DETERMINING ANGLE POSITION OF AN OBJECT USING ACCELEROMETERS

Marin Berov Marinov*, Marin Hristov Hristov, Ivan Pavlov Topalov*****

Technical University of Sofia, Faculty of Electronics, P.O. Box 43, BG-1756 Sofia, Bulgaria,
*e-mail: mbm@tu-sofia.bg, **e-mail: M.Hristov@ecad.tu-sofia.bg, ***e-mail: Ivan.Topalov@jci.com

Accelerometers are used to measure a combination of physical parameter like "Inertia", "Tilt/Inclination" and "Vibration or Shock". One of the common applications for low-g accelerometer is the measurement of the terrestrial gravity to determine the inclination. Tilt sensing is increasingly used in a variety of fields like Defence, Aerospace, Industry, Transport, and Instrumentation. Some common applications in these fields are Compass correction, Platform control and stabilization, High speed train control, Antenna and radar stabilization, Weapon security system, Drilling, Building monitoring and survey, etc.

The presented implementation is based on the low-cost microcontroller PIC16F876. A combination of measurement techniques, such as continuous self-calibration and multi-port measurement are used to obtain high accuracy and long-term stability. A data logging feature is also included allowing to store and lately analyze measurement results. Additionally, it is provided a connection with a PC for computing and visualizing the data.

Keywords: angle, position, accelerometer, tilt measurement.

1. INTRODUCTION

The term tilt sensor is often used to identify a large variety of devices that measure, indicate, or otherwise provide a signal of some type when tilted from a level position, using gravity as a reference.

A tilt sensor can be defined as a device that produces an electrical output which varies with angular movement. This definition excludes all visual/mechanical devices such as "ball-in-tube" slope indicators, pendulum protractors, and bubble levels, as well as devices that use mercury switches and/or electromechanical triggers. Within the sensor industry, tilt sensor generally refers strictly to the sensing element itself. Once conditioning electronics are added, the enhanced device becomes known as an inclinometer.

Many types of tilt sensors and inclinometers are available on the market today, some of them dating back more than 50 years. Most can be assigned to one of three categories: force balanced, solid state (MEMS), and fluid filled. Each category encompasses many variations, each having its own advantages and disadvantages. For example, the force-balanced type generally provides superior performance but costs more. MEMS-based designs feature integral signal conditioning and relative ease of installation, but their extremely high thermal coefficients require significant compensation to obtain acceptable accuracy in many applications. Fluid-filled tilt sensors constitute the largest industrial market sector by far, due primarily to their relative low cost-to-performance ratio [8].

This work describes how MEMS-based accelerometers are used to measure the tilt of an object. Accelerometers can be used for measuring both dynamic and static measurements of acceleration [4]. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree resolution of a tilt measurement, a low-g, high-sensitivity accelerometer is required [1]. The Freescale MMA7260Q accelerometer is a good solution for XYZ tilt sensing [3]. This device provides a sensitivity of 800 mV/g in 3.3 V applications. It will experience acceleration in the range of +1g to -1g as the device is tilted from -90 degrees to +90 degrees.

