Transformation of Sensing to Address the Expanding Contextual World

Technology Innovation at Work white paper series

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Introduction

In action movies and video games, characters perform sci-fi tricks such as visually manipulating data in three dimensions and wearing glasses that show a rich information overlay describing their surroundings. These imaginative ways of interacting with the world are closer to reality than we might think, and can be much more useful than computer graphics on a screen. From using accelerometer data to diagnose possible concussions to tracking your altitude in a high-rise building using pressure sensors, or sensing touch or presence over a screen or object, sensor technology can enable a host of valuable applications—some we thought we'd only see at the movies. Our innovative Xtrinsic sensing solutions are a key player in these current and future developments.

Micro-electromechanical systems (MEMS) are our enabling sensor technology. MEMS-based sensor products provide an interface that can sense, process and even control the surrounding environment. Our MEMS-based sensors incorporate very small electrical and mechanical components on a single chip. With more than one billion MEMS devices shipped, Freescale is a leader in sensor technology that enables cost effectiveness, low power consumption, miniaturization, high performance and integration.

Xtrinsic touch-sensing solutions offer the best fit for HMI designs. Touch-sensing technology can reliably replace mechanical buttons and switches to eliminate mechanical wear and tear or help implement advanced HMI with gesture recognition on resistive screens.

The Sensor Market

The consumer market is driving fast growth in the sensor business, led by mobile devices and video games. Three or four years ago, it was unusual to see a mobile phone with an accelerometer or touch screen. Now, it's hard to find a smartphone without one. Phone manufacturers are playing leapfrog with each other to innovate in the consumer space. For example, the current Android™ operating system does not require 9-axis sensor fusion as part of the underlying framework, but Windows® 8 does. Android will most likely integrate nine-axis sensor fusion in their next release and also include some sensor technology that Windows 8 does not yet have. Also worth mentioning is the continuous growth and improvements we've seen in screens and user interfaces. This competition is fueling the sensor market like never before.

According to an April 2012 iSuppli report, the MEMS market will almost triple from 2011 to 2016—with 13.7 billion MEMS devices sold. Wireless communication will lead this growth with 26 percent of the $12.5 billion market, followed by consumer electronics at 21 percent, industrial at 19 percent and medical at 16 percent and automotive at 13 percent. iSuppli also reports that touch-sensing penetration is expected to grow from 31 percent during 2010 to 69 percent by 2014 in the mobile handset market.

MEMS-based sensors and touch-sensing technologies are crucial components in automotive electronics, medical equipment, hard disk drives, computer peripherals, wireless devices and smart portable electronics such as cell phones and PDAs. Freescale is not only innovating with sensor hardware, but also looking toward future applications with intelligent contextual sensing and sensor fusion. At their core, these approaches combine sensor outputs to achieve an output that is more detailed, accurate and useful than a reading from a single sensor. There is great technical and monetary potential in intelligent contextual sensing and sensor fusion, helping us perceive and process the world in new ways—and ultimately making the world a smarter place.

Toward Sensor Fusion

Today's smartphones and tablet computers usually contain a complement of sensors including an accelerometer to detect changes in force resulting from fall, tilt, motion, positioning, shock and vibration, a magnetometer for sensing the earth's magnetic field and a gyroscope for sensing rotational velocity. Pressure sensors are becoming more common in tablets, specifically in location-based services. These sensors form the basis for navigation systems and many user interfaces. The sensor industry is moving toward a goal of measuring 10 axes: a three-axis accelerometer, three-axis gyroscope, three-axis magnetometer and a pressure sensor. GPS in a mobile device can tell exactly where it is on the face of the earth, but sensors add another level of intelligence about how the device is moving. Is the user turning it upside down or rotating it? If it's moving fast, is it on a train or is someone throwing it? Is it moving fast in a straight line or is it tumbling end over end? This data will enable new classes of applications across a number of markets.

In the mobile market, the iPhone® and iPod® Touch introduced the use of an accelerometer to enable basic functions such as switching from portrait to landscape view depending on the angle of the device. The Nintendo® Wii™ and similar systems introduced gamers to the full-body interactivity of accelerometers in game boxes. In later generations, sensors themselves contained enough intelligence so that they could tell when the device was being tapped or shaken, and wake up the CPU to perform an action. Simple gesture recognition is poised to become even more complex and allow computers to sense and interpret natural human movements as a way of interacting with devices. For example, if you're holding a tablet computer in front of your face, moving the tablet away from your face would zoom out of a map or photo, while moving the tablet toward your face would zoom in.

