Capacitive Accelerometers for Head Tracking Devices

Introduction

Accelerometers are devices that measure the forces of acceleration on the system they are a part of. They are characterized by their sensing range, number of axes along which acceleration is measured, sensitivity, operation temperature range, and power usage. The sensing element in commercially available accelerometers varies between piezoelectric, piezoresistive, and capacitive depending on the application. Capable of determining the tilt of a system with respect to Earth, measuring vibrations in buildings and bridges [1] and quantifying the shock in automotive crash testing [2], accelerometers are used in a variety of systems ranging from aircrafts to mobile phones [3].

Head tracking devices are often used by persons with spinal cord injuries, paralysis, and other disabilities, to help them use a computer [4]. Due to the development of Augmented Reality games and immersive Virtual Reality applications, Head Mounted Displays (HDMs) employing accelerometers and capable of head tracking are being extensively researched [5]. This paper is a review of capacitive accelerometers and their use in head tracking devices.

Commercial Applications

There are several capacitive MEMS (micro-electro-mechanical system) accelerometers manufactured for embedded systems. The price ranges from less than a dollar to over $100 per chip based on the sensitivity, sensing range and built in logic functions [6].

The 3-axis, 12-bit MMA8452Q accelerometer manufactured by Freescale Semiconductor Inc. costs $1.43 and has a dynamically selectable sensing range of ±2g, ±4g or ±8g [7]. It has built in logic function for free fall detection and an I^2C communication bus to interface with a microcontroller.

The ADXL345 3-axis accelerometer manufactured by Analog Devices Inc. costs $7.15 and is capable of measuring less than one degree tilts [8]. It has an ultra-low power consumption of 40uA in measurement mode, 0.1uA in standby mode at 2.5V. It supports both SPI and I2C communication protocols. The accelerometer also has built in logic function to detect taps, double taps and free-fall.

The MMA8225EG, manufactured by Freescale Semiconductor Inc. is useful in applications requiring higher sensing range of up to 250g [9]. This is a single axis accelerometer that operates in the 6.3 - 30V range and costs about $30. For systems requiring 3-axis sensing, three ADXL193's can be positioned orthogonal to each other.

Underlying Technology

Capacitive MEMS accelerometers are structured like a diaphragm, consisting of a loaded movable microstructure paired with a stationary microstructure, which acts as the reference frame. The mass of the movable microstructure, also known as the proof mass, is in the order of micro-grams [10]. The capacitance associated with the pair of microstructures is a function of the gap between them, which is in the order of micro-meters [10].

Forces acting on the accelerometer displace the two microstructures relative to each other, thus changing the capacitance between them. Sensing the change in capacitance by using a bridge circuit provides an electrical voltage proportional to the acceleration [11]. Most MEMS accelerometers consist of several sets of capacitors (46 pairs in Analog Devices' ADXL05 [10]) wired in parallel to amplify the change in capacitance and make it detectable [10]. In addition to the acceleration sensing mechanism, digital accelerometers, as compared to analog accelerometers, also contain an Analog to Digital Converter along with the hardware required for implementing a communication bus.

Implementation of Technology

Capacitive accelerometers are capable of measuring both "static" and "dynamic" acceleration. In the case of a 3-axis accelerometer, the accelerometer outputs three values corresponding to the components of acceleration along the three axes. These can be directly used to calculate the tilt of the system. When the accelerometer is stationary with respect to Earth, the only acceleration acting on it is due to Earth's gravity. When calibrated correctly, the resultant of the three outputs from a stationary accelerometer should equal 1g (9.8 m/s^2). In order to determine the acceleration of a system, the components of acceleration due to gravity are subtracted from the outputs of an accelerating system's accelerometer. Moreover, for purposes of determining a system's exact orientation, position and velocity, accelerometers are generally coupled with gyroscopes, which provide angular velocity measurements, to form an IMU (Inertial Measurement Unit) [12].

Implementation of accelerometers in embedded systems, for instance for head tracking applications, require interfacing with microcontroller, such as the Atmel ATmega328, to read and process the accelerometer values. Processed data is then transmitted to the software application responsible for controlling the cursor on the computer screen.

References

[1] E. S. Newman, "Piezoelectric Accelerometers in Structural Health Monitoring," Department of Civil and Environmental Engineering, University of Massachusetts Lowell, Tech. Report. SERG-10-01, 10 May 2010.

[2] B. Lent, "Simple Steps to Selecting the Right Accelerometer," www.sensorsmag.com, para. 22, Mar. 1, 2009. [Online]. Available: http://www.sensorsmag.com/sensors/acceleration-vibration/simple-steps-selecting-right-accelerometer-1557. [Accessed Jan. 20, 2013].

[3] Dimension Engineering, "A beginner’s guide to accelerometers," Dimension Engineering. [Online]. Available: http://www.dimensionengineering.com/info/accelerometers. [Accessed Jan. 20, 2013].

[4] Y. W. Kim, "Development of headset-type computer mouse using gyro sensors for the handicapped," Electronics Letters Online, Vol. 38, No. 22, October, 2002. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1047066. [Accessed Jan. 20, 2013].

[5] M. S. Keir1, C. E. Hann, J. G. Chase, and X. Q. Chen, "A New Approach to Accelerometer-based Head Tracking for Augmented Reality & Other Applications," In Proceedings of the 3rd Annual IEEE Conference on Automation Science and Engineering, Scottsdale, AZ, USA, Sept 2007

[6] Digi-Key Corporation, "Product Search," Digi-Key Corporation. [Online]. Available: http://www.digikey.com/product-search/en?x=0&y=0&lang=en&site=us&KeyWords=accelerometers. [Accessed Jan. 20, 2013].

[7] Freescale Semiconductor, "3-Axis, 12-bit/8-bit Digital Accelerometer," MMA8452Q Datasheet, Aug. 2011 [Revision 4.1]

[8] Analog Devices, "3-Axis, ±2g/±4g/±8g/±16g Digital Accelerometer," ADXL345 Datasheet, May. 2009

[9] Freescale Semiconductor, "Digital X-Axis Accelerometer," MMA8225EG Datasheet, May. 2010 [Revision 5]

[11] Sensor Land, "The Capacitive Accelerometer," PCB Piezotronics Inc. [Online] Available: www.sensorland.com/HowPage011.html. [Accessed Jan. 20, 2013].

[10] M. Andrejašic, Seminar, Topic: "MEMS Accelerometers," Department of physics, University of Ljubljana, Mar. 2008

[12] "Accelerometer, Gyro and IMU Buying Guide," www.sparkfun.com, para. 21. [Online] Available: www.sparkfun.com/pages/accel_gyro_guide. [Accessed Jan. 20, 2013].