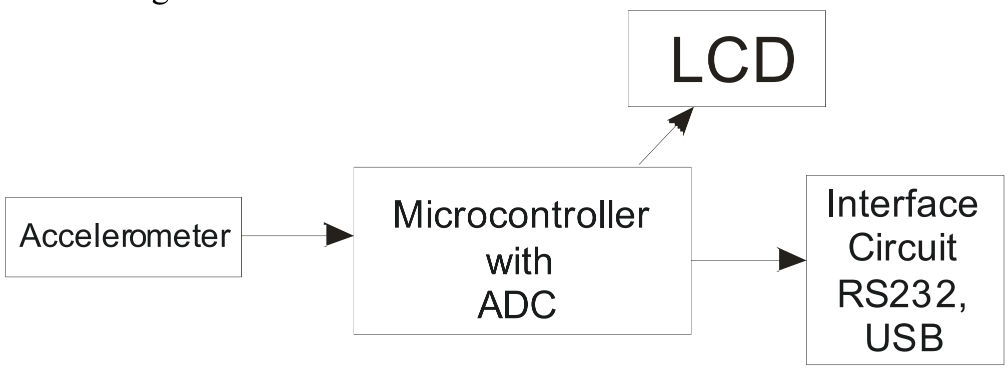

Fig. 1. Typical Tilt Application Block Diagram

A simple tilt application can be implemented using an 8 or 10-bit microcontroller that has 3 ADC channels to input the analogue output voltage of the accelerometers and general purpose I/O pins for displaying the degrees either on a PC through a communication protocol or on an LCD. See Fig. 1 for a typical block diagram. Some applications may not require a display at all. These applications may only require an I/O channel to send a signal for turning on or off a device at a determined angle range.

2. MOUNTING CONSIDERATIONS

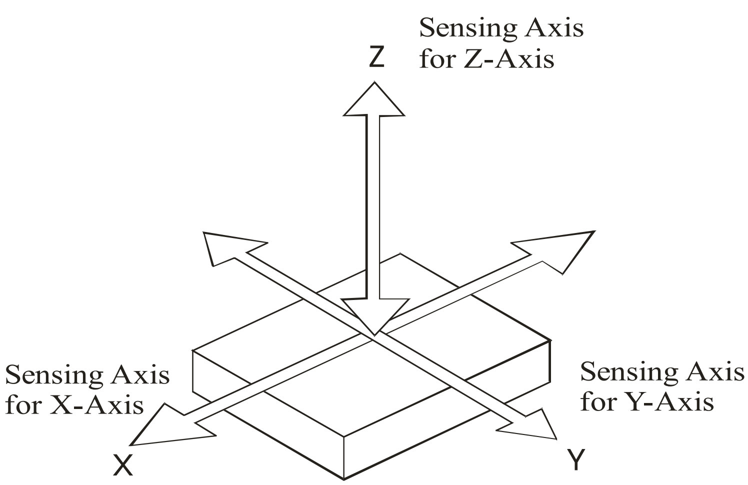

Fig. 2. Sensing Axis for the MMA7260Q Accelerometer With X, Y, and Z-Axis for Sensing Acceleration

Device selection depends on the angle of reference and how the device will be mounted in the end application. This will allow you to achieve the highest degree

resolution for a given solution due to the nonlinearity of the technology. First, you need to know what the sensing axis is for the accelerometer. See Fig. 2 to see where the sensing axes are for the MMA7260Q [3].
To obtain the most resolution per degree of change, the integrated circuit (IC) should be mounted with the sensitive axis parallel to the plane of movement where the most sensitivity is desired. For example, if the degree range that an application will be measuring is only 0° to 45° and the printed circuit board (PCB) will be mounted perpendicular to gravity, then an X-Axis would be the best solution. If the degree range was 0° to 45° and the PCB will be mounted perpendicular to gravity, then a Z-Axis device would be the best solution. This is understood more when thinking about the output response signal of the device and the nonlinearity [2].

3. CALCULATING DEGREE OF TILT

In order to determine the angle of tilt, θ, the analogue-to-digital (A/D) values from the accelerometer are sampled by the ADC channel on the microcontroller. The acceleration is compared to the zero g offset to determine if it is a positive or negative acceleration, e.g., if value is greater than the offset then the acceleration is seeing a positive acceleration, so the offset is subtracted from the value and the resulting value is then used with a lookup table to determine the corresponding degree of tilt, or the value is passed to a tilt algorithm. If the acceleration is negative, then the value is subtracted from the offset to determine the amount of negative acceleration and then passed to the lookup table or algorithm.