This new sensing experience requires a new level of sensor intelligence. Sensor fusion essentially combines the output from two or more sensors to obtain a result that is more intelligent and useful than the output from a single sensor. Take the example of walking through an office building with a mobile device that contains a magnetometer, gyroscope and accelerometer. All these devices need to work together to provide a true picture of the user's location and surroundings. The magnetometer could be thrown off by metal in walls and desks, but if the gyroscope and accelerometer detect that the user is walking in a straight line, they can subtract those effects. The accelerometer measures acceleration plus gravity. Gravity is the same as acceleration from the sensor's perspective. An accelerometer measures tilt very well if you're standing still, but what happens if you're walking (or moving on a train or in a car)? The magnetometer and gyroscope can separate the effects of linear acceleration from gravity and help make those decisions.

New Algorithms

Software innovation will be one of the keys to sensor fusion. A magnetometer, for example, measures the ambient magnetic field of the earth as part of mapping and compass functions. But phones and other mobile devices contain a lot of ferromagnetic material, for example in the speakers and ferrous materials for shielding. This metal directly affects the magnetic field in the immediate area of the device. Freescale has developed algorithms to separate these external effects from the true magnetometer reading. The Xtrinsic Capacitive and Resistive Touch-Sensing Platform (CRTouch) uses patented algorithms to translate multi-touch events in a regular four-wire resistive screen, into gesture recognition for HMI design. Another example is pressure sensors in a mobile device. If you're in a high-rise building and want to keep track of what floor you're on, your device can do that by identifying where you are on the face of the earth, taking a pressure reading and converting that to altitude. Freescale has demonstrated this application using the Xtrinsic MPL3115A2 altimeter pressure sensor in a laptop. However, an approaching weather front or even turning on the air conditioning can alter the air pressure. The goal is to build heuristic software which allows sensors to make intelligent guesses about what is really happening in the environment. This is an area where semiconductor companies do not traditionally work, and an area in which Freescale has taken a lead.

Intelligent Contextual Sensing

One result of sensor fusion is intelligent contextual sensing, where sensors enable decision making capabilities within the context of their environment. Intelligent contextual sensing is more than a sensor translating a signal—it is greater levels of sensing context and intelligence. Increasing levels of modular integration combine with multiple sensor inputs, logic and other building blocks to bring greater value and decision making to the overall sensing solution.

For mobile devices, intelligent contextual sensing means that the device not only knows where you are (GPS) but what and who you're near, and provides access to information about those people and places. Much has been written about the opportunity for stores to serve coupons or other deals to consumers' mobile devices as they approach the store. In future generations, this kind of interaction will become much richer. Using sensors, your device will know where you are and understand your movements and the context of your location to provide dedicated services in a proactive manner. Augmented reality puts a virtual view on top of your real world. For example, an augmented reality home medical assistance system uses a camera that can recognize a pill box and overlay useful information, such as when the next dose should be taken. Instead of simply seeing store coupons through your phone in the vicinity of where you are, you now could see actual merchandise and pricing from the nearby store.

The Eudora email program made the news when it debuted an "emotion monitor" for email. The program scans email text for aggressive language patterns and notifies the writer if they've said something they might regret later. Sensors can take this kind of emotion sensing to a whole new level. In a video game with a first-person perspective, body sensors might detect that the player is sweating or gripping the game remote very hard. That data can be translated to a game image blurred by virtual sweat dripping down the screen, or a game weapon shaking as if the player were gripping it too hard. This emotion sensing technology has potential not only for gaming but also for medical

Table 1 lists the kind of information that sensors will be able to collect and some potential applications of that information.

Personal information	Device information	Environment information	Potential applications
• Motion, reaction • Posture, cadence • Biometrics • Emotion • Presence • Touch	• Position • Motion, velocity, trajectory • Impact, vibration • Entertainment	• Location, altitude • Temperature, humidity • Light and sound • Touch	• Social networks • Gaming communities • Demographic data • Click-through data • Survey data • Human machine interfaces • Purchasing preferences • Fitness tracking • Health monitoring • Applications we haven't even thought of yet

technology. Sensors that monitor conditions such as blood pressure could combine their information with emotion sensors to detect an impending emergency and alert medical professionals.

