Introduction

This application note describes how to use a Kionix tri-axis accelerometer to perform a screen rotation function and a device orientation function on a portable handheld electronic device. An accelerometer is used to measure the orientation of the device. Based on the orientation of the device, images and text can be rotated on the screen to appear upright to the user. Figure 1 shows an example of screen rotation. In addition to simply rotating images and text based on orientation, device function can also be changed based on orientation.

Figure 1. Screen rotation example

Screen Rotation Basics – Tilt Sensing

Screen rotation applications utilize the tilt-sensing capabilities of a tri-axis accelerometer. A tri-axis accelerometer measures acceleration in three orthogonal directions, as shown in Figure 2.

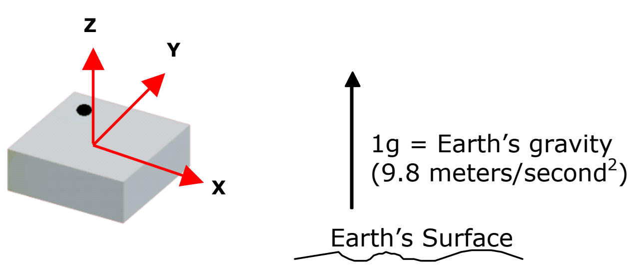

Figure 2. Three orthogonal axes

In Figure 2, the Z-axis is measuring 1g of acceleration because it is aligned with the direction of gravity, and the X-axis and Y-axis are measuring 0 acceleration because they are perpendicular to the direction of gravity. As the accelerometer is rotated around the Y-axis or X-axis, the portion of gravity measured by each axis will change. The mathematical relationship between tilt angle and acceleration is shown in Figure 3.

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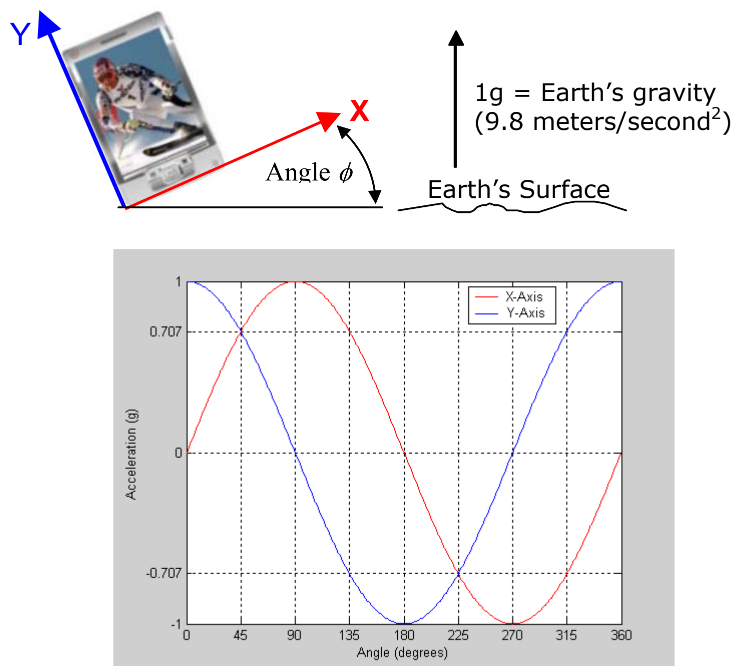

X acceleration = sin(ϕ)

Y acceleration = cos(ϕ)

Figure 3. Graphical representation of relationship between tilt and acceleration

As shown in Figure 3, the four orientations (0°/360°, 90°, 180°, and 270°) are simple to distinguish from each other by looking at the X-Axis and Y-Axis accelerations. Table 1 shows the acceleration at each of the four orientations.

Orientation	X Acceleration (g)	Y Acceleration (g)
0°/360°	0	1
90°	1	0
180°	0	-1
270°	-1	0

Table 1. Acceleration at the four orientations

To determine the orientation of the device, it is a simple matter of checking whether the X-Axis or Y-Axis accelerations are close (within a certain threshold) to 0g, 1g or –1g. Table 2 shows the comparisons that should be done to determine the orientation, with a threshold tilt angle ϕ_T. For the device to be at a specific orientation, the tilt angle needs to be within ϕ_T degrees of that orientation.