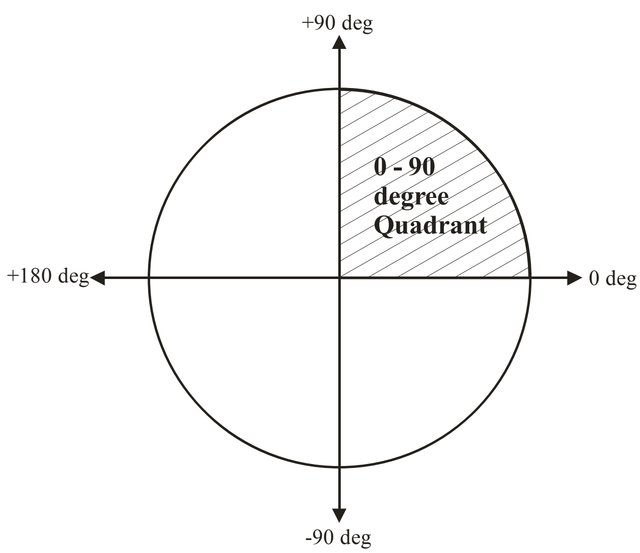

Fig. 3. The Quadrants of a 360 Degree Rotation

One solution can measure 0° to 90° of tilt with a single axis accelerometer, or another solution can measure 360° of tilt with two axis configuration (XY, X and Z), or a single axis configuration (e.g. X or Z), where values in two directions are converted to degrees and compared to determine the quadrant that they are in.

A tilt solution can be solved by either implementing an arccosine function, an arcsine function, or a look-up table depending on the power of the microcontroller and the accuracy required by the application [5], [6]. For simplicity, we will use the equation: $\theta = \arcsin(x)$. The arcsin(y) can determine the range from 0° to 180°, but it cannot discriminate the angles in range from 0° to 360°, e.g. arcsin(45º) = arcsin(135º). However, the sign of x and y can be used to determine which quadrant the angle is in. By this means, we can calculate the angle β in one quadrant (0-90º) using arcsin(y) and then determine θ in the determined quadrant.

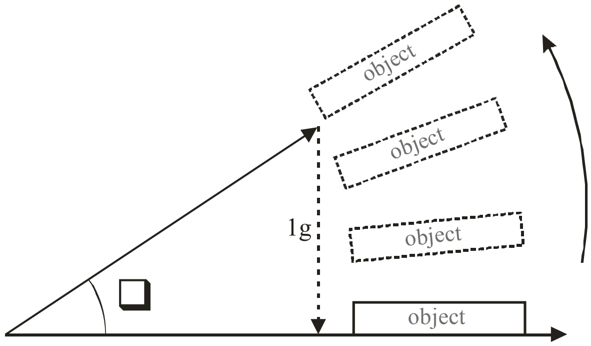

Fig. 4. An Example of Tilt in the First Quadrant

$$V_{OUT} = V_{OFF} + \left(\frac{\Delta V}{\Delta g} \bullet 1.0g \bullet \sin\theta\right) \qquad (1)$$

where:
V_{OUT} = Accelerometer Output in Volts
V_{OFF} = Accelerometer 0g Offset
$\Delta V/\Delta g$ = Sensitivity
1g = Earth's Gravity
θ = Angle of Tilt
Solving for the angle:

$$\theta = \arcsin\left(\frac{V_{OUT} - V_{OFF}}{\frac{\Delta V}{\Delta g}}\right) \qquad (2)$$

This equation can be used with the MMA6260Q as an example:

$$V_{OUT} = 1650mV + 800mV \times \sin\theta \qquad (3)$$

Where the angle can be solved by

$$\theta = \arcsin\left(\frac{V_{OUT} - 1650mV}{800mV/g}\right) \qquad (4)$$

From this equation, you can see that at 0° the accelerometer output voltage would be 1650 mV and at 90° the accelerometer output would be 2450mV.