Technical Innovation

More intelligence is moving from the CPU into sensors. Typical sensors are passive devices. In a system built with typical sensors, the host CPU must constantly poll the sensors and process their readings. Systems with a lot of typical sensors require a lot of CPU overhead and power use. The Xtrinsic MMA9550L intelligent motion-sensing platform has a 32-bit MCU on the sensor itself, which means that an intelligent sensor alone could control an application. This can save costs for manufacturers, in some cases eliminating the need for a separate MCU. Having the CPU local to the accelerometer enables far higher data samples to be gathered. Typical "dumb" digital sensors run up to 500 Hz. The Xtrinsic MMA9550L can run up to four times faster, enabling better detection of small or fast motions that are part of a user interface.

Another good example is our touch-sensing software (TSS), where the MCU actually becomes the sensor through embedding our software library into the controller. This enables our general-purpose MCUs to work as touch-sensing devices, helping to not only reduce the cost by eliminating the need for an external sensor but also reducing time to market.

Freescale Xtrinsic sensing solutions use I^2C and SPI to integrate with other devices—including other sensors—and work cohesively as part of an entire system. The MMA9550L is also user programmable, making it easy to use and flexible for a variety of applications. This can help expand sensors into lower cost mass market applications such as toys that could be manufactured with small stand-alone embedded systems.

Energy efficiency is a constant concern for mobile devices. As sensors become more integral to mobile devices, they should do as much work as possible without waking up the main applications processor. Smaller sensor processors can be turned on without a lot of power overhead, making mobile devices more power efficient. For example, the Xtrinsic MMA9550L running at less than 3 mA can pre-process the data involved in gesture recognition and pass that to the host processor, saving processor overhead and power. In a pedometer application (included with the Xtrinsic MMA9553L), where the sensor must be constantly on to track steps, the applications processor only needs to be on occasionally. Compared to the already low power consumption of a Freescale i.MX51 applications processor, distributing processing to the Xtrinsic MMA9550L can save more than 90 percent of system power. As sensors make their way into more mobile devices, namely home medical devices that must be constantly on, energy efficiency will be one of the most important sensor characteristics.

Conclusion

Innovative sensors will ignite innovative applications and devices. Freescale's portfolio of Xtrinsic sensing solutions provides a strong foundation of multiple sensor types to enable these intelligent products. Integration levels in the Xtrinsic portfolio increase with multiple sensor types, connectivity, power management, logic and actuation. Intelligence levels increase with decision making capabilities, software enablement, programmability, applications and software from our wide ecosystem. All these capabilities are coming together to enable new ways of sensing the world around us.

Expanding on our more than 30-year heritage of sensor innovation, Freescale Xtrinsic sensing solutions are designed with the right combination of high-performance sensing capability, processing capacity and customizable software to help deliver smart, differentiated sensing solutions. With Xtrinsic sensors, our vision is to offer a diverse and differentiated product portfolio to meet the expanding needs of the automotive, consumer and industrial segments. Xtrinsic solutions offer ideal blends of functionality and intelligence designed to help our customers differentiate and win in highly competitive markets.

Our comprehensive sensor portfolio includes e-compass, magnetometers, accelerometers, touch sensors, altimeter and pressure sensors. The latest and most innovative additions to this portfolio include:

The Xtrinsic MAG3110 magnetometer operates at the highest resolution and lowest noise in an ultra-small size. A combination of tunnel magneto resistive (TMR) technology, high-resolution analog design and dedicated embedded logic results in phenomenal performance. The Xtrinsic MAG3110 magnetometer measures the magnetic field in all three axes with ranges up to 1000 uT, at data rates up to 80 Hz, with resolution down to 0.1 uT and with noise as low as 0.05 uT. The combination of the magnetometer with the accelerometer provides a full tilt-compensated electronic compass capability. Applications include e-compass enhanced user interface, GPS assist and location-based services, and enhanced gaming interfaces. The MAG3110 is ideally suited for smartphones, tablets and any portable devices requiring an electronic compass capability.

Freescale's MMA9550L is the industry's first intelligent, high-precision motion-sensing platform that manages multiple sensor inputs and makes system-level decisions to enable new applications such as gesture recognition, pedometer functionality and touch-sensing software tilt compensation. Its highly configurable and customizable sensor decision engine enables complex calculations through interpreted sensing information and control over a number of system-level sensing decisions, rather than simply processing raw data. This is accomplished without interrupting the system application processor, reducing total system power consumption. Advanced processing is made possible in the MMA9550L through the 32-bit ColdFire V1 processor that is embedded alongside the sensor to make decisions within the context of its environment and enables a variety of use cases.