Orientation	X Acceleration (g)	Y Acceleration (g)
0°/360°	$-\sin(\phi_T) < a_x < \sin(\phi_T)$	$a_y > \cos(\phi_T)$
90°	$a_x > \cos(\phi_T)$	$-\sin(\phi_T) < a_y < \sin(\phi_T)$
180°	$-\sin(\phi_T) < a_x < \sin(\phi_T)$	$a_y < -\cos(\phi_T)$
270°	$a_x < -\cos(\phi_T)$	$-\sin(\phi_T) < a_y < \sin(\phi_T)$

Table 2. Acceleration at the four orientations with threshold tilt angle ϕ_T

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Table 2 shows that in order for the orientation to be 0°/360°, the X acceleration must be between $-\sin(\phi_T)$ and $\sin(\phi_T)$, AND the Y acceleration must be greater than $\cos(\phi_T)$. To determine screen orientation, perform tests on the X and Y acceleration at a regular time interval. If none of the above criteria are met, then the orientation should not be changed.

The choice of ϕ_T, the threshold, determines the angle at which the screen rotates. Table 3 shows the acceleration limits for a threshold, ϕ_T = 45°.

Orientation	X Acceleration (g)	Y Acceleration (g)
0°/360°	$-0.707 < a_x < 0.707$	$a_y > 0.707$
90°	$a_x > 0.707$	$-0.707 < a_y < 0.707$
180°	$-0.707 < a_x < 0.707$	$a_y < -0.707$
270°	$a_x < -0.707$	$-0.707 < a_y < 0.707$

Table 3. Acceleration at the four orientations with threshold tilt angle 45°

Advanced considerations

The method introduced above is adequate, but it does not consider some important factors that can enhance the implementation if taken into account. These factors are: Hysteresis, Sample Rate, Averaging/Delay, Device Orientation Angle, and High-g Accelerations.

Hysteresis

A 45° tilt angle threshold seems like a good choice because it is halfway between 0° and 90°. However, a problem arises when the user holds the device near 45°. Slight vibrations and noise will cause the acceleration to go above and below the threshold rapidly and randomly, so the screen will quickly flip back and forth between the 0° and the 90° orientations. This problem can be avoided by choosing a threshold angle less than 45°; 30° is a good choice. With a 30° threshold, the screen will not rotate from 0° to 90° until the device is tilted to 60° (30° from 90°). To rotate back to 0°, the user must tilt back to 30°, thus avoiding the screen flipping problem. Table 4 shows the acceleration limits for ϕ_T =30°.

Orientation	X Acceleration (g)	Y Acceleration (g)
0°/360°	$-0.5 < a_x < 0.5$	$a_y > 0.866$
90°	$a_x > 0.866$	$-0.5 < a_y < 0.5$
180°	$-0.5 < a_x < 0.5$	$a_y < -0.866$
270°	$a_x < -0.866$	$-0.5 < a_y < 0.5$

Table 4. Acceleration at the four orientations with threshold tilt angle 30°

Sample Rate

The sample rate is how often the accelerometer outputs are measured. For the screen rotation application, the sample rate can be low, less than 10 samples per second (10 Hz). The best sample rate for a particular application will depend on the desired response time. Slow sample rates will delay the screen rotation more than fast sample rates. If power savings are desired, the accelerometer can be disabled (if the accelerometer supports a low-power shutdown mode) between samples to reduce the average current draw.

Averaging/Delay

In any handheld application there will be significant vibrations caused by natural human motion. These vibrations can cause the acceleration to appear within an incorrect orientation range for a very brief time. If no averaging of multiple samples or delay is used, the screen orientation could be incorrect for a short time. The use of averaging and/or delaying will solve this problem.

To implement averaging, store the most recent acceleration samples and average them before comparing to the appropriate thresholds. Any spurious acceleration spikes will be smoothed out, and not interfere with the screen orientation. At least 3 samples should be averaged to have any effect; more averages will improve stability but slow down the response time.

To implement a delay, choose a certain number of samples where the orientation is the same before switching to that orientation. For example, with a delay of 3, the orientation must be the same for 3 samples before switching to that orientation. An appropriate delay will prevent undesired screen rotations while still responding quickly enough.

