

MotionProcessing™ Technology Driving New Innovations in Consumer Products

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The Motion Revolution

A primary driver today for innovation in handheld consumer products is the application of motion functionality to introduce human actions into the digital domain. InvenSense™ *MotionProcessing™* technology, which combines inertial measurement units with digital processing and motion-based applications, enables consumer devices to readily incorporate motion while still meeting critical cost, size, robustness, and battery life requirements. As consumer electronics companies continually search for their next product features for differentiation, they are increasingly turning toward *MotionProcessing* technology in gaming, handsets, digital still cameras, TV remote controls, medical devices, and sports and fitness equipment. The resulting devices are providing a more immersive and intuitive user experience and are adding functionalities that were previously not possible.

Advancements in motion-based technologies have enabled a motion revolution as they perform their

own unique yet complimentary functions. Inertial sensors such as MEMS gyroscopes and accelerometers – at the heart of an Inertial Measurement Unit (IMU) – as well as compass sensors, cameras, and GPS receivers are all used in solutions today. *MotionProcessing* technology includes a combination of sensors to achieve optimal performance by using more than one type of sensing element.

This paper presents novel applications of *MotionProcessing* technology in existing consumer devices, and presents ideas for further development, to give the reader ideas of how they can use motion in their next product development.

Sensor combinations in existing electronic devices

Table 1 shows the combination of sensors used in electronic devices today, and proposes what sensors may be used in these applications in the future. This table provides the reader with an understanding of the sensor combinations used in consumer electronics.

Table 1. Common Sensor Arrangements with Future Trends in Consumer Electronics

Equipment	Common Sensors Today	Possible Future Additions	Notes
Game Controllers	Accelerometers, gyros, image sensors	Compass sensors	Accelerometers, gyros, and image sensors provide true one-for-one motion tracking. The addition of compass sensors provides yaw compensation and absolute heading.
Remote Controls	None	Accelerometers, gyros, compass sensors	Accelerometers and gyros allow gesture shortcuts, game control, and motion-based menu/Internet navigation for connected DTVs. Compass sensors provides absolute heading.
Smart Phones	Accelerometers, compass, cameras, GPS	Gyros	Accelerometers enable rudimentary gaming and tilt compensation. Compass and GPS provide for locational awareness. The addition of gyros enables improved gaming, camera image stabilization, location based services, motion-based user interface, gesture short cuts, motion authentication, and augmented reality.
Digital Cameras	Gyros	Accelerometers, compass, GPS	Gyros today allow for image stabilization. The addition of accelerometers, compass, and GPS allow for position and heading data to be included with photos. Also enables motion-based user interface and gesture short cuts.
Sports Equipment	Accelerometers	Gyros	Accelerometers support pedometer functionality. Adding gyros allows for true 3-D motion tracking, which can be useful for evaluating trajectories of balls, racket swings, body movement, etc.

Applications in Consumer Products Using Motion Processing

Enhancing MotionProcessing Technology with Wearable Sensors and Haptic Feedback

Body-worn *MotionProcessing* solutions offer a variety of user experiences previously unavailable. With wearable sensors, body movements and position can be accurately tracked and represented. This has implications for any activity in which body position and movement is important, such as remote patient monitoring, rehabilitation, sports monitoring, first responder monitoring, and other health and fitness applications. Using *MotionProcessing* technology, even the quickest and most subtle movements can be accurately detected and reproduced.

With accurate remote tracking, patient assessment and rehabilitation can now be performed cost effectively. Sports training can be augmented by capturing highly-accurate body movement data. An on-screen avatar can be used to show actual body position relative to the desired pose, providing motion feedback not previously available. In addition, with haptic actuators embedded into the wearable sensors, vibration-based feedback provides a new dimension of usability and training. With respect to gaming, more accurate body movement sensing through the use of multiple wearable sensor nodes adds a whole new dimension to the game experience in activities such as dance, soccer, tennis, boxing, exercise, and table tennis.

High-end wearable sensor networks are already employed for body motion capture. For example, the Xsens MVN Motion Capture solution (**Figure 1**) consists of 17 nine-axis (gyroscope, accelerometer, compass) sensor nodes connected to a central node via a wired network that is wirelessly connected to a remote computer via Bluetooth. Applications for the device include 3D character animation for games, film, TV, and advertising; sports science; rehabilitation and biomechanics research; and training and simulation.

