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Inertial Sensing for Hard Disk Drive Drop Protection

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HDD Protection — A Market Imperative

The worldwide growth rate for portable electronic products, which are more and more likely to contain a hard disk drive (HDD), is impressive.

Earlier this year, the IT market research specialists at IDC reported that worldwide mobile phone shipments totaled 194.3 million units in the fourth quarter of 2004; that 46.8 million digital music players were sold in 2004, with a projection of 132 million in 2009; and that worldwide PDA shipments totaled 3.4 million units in the first quarter of 2005. *USA Today*, in an April 14 special report, indicated that nearly 49 million laptops were sold worldwide in 2004, almost double the number sold in CY 2000.

These numbers alone add up to a compelling requirement for an active hard disk drive drop-protection feature in highly-portable, “always-on” products. Data loss, and its resulting impact on productivity, adds another persuasive argument to the critical need for HDD drop protection.

Objectives and Complexities

The objective in HDD drop detection is to reliably detect, by means of an inertial sensor (accelerometer), an object in free fall and to signal the drive head to park safely prior to impact. Very simply, free fall is the descending motion of an object subject only to gravity.

Drop detection is a simple notion that involves a complicated detection process, largely because portable electronic products are subject to complex motion during use. For example, we want to signal free fall when a device is at risk and tumbling toward the ground. But, we do not want to signal free fall when the device is responding to typical-use events such as running, where low-g periods are long enough to look like free-fall, and dancing, where high-g periods can reach 4.2g. Thus, the process must be capable of distinguishing between typical-use motion and a genuine fall, so as to not trigger a false positive. Consumers grow tired quickly of a protection feature that disables a portable computer when the user was adjusting its tabletop position.

The process is further complicated by irregular real-life motions such as tapping or shaking, the requirements for positioning the motion sensor, the complexities associated with threshold detection techniques, and the changes in the center of mass on products such as flip phones and laptops when open or closed.

The Physics of Free Fall

In a simple free fall event, since a = 1 g (9.8 m/s^2) and initial velocity is 0 ($v_0 = 0$), the equation of motion can be used to determine the position of an object at any time after it is dropped.

Equation of Motion $z = z_0 + v_0 t + ½\, a t^2$

If the initial height from the ground (z_0) is known and the initial velocity (v_0) is zero, then the time it takes for an object to impact the ground is $t = (2\, z_0/g)^{½}$. Therefore, from a height of one meter, an object will take 0.45 seconds (450 milliseconds) to impact the ground.

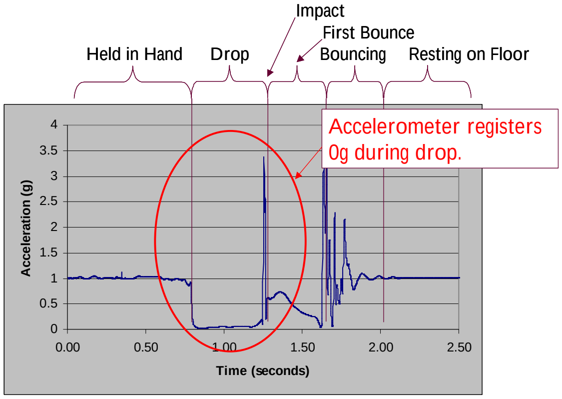
Unfortunately, free fall is not always simple because hand-held devices rarely fall without incurring a tumbling spin, thus complicating the physics. A spinning object is subject to acceleration that can be significant in its centripetal and centrifugal forces. Centripetal force is that which holds the object in the center of the spin; centrifugal force is Newton's "equal and opposite reaction," displacing the object from the center of the spin.

Accelerometers for Drop Detection

Silicon micromechanical technology has enabled the production of low-cost, small form-factor accelerometers capable of detecting linear acceleration on one, two or three axes. These devices are etched from single-crystal silicon and function on the principle of differential capacitance. Essentially, it is a mass on a spring. The mass is capable of motion relative to the substrate and moves in response to acceleration. This movement results in a change of capacitance that is detected and transformed into an electrical signal by an Application Specific Integrated Circuit (ASIC).

An accelerometer at rest measures 1g of acceleration and an accelerometer in simple free fall measures 0g of acceleration, no matter their orientation. Simple free fall suggests a very simple drop detection algorithm: When total acceleration equals 0, the object is in free fall.

The "signature" of a simple drop is shown in Graphic 1. The signature depicts the fall from the object's pre-drop (1g) condition to its post-drop (1g) condition.