Xtrinsic MMA845xQ family of pin-compatible 14-, 12- and 10-bit accelerometers provides scalable, configurable and accurate motion analysis. To operate with extremely low power, the MMA845xQ accelerometers have six user-configurable sample rates that can be set over a wide range of 1.5 to 800 Hz. The power scheme contains four different power modes from high resolution to low power, offering best-in-class savings in supply current and extremely high resolution for very small motion detection. Pin-to-pin compatibility with register map alignment maximizes hardware re-use between 10-bit and 14-bit designs where there is zero development cost to migrate from 10-bit to 14-bit performance. The MMA845xQ accelerometers are feature-rich with a wide range of real-time motion detection such as orientation, directional shake and tap, jolt, freefall and pedometer applications. The MMA8451Q 14/8-bit FIFO holds up to 32 samples of either low pass filtered (LPF) or high pass filtered (HPF) data, depending on user selection.

The 12-pad capacitive touch sensor simplifies touch sensing design. Embedded developers require design simplicity and power conservation in a small form factor for compact system designs. The MPR121 solution replaces mechanical buttons, switches and other moving parts that typically wear out and are less reliable. This CMOS-based state machine simplifies designing numerous touch applications for lighting controls, mobile phones, MP3 players, remote controls and other low-power, hand-held electronic products. The MPR121 operates with extremely low power at 29 µA average supply current—contained in a small, low-profile 3 x 3 x 0.65 mm 20-lead QFN package. It provides 12 electrodes with increased internal intelligence such as a flexible independent calibration feature, an increased electrode count, a hardware configurable I^2C address, an expanded filtering system with de-bounce and completely independent electrodes with built-in auto configuration.

The Xtrinsic MPL3115A2 pressure sensor is the smart choice for precise pressure and altitude detection. It provides highly precise pressure and altitude data with variable sampling rate capability up to 140 Hz, extremely high accuracy, 30 cm resolution (20-bit resolution measurement) with flexible output in either meters or Pascals. Other smart features include temperature compensation, embedded direct readings for altitude, pressure and temperature. No extra software is needed, saving a lot of development time. The Xtrinsic MPL3115A2 pressure sensor is an industry first because it performs all of this compensation on-board, reducing the need for the host MCU to continually convert raw altitude, pressure and temperature data through compensation algorithms. This smart integration results in significant power savings with the MPL3115A2 operating in standby mode at 2 micro amps and low-power mode at 8.5 micro amps at 1 Hz. Other low-power consumption benefits include the MPL3115A2 selectable sample rates and the 32 sample first-in/first-out (FIFO) memory buffer with configurable interrupts to offload communications with the host processor. It has very low power consumption, smart features and requires

zero data processing for mobile devices, medical and security applications.

Our ACE award-winning **CRTouch Ready Play solutions** integrate functionality to different applications, allowing customers to add features while reducing development cost, simplifying design cycles and enabling scalability in applications and systems. CRTouch enables resistive touch screens to handle basic gesture recognition. CRTouch also allows the addition of up to four capacitive electrodes to your system, all packaged on a 5 x 5 mm lead free 32-pin QFN. It supports 4- and 5-wire touch screens and communicates over UART and IIC communication protocols.

Freescale Xtrinsic TSS gives over 1,000 MCUs in our portfolio the flexibility to add cost-effective touch-sensing functionality. Xtrinsic touch-sensing software transforms any standard MCU into a touch sensor with the ability to manage multiple configurations of touch pads, sliders, rotary positions and mechanical keys, all while maintaining standard MCU functionality. Touch sensing helps increase product lifetimes by eliminating mechanical wear and tear associated with buttons and switches.

The Freescale Sensor Toolbox offers a customizable selection of sensor development tools, accessories and software to help you achieve quick time to market with our acceleration, magnetic, pressure and touch sensors. All sensor evaluation kits are USB-enabled plug-and-play devices. A GUI interface uses a single software install that reduces complexity and improves reliability through periodic software updates. It provides development ease with a unified set of development software, hardware (including interchangeable daughter cards), documentation and accessories. The Sensor Toolbox also includes complimentary sensor algorithms to help developers get the most from sensor functions such as orientation, shake, tap, freefall, motion, tilt, positioning, shock or vibration with inertial sensors, PSI conversion for gauge pressure and altimetry for absolute pressure with pressure sensors, water level monitoring, switch replacement and touch pad implementations with touch sensors. In addition, the magnetic sensors can work in conjunction with our accelerometers for accurate compass heading information.

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