Motion-Based AV Remote Controls

TVs and set top boxes are becoming increasingly more interactive through the addition of advanced functionality such as Internet browsing; applications such as Yahoo!® TV Widgets; viewing and navigating through personal media files; and the navigation of Netflix™, YouTube™ and other video-on-demand (VoD) services. This has created the need for a user interface device with the functionality of a mouse, but which can be used while sitting on a couch. With a

motion-based approach to menu and Web navigation, users can move an on-screen cursor using hand motions in a manner similar to motion-based game controllers. This approach has the benefit of allowing for additional functionality such as gesture shortcuts and embedded game play in the AV system.



Figure 1. The 17 wearable sensors of the Xsens MVN motion capture sensor system accurately capture body motion without the limitations of camera-based systems.⁴

Implementing new navigation functions requires modification of the existing menu and navigation systems and is initially being integrated into digital televisions.

Figure 2 shows the InvenSense IMU-3000™ Inertial Measurement Unit being used in a motion-based remote application. This device is the world's first IMU solution with 6-axis sensor fusion for consumer applications. It features an on-board 3-axis digital gyroscope that integrates accelerometer inputs to provide a complete 6-axis sensor fusion output that offloads the motion computation requirements from the TV processor. Additionally, the device has on-chip FIFO and dedicated external sensor bus to simplify system timing and lower system power consumption; the sensor bus allows the IMU-3000 to directly acquire data from the off-chip accelerometer without intervention from an external processor, while the FIFO allows a system microcontroller to burst read the 6-axis sensor data and then go to sleep while the IMU collects more data.



Figure 2. Motion-based AV remote control using InvenSense IMU-3000⁵

As an example of a commercialized motion-based remote, LG Electronics has begun shipping its Magic Motion™ TV remote control with several digital TV models. The remote uses motion processing to provide motion-based menu and game control, as well as to provide gesture control of volume and channel selection (**Figure 3**).



Figure 3. The LG Electronics Magic Motion™ remote uses motion processing for menu navigation and control of other functions.⁶

Extracting More Value From RF Remotes

As can be seen in **Figure 2**, the addition of motion processing to a standard remote requires the addition of an RF communications link to send the motion data to the host. One way to justify the cost of adding this feature is to make use of the RF link for additional functionality, such as adding audio. Bluetooth RF ICs support a variety of profiles and can support headset and stereo audio functionality. With a Bluetooth link, the designer could easily add a wireless microphone function for use in on-line gaming applications or video conferencing. Or a stereo wireless headset function can be added for privately watching TV with the stereo audio being sent to a wired headset that connects to the remote control.

Motion-Based Air Mice

The application of motion-based air mice has traditionally been as a presentation device which allows a user to control a cursor by directly pointing at the screen. As the PC is increasingly used as a gaming platform and used for accessing and viewing multimedia content, 3D mice are also serving as game controllers and remote control devices for the PC and laptop.

Figure 4 shows two examples of mice which combine a traditional 2D desk-type mouse with a 3D air-mouse capability. Inertial sensors are used for the 3D usage pattern, while optical sensors are used for the 2D operation.



Figure 4. The Logitech® MX™ Air Mouse and the Air Mouse Elite™ from Gyration both feature inertial sensors for air mouse functionality and optical sensors for standard 2D mouse functionality.^{7,8}

Adaptive Dead-Band Setting for 2D/3D Mice

Dead band refers to ignoring signals below a certain threshold level, in order to minimize the effects of sensor drift, handshake, etc. To add increased functionality, an adaptive dead-band process may be applied based upon the mouse learning the usage patterns of various users, i.e., an older person who shakes versus younger person who doesn't.

Automatically Switching Between 2D Desk-Top Mouse to 3D Motion-Sensed Mouse Operation

When a combination 2D/3D motion-sensed mouse/pointer is removed from the desktop, it is important to switch between 2D (desk) mode and 3D (air mouse mode). One method to accomplish this when using an optically-sensed 2D mouse is to sense optical distance. Another method applicable to any 2D mouse is to sense mouse packet data inactivity. A third method is to positively detect pitch/roll rotation.

Innovations for Musicians

Motion-Controlled Musical Instruments

Musical instruments for personal and professional entertainment are pervasive and have increased in popularity with the advent of new broadcast media beyond traditional records, radio and television. Motion-sensed control of the musical instrument and of effects such as stage lighting adds an important new dimension to the user and audience experience. “Instrument” in the context of this discussion may include:

- Traditional music instruments
- Computer-generated “virtual” musical instruments
- MIDI synthesizers, drums, or other MIDI-controlled instruments
- “Air” (pretend) musical instruments that the user plays without having a physical instrument in their hands
- Images of musical instruments on a computer, handset, or TV screen that the user can play and control

Virtual Instruments with Haptic Feedback

Virtual instruments may be made using a remote control based on *MotionProcessing* technology. Particularly suited for this are any sort of percussive or stringed instruments, such as guitars, setars, drums, marimbas, and glockenspiels.