Device Orientation Angle

The method considered so far has assumed that the device is in the ideal vertical orientation – where the angle θ in Figure 4 is 90°. This won't always be the case for a handheld device.

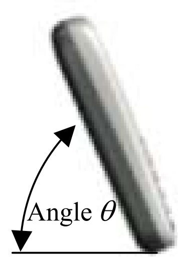

Figure 4. Device Orientation Angle

As the angle in Figure 4 is decreased, the maximum gravitational acceleration on the X-axis or Y-axis will also decrease. Therefore, when the angle becomes small enough, the user will not be able to make the screen orientation change. Using the above example of a ϕ_T = 30° tilt threshold, this problem will occur at a device orientation angle θ of 60°. A more advanced screen rotation algorithm is needed to take into account the device orientation angle.

One way to account for the device orientation angle is to use the Z-axis of the tri-axis accelerometer. As the orientation angle decreases, the acceleration on the Z-axis increases and the maximum gravitational acceleration on the X-axis or Y-axis decreases. So, the threshold tilt angle ϕ_T can be a function of the Z-axis acceleration. As the Z-axis acceleration increases, the threshold tilt angle can be increased as well according to the following equation:

$$\phi_{T\_NEW} = \cos^{-1}\left(\sqrt{1-a_z^2} \times \cos(\phi_T)\right).$$

When the device orientation angle becomes 0° (device is flat on a desk or table), a_x = a_y = 0g, a_z = +1g, and there is no way to determine which way the screen should be oriented. An effective screen rotation algorithm should only change the screen orientation when the orientation angle is above a certain threshold. The device orientation angle can be detected using the Z-axis acceleration:

$$\theta = \cos^{-1}(a_z).$$

High-g Accelerations

Under normal tilt circumstances, the total acceleration on the device is always equal to 1g, gravitational acceleration.

$$a_{total} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Total Acceleration

If the device is shaken or moved quickly, the accelerometer will measure more than 1g of acceleration. In these high-g situations, the screen orientation should not be changed, so the screen rotation algorithm should not change the screen when high-g accelerations are detected.

Device Orientation

In addition to rotating text and images on the screen based on device rotation, device functions can be controlled by the device orientation. For example, if a mobile phone is sitting flat on a desk and an incoming call is received, flipping the phone over can direct the call to voicemail. This is a simple, effective use of the accelerometer Z-axis. Figure 5 shows the Z-axis accelerations in both orientations.

Figure 5. Z-axis acceleration in right side up and upside down orientations

To detect whether the device is oriented right side up or upside down, measuring the Z-axis acceleration is necessary. When the device is right side up, the Z-axis acceleration is close to 1g. When the device is upside down, the Z-axis acceleration is close to –1g. In both cases, the X-axis and Y-axis acceleration are close to 0g because they are perpendicular to gravitational acceleration, so the orientation cannot be sensed with a dual-axis accelerometer.

Conclusions

A single Kionix tri-axis accelerometer can be used to enable both screen rotation and device orientation functions in a handheld electronic device. To achieve a successful implementation, careful consideration must be given to the subtle factors described above.

The Kionix Advantage

The Kionix tri-axis accelerometers can measure 360° of tilt around any axis with great precision. Kionix technology provides for X, Y and Z-axis sensing on a single, silicon chip. One accelerometer can be used to enable a variety of simultaneous features including, but not limited to:

Tilt-screen navigation
Game playing
Image stability, screen orientation
Drop force modeling for warranty protection
HDD shock protection
Theft, man-down, accident alarm
Computer pointer
Navigation, mapping
Automatic sleep mode

Theory of Operation

Kionix MEMS linear tri-axis accelerometers function on the principle of differential capacitance. Acceleration causes displacement of a silicon structure resulting in a change in capacitance. A signal-conditioning CMOS technology ASIC detects and transforms changes in capacitance into an analog output voltage, which is proportional to acceleration. These outputs can then be sent to a micro-controller for integration into various applications. For product summaries, specifications, and schematics, please refer to the Kionix MEMS accelerometer product sheets at http://www.kionix.com/sensors/accelerometer-products.html.