4. INTERFACING TO ADC

4.1 An 8-Bit ADC

An 8-bit ADC cuts 3.3V supply into 255 steps of 12.9mV for each step. Therefore, by taking one ADC reading of the MMA6260Q at 0g (0°of tilt for an X-axis device) and 1g (90° of tilt for an X-axis device), would result in the following:

0°: 1650mV + 12.9mV = 1662.9mV,
which is 0.92° resolution

90°: 2450mV+ 12.9mV = 2462.9mV,
which is 6.51° resolution

Due to the nonlinearity, you will see that the accelerometer is most sensitive when the sensing axis is closer to 0°, and less sensitive when closer to 90°. Therefore, the system provides a 0.92 degree resolution at the highest sensitivity point (0 degrees), and a 6.51 degree resolution at the lowest sensitivity point (90°).

4.2 A 10-Bit ADC

A 10-bit ADC cuts 3.3V supply into 1023 steps of 3.2mV for each step. Therefore, by taking one ADC reading of the MMA6260Q again at 0g (0° of tilt for an X-axis device), would now result in the following:

0°: 1650mV + 3.2mV = 1653.2mV

90°: 2450mV + 3.2mV = 2453.2mV

This results in a 0.229 degree resolution at the highest sensitivity point (0°) and a 3.26 degree resolution at the lowest sensitivity point (90°).

4.3 A 12-Bit ADC

A 12-bit ADC cuts 3.3V supply into 4095 steps of 0.8mV for each step. Therefore, by taking one ADC reading of the MMA6260Q again at 0g (0° of tilt for an X-axis device), would now result in the following:

0°: 1650mV + 0.8mV = 1650.8mV

90°: 2450mV + 0.8mV = 2450.8mV

This results in a 0.057 degree resolution at the highest sensitivity point (0°) and 1.63 degree resolution at the lowest sensitivity point (90°). However, for 0.8mV changes, the noise factor becomes the factor to consider during design. How much noise the system has will depend on how much resolution you can get with a higher bit count.

Our solution is based on a mid-range low cost microcontroller from Microchip – 16F876 [7]. It is suitable because of its internal analogue to digital converter (ADC). The ADC is 5-channel with 10 bits resolution allowing us to achieve 0.229 degree resolution at the highest sensitivity point (0°). The reference voltage for the ADC is externally supplied allowing specifying a precise reference point for the measurement. The microcontroller has a serial port which enables connectivity with other devices such as personal computer for transferring the measured tilt.

5. Conclusion - Tilt Applications

The combination of low cost MEMS accelerometers and microcontrollers opens the door to economically feasible tilt measurement and monitoring equipment for widespread use in industrial environments where financial considerations today still limit it. The presented intelligent module supports the development and evaluation of new and cost-effective alternatives for some of the existing solutions.

There are many applications where tilt measurements are required or will enhance its functionality. In the cell phone market and handheld electronics market, tilt applications can be used for controlling menu options, e-compass compensation, image rotation, or function selection in response to different tilt measurements. In the medical markets, tilt is used for making blood pressure monitors more accurate. They can also be used for feedback for tilting hospital beds or chairs. A tilt controller can also be used for an easier way to control this type of equipment. Accelerometers for tilt measurements can also be designed into a multitude of products, such as game controllers, virtual reality input devices, HDD portable products, computer mouse, cameras, projectors, washing machines, and personal navigation systems.

6. REFERENCES

[1] Kitchin, Charles, Using Accelerometers in Low g Applications, Analogue Devices Application Note AN- 374.
[2] Chua, C. S., Impact Measurement Using Accelerometers, Freescale Semiconductor Application Note AN1611.
[3] Freescale Semiconductor Technical Datasheet, MMA7260Q, 2005.
[4] Payne, R. P., Dinsmore, K. A.: Surface Micromachined Accelerometer: A Technology Update. SAE Int. Cong., Detroit, 1991, pp. 127 – 135.
[5] Shearman, S.: Machine Condition Monitoring, Sensors Magazine, May 2002.
[6] Doscher, J., Kitchin, C.: Monitoring Machine Vibration with Micromachined Accelerometers, Sensors Magazine, May 1997.
[7] Microchip, PIC16F87x Data Sheet
[8] Puccio, M. R., Electrolytic Tilt Sensors and Inclinometers: A Primer, Sensors Magazine, September 2004.