For example, in popular jazz and rock music, a drummer uses a drum kit to drive the beat. Key instruments in the drum kit are the snare drum, high-hat cymbal, tom tom, ride cymbal and kick drum. Most audience observers are familiar with the classic drummer seated in front of the drum set. A casual observer can readily position their arms and hands to mimic playing “air” drums. The virtual drum kit will know the relative relationship of each of the instruments in the drum set by the user’s absolute position of the hand controllers to the core snare drum, i.e., drumming in front of the user’s lap makes the snare sound, moving the arm 30 degrees to the right creates the tom tom sound, raising the controller in the air hits the cymbal, etc.

A key advantage to the motion-controlled virtual drum set is that it takes virtually no space and can create the entire drum set experience.

For virtual instruments, haptic feedback may be added so that the musician feels the instrument. For

example, when playing a virtual guitar, the haptics may allow the musician to feel the plucking of the strings as he plays them.

Musical Instrument Motion-Sensed Sound and Lighting Contour Device

When playing music on an instrument, it is often desirable for the musician to change the timbre, tone or contour of the sound while playing or to add a sound effect. Examples of where this is required may include:

- When the music passage changes intensity, speed or mood
- When another musician, or music performer’s sound or lighting must change in prominence
- When songs start or end, or change between a medley of songs and performances

Traditional user-controlled sound and lighting changes have been typically floor-mounted “effects pedals”, keyboard controls and pedals, and/or hand-controlled switches. User control based on *MotionProcessing* technology permits body motion and instrument position to do this so a more fluid and interpretive experience is created.

Guitar Motion-Based Sound and Light Effects Controller

Commonly, guitar players will use floor mounted or rack-mounted sound effects devices such as distortion, wah-wah, tremolo, and reverberation or delay pedals. When the musical passage requires a change from “clean” to “distortion” the guitarist presses a switch on the floor pedal and a sudden change in tone occurs. Similarly, another switch introduces the tremolo effect, with some preset parameters set for tremolo speed and depth.

A six-degrees-of-freedom controller with *MotionProcessing* worn on the guitar or on the musician’s body will permit fluid and gradual tone changes between two or more sound effects, or may be used to change parameters fluidly.

Similarly, when the guitarist moves to a new position on the stage, the lighting may follow or change for the musician automatically, which is desirable because it enables the musician or performer to concentrate on their performance without watching for specific stage lighting boundaries.

Location Awareness – Social Networking, Augmented Reality, and Map-Mode Photo Viewing

The use of GPS technology is proliferating in consumer devices, resulting in applications that take advantage of location awareness. For example, Google Latitude allows one to see where friends are by using the GPS functionality built into cellular handsets.

Another application example that takes advantage of location awareness, Layar, provides an augmented reality browser that combines camera sensor data with geographical overlays that provide information about points of interests (POIs) within the field of view of a cell phone's camera

Figure 5 This technology not only requires knowledge of one's position, it also requires knowledge of heading (i.e. where the phone is pointing). Heading information is typically provided through the compass sensor; however for a faster response to changes in direction, a full *MotionProcessing* solution including a gyro sensor improves responsiveness.



Figure 5. In this application of augmented reality by Layar, knowledge of one's position and heading are used to layer POI information on top of the information being received by the handset's camera.⁹

Digital still cameras (DSCs) are also starting to incorporate position and heading sensors. For example, the Sony HX5V DSC includes heading and position data with the photo, allowing a "map view" of photos (**Figure 6**).



Figure 6. The Sony® HX5V includes GPS and heading data with its photos, allowing photos to be viewed in a map view.¹⁰

Innovations for Sports Equipment, Medical Devices, Toys and Consumer Electronics

MotionProcessing technology functionality can also enhance application areas such as toys, business tools, and recreational equipment. As an example, children's toys, bowling balls, baseball bats, tennis rackets, toboggans, snowboards, wind surfers, and skis all may benefit from speed or motion tracking analysis.

