload sensor design can substantially reduce system architecture and design complexity.

To help speed time-to-market, Kionix offers a full suite of sensor software, ranging from device drivers for Windows, Android, and Open Source systems to its extensive Sensor Fusion Library that will be optimized for the ARM Cortex-M0 architecture of the KX23H. Kionix is an expert in motion sensing for a wide range of application nodes and has developed a comprehensive library of application-specific algorithms based on its extensive in-field experience, including:

- **SCREEN ORIENTATION**—Signals when the user has rotated the device and the screen orientation should be changed.
- **FREE FALL**—Determines when a device is falling (Figure 4). This is important for devices like laptops that have a hard disk drive. If falling can be identified in time, the hard drive can be parked to minimize damage. It can also be used to assist in detection and trigger an alert when a person falls. Lastly, it can be used to monitor for drops for purposes such as managing warranty claims.
- **PEDOMETRY**—Accurately measures steps taken by a user.
- **MOTION WAKE UP**—Many devices can be put to sleep when they are not in motion. With this feature, systems can quickly wake once a user picks up the device.
- **TAP/DOUBLE TAP DETECTION**—Detect the direction of a user tapping on a device and identify whether it is a single or double tap.



Figure 4

While many of these algorithms may seem straightforward to implement, there are subtle issues that can significantly impact the customer experience. For example, the difference between whether the device is flat or vertical can affect the screen orientation algorithm. In such cases, special care must be taken to improve user experience and responsiveness while preventing jitter or false identification of orientation. In other cases, some device functions might interfere with motion detection. For example, the vibration from certain ring tones from the speaker can, to an accelerometer, be quite similar to a finger tapping, thus triggering false tap events. Only through careful algorithm design can these situations be minimized and the user experience maintained.

THE PATH TO ASIC

One of the key advantages Kionix brings to high-volume OEMs is a clear path to cost down the sensor hub to a custom device. An ASIC is often the lowest cost and most power-efficient route to implementing sensor-based functionality. However, ASIC design typically takes between 12 and 24 months and assumes that an OEM already has most of the IP in place to create the ASIC. This adds a delay that can be detrimental in the fast-changing consumer electronics industry by making OEMs late to market when introducing innovative new features or optimizations.

Instead, OEMs can lead the market by quickly implementing new features using the flexibility and programmability of the KX23H. This has the advantage of enabling OEMs to test features in the market and optimize them. Furthermore, any unexpected issues that arise can be addressed before the design has been committed to silicon.

Once a design is stable, Kionix is able to cost-down an OEM's design to create a custom device that achieves power and cost savings not possible with a software-based MCU design. Thus, OEM's are able to leverage the benefits of both low-risk design, a quick-to-market approach, as well as high-volume economies of scale.

OEMs can also leverage Kionix's comprehensive portfolio of sensors that share a common sensor fusion library. Kionix sensors offer excellent noise levels, accuracy, and robustness to ensure the best reliability and performance for today's demanding applications.

To further simplify design, Kionix's roadmap for its sensor hub products includes integrating more of the sensor solution for its customers over time. With its strong customer support team, Kionix is able to deliver turnkey solutions, both for new designs and existing applications. This includes working with OEMs to develop custom algorithms that can be preloaded onto the sensor hub during manufacturing calibration. In this way, OEMs can focus on their value-add rather than having to reinvent their own sensor IP.

With the KX23H sensor hub, OEMs can leverage the flexibility and programmability of the ARM Cortex-M0 paired with the high performance of its embedded accelerometer to bring new features and functionality to market quickly and at a lower risk. The KX23H is ideal for augmenting the existing capabilities of a system at a lower cost and power footprint via the sensor hub approach, as well as providing main processor functionality to those targeted applications requiring motion processing and computation capabilities in a small, low power package. ■