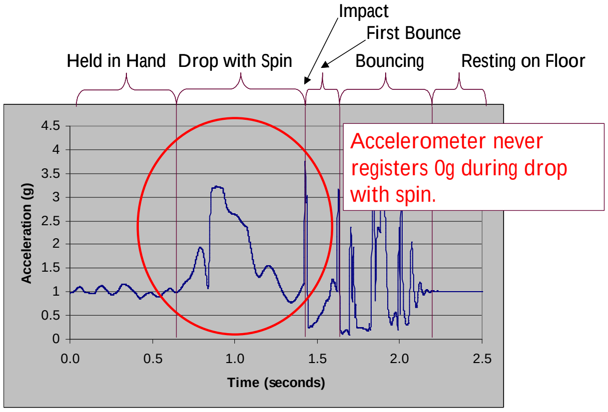


Accelerometer registers 0g during drop.

Graphic 1. Simple free fall of a cell phone.

In the above case, a Kionix KXM52-1050 tri-axis accelerometer was placed in a cell phone approximately 3 cm from the center of mass and flat-dropped to a hard surface from approximately one meter. The accelerometer, as expected, measured at or near 0g acceleration prior to impact in this simple free-fall experiment.

This same phone was dropped again to a hard surface but was subjected to a spin of approximately 4 revolutions per second, a more accurate real-life scenario. As can be seen in this drop signature below (Graphic 2), the accelerometer never registered 0g during the entire fall. Rather, it measured over 3.5g during the drop with spin. A similarly-mounted tri-axis accelerometer, located 5 cm from the center of mass on a popular MP3 player mock-up, produced the same impact profile, registering over 3g of acceleration as it spun out of control prior to impact.



Accelerometer never registers 0g during drop with spin.

Graphic 2. Free fall of a cell phone with spin.

Gauging Response Times

Damaging free-fall events consume very little time, but sufficient time is needed to execute hard drive protection. The accelerometer and associated microcontroller must recognize that an event is occurring and determine the nature of the event—free fall or not—and, if appropriate, trigger the hard drive protection feature while still leaving enough time to park the read/write head in safety. The challenge is to accomplish this within fractions of a second.

The table below presents the time it would take for an object to impact a hard surface from a range of fall heights.

Height From Which an Object Falls (m)	Time Consumed from Fall to Impact (ms)	Maximum Force Experienced (g)
0.01	45.16	
0.02	63.87	
0.1	142.81	
0.2	201.96	200
0.3	247.35	
0.4	285.62	400
0.5	319.33	500
0.6	349.81	
0.7	377.84	
0.8	403.92	1000
0.9	428.43	
1	451.60	1200
1.1	473.64	1500
1.2	494.70	
1.3	514.90	2000
1.4	534.34	
1.5	553.10	2800
1.6	571.23	

Table 1: Fall heights and response times.

Consider how a product might be protected from a 400g-impact threat. To sustain a shock of 400g, a product need be dropped only from a height of 0.4 meters, and the entire event, from fall to impact, will take approximately 285.62 milliseconds.

The KXM52-1050 accelerometer can determine the onset of free fall in four milliseconds. If an additional 70 milliseconds is required to park the hard drive head, there is only a budget of 211 milliseconds during which the microcontroller must discern free fall and signal the park.

Signaling the Drop Interrupt

A tri-axis accelerometer can reliably detect free fall. Once detected, the motion of the spinning hard drive must be interrupted, and the drive head must be signaled to park in safety. This critical function must occur at the appropriate time—at the point of actual free fall—within fractions of a second and without a misread.

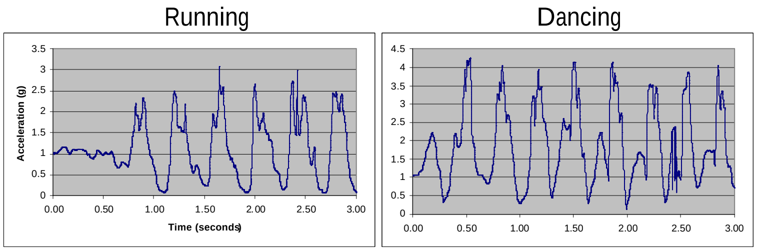
The following considerations are key to determining the correct timing for interrupt and the choice of low-g or high-g thresholds for triggering the interrupt:

1. Maximum g-forces experienced by the object during typical use.
2. Minimum g-forces experienced by the object during typical use.
3. The length of time an object spends at these levels (dwell time).
4. The maximum allowable g-force on the object.

In other words, we need to determine the maximum and minimum g-force points along with the length of time spent at these levels in order to determine the appropriate point to signal a drop interrupt. The time spent above or below a certain g-force level is the key to differentiating between a typical-use event and a tumbling drop.

The simple free-fall detection algorithm—an object is in free fall when acceleration on all three axes equals 0—works only if the object does not spin and/or the accelerometer is placed at the center of mass. If this placement is not possible, given the location of the hard drive in a particular product, more complex high-g/low-g threshold algorithms are required to accurately detect free fall.