Motion Processing in Sports Equipment

One example is the integration of a small, battery operated RF *MotionProcessing* solution in a bowling ball, which can track the velocity and the trajectory of the ball enabling instant feedback to the bowler. Integration into a baseball bat or tennis racquet measures the speed and the angle of swing. Adding *MotionProcessing* technology to personal media players supports pedometer and a count meter of various exercise activities including sit ups, pushups, chin ups, and curls with free weights.

Motion-enabled fitness devices exist today in the Nike+iPod Sports kit, where exercise information is transmitted from a motion sensor in a shoe to an RF receiver connected to an iPod Nano, iPod Touch, or an iPhone (**Figure 7**). In this configuration, the iPod's display shows items such as distance run, time run, pace, and calories burned. Alternately, the iPod can be used to provide an audio output. Post workout, data can be logged to a website.

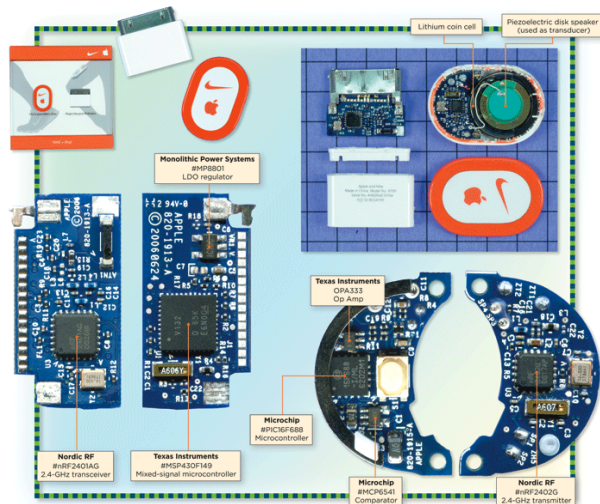


Figure 7. The Nike+iPod Sports kit uses a motion sensor and an RF link to send running statistics from a shoe to an iPod.^{11, 12, 13}

MotionProcessing Technology in Medical Devices

As health-care costs escalate, the need for moving health care services to lower cost settings becomes more important. Motion and heading sensors are two of the many technologies being employed along those lines. For example, the MotionPod™ from Movea measures body orientation using accelerometers and compass sensors, and can be used in remote physical therapy and elderly monitoring. **Figure 8** for example shows one usage mode where the motion nodes communicate wirelessly to a computer, providing feedback to the user. Alternately, the data may be transmitted to a remote location where specialists are employed to monitor the activities.

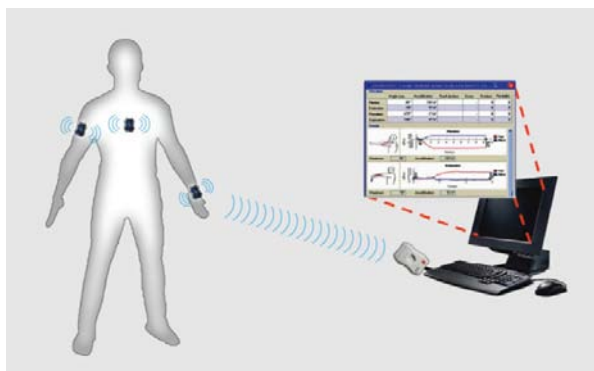


Figure 8. The MotionPod™ from Movea is used to accurately track body movements in applications ranging from physical therapy and rehabilitation to elderly monitoring.¹⁴

Motion Processing for Surround Sound

When listening to audio using fixed speakers, the sound appears fixed in space as a listener moves his head. When listening to headphones, the audio source physically moves with the head.

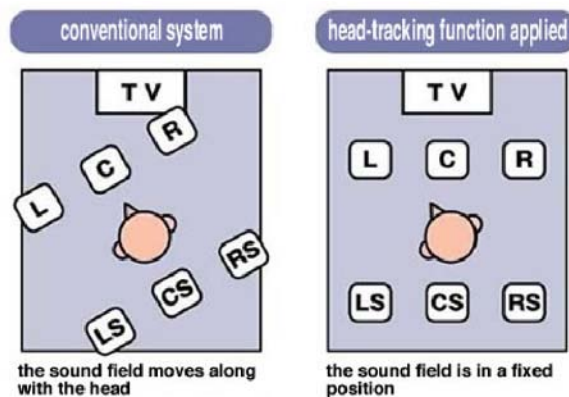


Figure 9. With head tracking, sounds can appear as if they come from fixed positions when wearing headphones.¹⁵

To overcome this limitation, the MDR-DS8000 from Sony features surround sound using the Gyrotrak™ head tracking system to enhance the surround sound experience, by making the sound appear stationary in the sound field while the head is moving, instead of having the sound source move along with the head, as is the case with standard headphones (**Figure 9**). This is particularly useful for watching movies in surround sound or playing video games.

