Session 4

Motion Sensing with Accelerometers – Present and Future

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Abstract

Motion sensitive devices are quickly becoming an accepted and expected part of our lives. Our vehicles, computers, cell phones, MP3 players, game consoles, and even our sneakers are measuring motion to enhance their functionality. The sensor that has enabled these applications is the Micro-Electro-Mechanical Systems (MEMS) accelerometer. Within the past few years, the price, performance, and size of MEMS accelerometers have achieved a level that has enticed designers to include them in many consumer electronic devices.

Motion sensing vehicles automatically correct for driver error to keep us safe on the road. Notebook computers protect their hard disk drives from damage due to a fall. Pedometers in mobile phones, MP3 players, and sneakers help us maintain a healthy, active lifestyle. We can now play video games with intuitive motion and gesture-based controls.

The number of applications for accelerometers will increase in the future. The driving force behind this expansion, besides the cost, performance, and size of the sensors, will be user expectation. System designers, engineers, programmers, and students will learn, through experience, the capabilities of the sensors and will develop new algorithms to enhance the motion sensing experience.

Introduction

The age of motion sensing has arrived. Nearly every automobile manufacturer offers vehicles with Electronic Stability Control. Apple Computer, IBM/Lenovo, Samsung, Nokia, LG, Nike, and many other companies make products with motion-enabled features. The two next-generation game consoles that will be released in November 2006, the Sony Playstation3 (PS3) and the Nintendo Wii, will both feature motion-sensing controllers. A specific type of sensor makes all these applications possible: the MEMS accelerometer.

MEMS is an acronym for Micro-Electro-Mechanical Systems. MEMS accelerometers are tiny devices that measure acceleration. Fabricated on a silicon substrate, they contain an extremely small mass suspended between two springs. As the accelerometer is moved, tilted, or shaken, the mass moves relative to its surrounding substrate. This motion causes a change in capacitance or resistance, which is then measured by an integrated circuit and converted to an analog voltage or a digital signal. This analog voltage or digital signal can be used to determine the orientation and trajectory of any device to which the accelerometer is attached. A single-axis accelerometer can sense motion in only one direction, along a line. More advanced dual-axis accelerometers can sense acceleration in a two-dimensional plane. Tri-axis accelerometers, the latest advancement in MEMS accelerometers, can sense acceleration in all three dimensions.

Airbag deployment sensors were the first commercial application for MEMS accelerometers. At a cost of approximately $10 each in the 1990's, these single-axis accelerometers were inexpensive compared to the $50 sensors that were used previously. However, there are several factors that prevented motion sensing from gaining popularity until recently. Cost is the first factor. Ten dollars was and is far too expensive for a component in mainstream consumer electronics. Size was another critical consideration. Before MEMS sensors, accelerometers were measured in inches. These large and relatively poor performing accelerometers also consumed far too much electrical current to be acceptable for the growing battery-powered consumer electronics market. Advances in MEMS technology over the past decade have resulted in tri-axis accelerometers that are as small as 3mm x 5mm x 0.9mm, operate on less than 1 milliwatt of power, and cost less than one dollar. The low cost, small size, high performance, and miniscule power consumption of today's MEMS accelerometers has led to an explosion of motion sensing applications in automobiles, cell phones, game consoles, MP3 players and hand held computers.

Current Applications

Many vehicles utilize motion sensors to implement Electronic Stability Control, or ESC. ESC compares the driver's intended direction in steering and braking inputs to the vehicle's response, via lateral acceleration, rotation (yaw) and individual wheel speeds. In an emergency situation, ESC applies braking force to individual front or rear wheels and/or reduces engine power to correct understeer (plowing) or oversteer (fishtailing) before the driver knows that the vehicle is out of control. ESC also integrates all-speed traction control, which senses drive-wheel slip under acceleration and individually applies braking force to the slipping wheel or wheels, and/or reduces excess engine power, until control is regained. ESC has the potential to dramatically reduce the number of automobile accidents and their associated injuries and fatalities. It first appeared in expensive luxury and sports cars and, as motion sensors have become more economical, is now available in many lower-priced models.