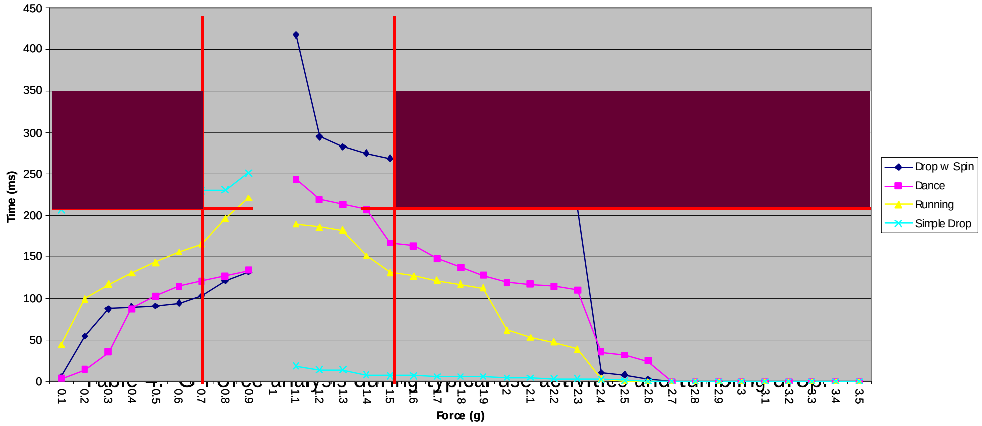
The centrifugal force experienced by an object during a tumbling fall is read by the accelerometer as a high-g event, as depicted earlier in Graphic 2. But, accelerometer readings can show high-g and low-g events in typical-use activities such as running and dancing, as depicted in Graphic 3 below.


Running

Dancing

Graphic 3. G-force analysis during typical use activities, running and dancing.

Again, the key to differentiating between typical use and a tumbling drop is the time spent above or below a certain g-force level (dwell time). Graphic 4 below presents the maximum dwell times for a simple drop, a drop with spin, dancing and running for a 400g threat.

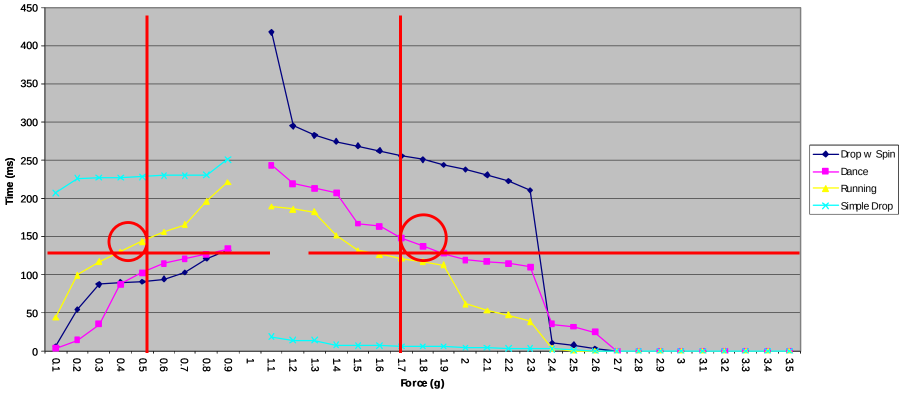


Graphic 4. Maximum dwell times for a 400g threat.

In the above depiction, the "algorithm" is set to trigger a free-fall notification for any event lower than 0.7g for longer than 211 ms or any event higher than 1.5g for longer than 211 ms. In this case, the interrupt will be triggered appropriately by a simple drop (low-g case) or by a drop with spin (high-g case).

If the object can be used in an active environment and will withstand an operating impact of 400g, the accelerometer settings would be as follows: The low-g threshold would be set at .5g with a minimum dwell time of 175 ms or a maximum dwell time of 211 ms, and the high-g threshold would be set at 1.5g with the same minimum and maximum dwell times. Set at these levels, the accelerometer will trigger a park prior to an impact of 400g or greater and will not park the heads during typical use.

The graph below presents the maximum dwell times for a simple drop, a drop with spin, dancing and running for a 200g threat with a wait time of 127 ms before interrupt is triggered.



Graphic 5. Maximum dwell times for a 200g threat.

At these levels and these dwell times, as depicted in Graphic 5 (see red circles), some typical-use events will cause a false positive.

Conclusions

The convergence of larger and larger capacity hard disk drives in ever smaller, more portable products is creating a compelling need for drop protection features. Moreover, the environment for portable platforms is rapidly becoming one in which these products are operating while in motion, again making drop protection features an imperative.

Accurate and reliable free-fall detection, with adequate time to park the disk head prior to impact, is possible with a tri-axis accelerometer. Understanding that the key to distinguishing between typical-use activities and genuine threats is the amount of time the product spends above or below certain g-level thresholds, Kionix has developed tri-axis accelerometers with features specific to hard disk drive drop detection. These products allow customers to program the part with the high-g and low-g limits and program the duration of the high-g and low-g periods. Armed with this information, the accelerometer knows if and when to signal the hard drive to park.

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