Cameras for Calibration and User Feedback

Video Cameras for Calibrating Handheld Motion-Sensed Game Controllers

The image sensor has become ubiquitous in home and portable computing and communications electronics devices such as cellular handsets, computers, portable gaming devices, etc. In addition to providing photos and video images, the camera may be used to augment the performance of the inertial sensors increasingly used in electronic devices.

As shown in **Appendix 1**, accelerometers and gyroscopes require a mathematical integration to measure relative distance and relative angles, respectively. Due to the nature of integration, these distance and angle measurements have errors that compound over time. As stated in the appendix, a camera can be used to overcome these limitations.

Use of Camera in Cell Phone, Computer, or Portable Game for Gaming Feedback and User Positional Data

Just as the next-generation Sony and Microsoft gaming systems use cameras for increasing game play enjoyment by placing the user in the game, other non-traditional game platforms may also add this feature through the use of built-in or auxiliary cameras. These systems include cellular handsets, portable gaming devices, TVs, set top boxes, and computers.

In addition, the imager in these systems may also be used to help provide spatial information, such as the user and/or their handheld controller's location and position. A benefit from this approach is that it allows the desired game center to follow the user as they move around within a field of view.

Summary

InvenSense *MotionProcessing* technology is creating never-seen-before motion-based innovations in consumer electronics, making motion the new “must have” function for consumer product differentiation. With new IMUs for consumer electronics, products based on *MotionProcessing* are driving the creation of whole new classes of consumer devices, applications and services. Today a wide variety of opportunities exist to interpret physical motion into a digital form for gaming, sports, healthcare, augmented reality, digital entertainment and social networking. New *MotionProcessing*-enabled solutions offer the most novel approach to delivering a more accurate and authentic motion-aware user experience and innovation in consumer applications at improved levels of cost, size and performance.

Appendix 1. Sensor Overview

Sensor	Primary Usage	Benefits	Limitations & Solution
Accelerometer	<ul style="list-style-type: none"> Measures linear acceleration and tilt Velocity is obtained by a single integration Relative distance is obtained by a double integration 	<ul style="list-style-type: none"> Can directly measure tilt angle (based on acceleration of gravity) Can measure linear distance 	<ul style="list-style-type: none"> Cannot distinguish between acceleration due to linear movement and acceleration due to gravity. Problem solved by combining accelerometer with gyroscope sensor Relative linear distance is measured by double integrating the accelerometer. Integration leads to errors over time. Problem is solved by using a camera or GPS for calibration.
Gyroscope	<ul style="list-style-type: none"> Measures absolute rate of rotation Relative angle is obtained by a single integration 	<ul style="list-style-type: none"> Fast, accurate measurement of angular rate Is not corrupted by linear acceleration or magnetic fields 	<ul style="list-style-type: none"> Relative angles are measured by integrating the rate output of a gyroscope. Integration leads to errors over time. Integration errors solved by combining with accelerometer (for tilt angle) or compass (for yaw angle), or by using a camera sensor
Compass	<ul style="list-style-type: none"> Measures magnetic fields 	<ul style="list-style-type: none"> Absolute heading measurement 	<ul style="list-style-type: none"> Geomagnetic field signal corrupted by other magnetic sources or interferers Tilt compensation required Field corruption solved by using gyroscope sensor in conjunction with compass Tilt compensation achieved by using accelerometer for tilt angle
Camera	<ul style="list-style-type: none"> Measures optical images 	<ul style="list-style-type: none"> Can be used to tell relative positions, rates of movement, and distances between objects Useful for image capture for various applications Useful for augmenting other sensors 	<ul style="list-style-type: none"> Does not work in low light conditions Does not work when image out of field view Limited to update rate of image sensor Lighting issues solved by using auxiliary light sources Viewing angle solved by using other sensors such as gyros and accelerometers
GPS Receiver	<ul style="list-style-type: none"> Measures absolute position 	<ul style="list-style-type: none"> Worldwide positional data Useful for augmenting other sensors 	<ul style="list-style-type: none"> Signal may not be available or may be corrupted, for example when in urban canyons or indoors Movement required to measure heading Use of other sensors such as gyros, accelerometers, and compass solve lack of signal problems, over a limited time scale Heading solved by compass and gyro combination



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