Besides protecting humans, motion sensing is also used to protect hard disk drives from damage due to a fall. When a notebook computer is dropped onto a hard surface, the hard disk drive is subject to accelerations high enough to damage the drive and cause data loss. Several computer models available today utilize motion sensors to detect a fall before the computer hits the ground. Once a dangerous situation is detected, the computer places the hard disk drive into a parked state, which actively unloads the read/write head, to protect the drive from damaging impacts. Even though some components of the computer may be damaged, the hard drive and the data on it are protected.

IBM was the first to employ motion sensing hard drive protection, in the ThinkPad line of notebook computers. IBM's implementation used a dual-axis accelerometer to sense motions that indicated a fall was about to occur. At this point, the hard disk drive was parked and the user interface was frozen until the event was over. The protection sensitivity was softwareadjustable, but many users became frustrated with the frequent interruptions and simply turned off the protection feature.

Newer hard drive protection systems, such as Apple Computer's Sudden Motion Sensor, now found in the PowerBook, iBook, and MacBook/MacBook Pro, utilize a tri-axis accelerometer for improved implementation. The tri-axis accelerometer is capable of detecting freefall in less than 1 millisecond. In addition to detecting motions that indicate an impending fall, systems with a tri-axis accelerometer sense that the computer is actually falling. Such systems that delay the hard drive park until the computer is actually falling generate far fewer false events, thus eliminating the frequent interruptions that cause user frustration and protecting more hard drives. Most notebook computer manufacturers now offer hard disk drive protection enabled by tri-axis accelerometers and all major disk drive manufacturers are incorporating tri-axis accelerometers into their drives specifically for drop protection.

Apple notebook computer users have expressed their enthusiasm for motion sensing by creating a number of new applications that use the Sudden Motion Sensor. They have written rolling ball games, in which you tilt the computer to control a ball on the screen, virtual bubble levels, windows that rotate so they are always right side up, and even a motion sensitive security alarm. One notable application, Bumptunes, skips to the next song in an iTunes play-list when it senses a tap on the side of the computer.

Following the trend of creating products that help people achieve an active, healthy lifestyle, accelerometers are being used to implement pedometer/calorimeter features in MP3 players and mobile phones, including the MSI Mega Player 521 MP3 player, Samsung SCH-S310 cell phone, and Nokia 5500 cell phone. The integration of a pedometer into these common devices makes it easy to track daily exercise. In addition, tri-axis accelerometer-based pedometers are much more accurate than inexpensive mass-market standalone pedometers because tri-axis accelerometers can measure motion in any direction. Most pedometers have the capability to measure motion in only one direction, so they must be mounted on the body in a specific orientation and at a specific location. The inclusion of a tri-axis accelerometer allows an MP3 player or cell phone pedometer to be mounted in any orientation on any part on the body. One approach that has been met with success is to embed an accelerometer in a device that is worn on or in a sneaker. Nike and Apple have collaborated on a product called the Sport Kit, which features an accelerometer-enabled device that fits into a specially designed sneaker. A wireless transmitter sends accelerometer data from the sneaker to a receiver that plugs into an iPod. Exercise time and distance are then displayed on the iPod screen.

Gaming on mobile phones is extremely popular, so it is not surprising that embedded accelerometers in mobile phones are being used for gaming. Mobile phone keypads are so small and the buttons are so close together that it is easy to unintentionally press two buttons at once or press the wrong button. Both of these actions are frustrating and interrupt the game play. Given the limited amount of real estate available on the face of a mobile phone, not much can be done to solve the problem aside from removing the need to use the keypad. Motion sensing phones accomplish this by using tilt to control a character's movement in the game. Tilting the phone left or right steers a character on the screen, while tilting forward or backward moves the character vertically on the screen. For some games, tilting is the only input, while other games use one button for controlling various actions.

Future Applications

These types of applications, in which the user interacts with an electronic device through motion, are going to become more prevalent in the future, starting with the two new game consoles that will be released in November 2006. Sony is introducing the Playstation 3 (PS3), which will feature a controller that contains a tri-axis accelerometer to measure tilt/motion and a gyroscope to measure twist. In a manner similar to the motion sensitive mobile phone games, tilting and moving the controller will control the game characters. Nintendo is taking the motion sensitive capabilities one step further, and has completely redesigned the controller for their new console, the Wii. Instead of holding the controller with two hands, like a typical game controller, the Wii controller is designed to be held in one hand, like a television remote. Game actions are accomplished by simply moving the controller, called the Wii-mote, which eliminates the need for arrays of buttons and triggers. The simple appearance and intuitive nature of the controls will make the Wii appealing to a larger audience, including many people who have been intimidated in the past by complicated game controls.

Game developers are very excited about the possibilities that motion sensitive controllers offer – game controls can be simplified and made more realistic by replacing complicated button presses with intuitive gestures. The gamer can cast a spell by waving the controller in the air instead of executing a series of button presses. Conversely, game designers can choose to add new motion-based controls instead of replacing existing controls with motion. This option expands the amount of control the player has over the game rather than simplifying the controls.

Accelerometer-based controls, although intuitive for users, are much more complicated than traditional digital buttons and analog joysticks for a game console to interpret. It will take developers some time to learn, test, and refine their game control algorithms. Basic tilt control to move a character or change a camera view is relatively straightforward. Gesture recognition, in which predefined gestures replace button presses, is more complicated, but is being implemented in first-generation Wii titles. As game developers gain experience with motion sensing, they will implement analog gesture recognition. Instead of simply replacing button presses with gestures, analog gesture recognition will calculate how accurately the gesture was performed, the speed and size of the gesture, and other parameters that will determine the game character motion. For example, instead of simply recognizing a sword slash or tennis racket swing, next-generation gesture recognition will determine the strength, speed, and direction of the slash or swing. As motion sensing becomes more mainstream and game developers become more familiar with the technology, new genres of games will emerge for both consoles and handheld devices that were not possible previously.

One advantage that motion sensitive console gaming has over motion sensitive handheld gaming is that the console's display is fixed, eliminating the screen glare and poor viewing angles of LCD screens. However, technologies exist to reduce screen glare and widen viewing angle and these solutions will be integrated as motion sensitive handheld gaming gains popularity. Even with screen glare and poor viewing angle, plenty of opportunities exist currently for gaming and non-gaming motion sensitive handheld applications. Consider, for example, a golf game in which the player views the course and selects the appropriate club using traditional button controls, then switches to motion control to execute the swing. A tri-axis accelerometer measures the player's swing and calculates the golf ball's trajectory. The player then looks at the screen to watch the ball's flight through the air. Besides gaming, gesture recognition can be used to answer and hang up the phone, change volume, scroll through songs, lock and unlock the handset, among other feature options. For example if a mobile phone is lying on a table, to direct an incoming call to voicemail, just flip the phone over.

With the increasing number of handheld devices relying on hard drives for storage and the increasing capacity of these micro-drives, the danger of dropping the device and destroying the data on the drive is a genuine concern. The same sensors that are used for protecting the hard drives of notebook computers will be used to protect the hard drives of handheld devices. Since handheld devices are subject to various types of motion during normal use, detecting a dangerous event is not a simple matter. Careful consideration will need to be taken by the system designers to implement algorithms that protect the drives without interfering with the user experience.

Conclusion

Successfully implemented, motion sensitive features enhance the user's experience. Features like Electronic Stability Control and hard drive protection operate transparently, so the user is never aware of them. Others, like motion sensitive gaming, are fully interactive and simple to learn, since movement and gestures are a natural way of controlling our environment. Motion sensing is here to stay and will become more ubiquitous as sensors improve and designers learn their capabilities. Likewise, users will expect their devices to be motion sensitive, and devices without motion sensing will be viewed as "old technology."

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