Ask the Applications Engineer—29

By Harvey Weinberg*

ACCELEROMETERS—FANTASY and REALITY

Q. *As an Applications Engineer for the Micromachined Products Division supporting the compact, low-cost, gravity-sensitive Analog Devices line of integrated accelerometers[1] you must get to hear lots of creative ideas from prospective customers about how to employ accelerometers in useful ways.*

A. Yes, but sometimes what they are suggesting violates physical laws! We've come to rate them in various categories on an informal "reality" scale:

- ***Real*** – A real application that actually works today and is currently in production.
- ***Possible*** – An application that is technically feasible, but not (to our knowledge) in production.
- ***Fantasy*** – An application that could be possible if we had much better technology.
- ***Dream Land*** – An application that would be nice, but any practical implementation we can think of would violate some physical laws.

Would you like to see some of these ideas (the ones we're free to mention), hear about their potential benefits, think about them, and guess which category they belong in?

Q. *Sure, go ahead.*

A. O.K. You can find (and link to) the answers, with commentary, below.

Washing Machine Load Balancing
Unbalanced loads during the high-speed spin-cycle cause washing machines to shake, and in some cases, to even "walk" across the floor if unrestrained. An accelerometer senses the accelerations present during the unbalanced spin. If such an imbalance is present, the washing machine redistributes the load by jogging the drum back and forth a few times until the load is balanced. *Real or fantasy*? See answer A.

Machine Health Monitors
Many industries change or overhaul mechanical equipment using a calendar-based preventive maintenance schedule. This is especially true in applications where one cannot afford or tolerate unscheduled down-time. So machinery with plenty of service life left is often prematurely rebuilt at a cost of millions of dollars across many industries. By embedding accelerometers in bearings, or other rotating equipment, service life can be extended without additional risk of sudden failure.

The accelerometer senses the vibration of bearings or other rotating equipment to determine their condition. *Real or fantasy*? See answer B.

Automatic Leveling
Accelerometers measure the absolute inclination of an object (e.g. a large machine, a mobile home, etc.). The tilt information is used by a microcontroller to automatically level it. *Real or fantasy*? See answer C.

Scroll Control for PDAs and Handyphones
The accelerometer allows the microcontroller to recognize gestures allowing the user one handed control of mobile devices. *Real or fantasy*? See answer D.

Car Alarm
Here the accelerometer senses if a car is being jacked up or being picked up by a tow truck, and sets off the alarm. *Real or fantasy*? See answer E.

Ski Bindings
The accelerometer measures the total shock energy and signature to determine if the binding should release. *Real or fantasy*? See answer F.

Personal Navigation
In this application, position is determined by dead reckoning (double integration of acceleration over time to determine actual position). *Real or fantasy*? See answer G.

Subwoofer Servo Control
An accelerometer is mounted on the cone of the subwoofer to provide positional feedback used to servo out distortion. *Real or fantasy*? See answer H.

Neuromuscular Stimulator
This application helps people, who have lost control of their lower leg muscles, to walk—by stimulating muscles at the appropriate time. *Real or fantasy*? See answer I.

Car-Noise Cancellation
The accelerometer senses low-frequency vibration in the passenger compartment, and the noise-cancellation system nulls it out, using the speakers in the car stereo system. *Real or fantasy*? See answer J.

ANSWERS

A. *Washing-machine load balancing:* **Real**. This application is currently in production. With better load balance, faster spin rates can be used to wring more water out of clothing, making the drying process more efficient. Fewer mechanical components are required for damping the drum motion, making the overall system lighter, and less expensive. In addition, transmission and bearing service life may be extended because of lower peak loads present on the motor. See http://www.analog.com/industry/*i*MEMS/markets/industrial/washing_machine.html for more information about washing machines. *Go to next question.*

B. *Machine health monitoring:* **Possible.** This application has been demonstrated but is not yet in production.

Using the vibrational "signature" of bearings to determine their condition is a well proven and industry-accepted method of equipment maintenance, However, the cost of accelerometers and the associated signal conditioning equipment has been traditionally too high. The ADXL105[2] offers a complete vibration measurement and signal conditioning solution on a chip at very low cost. See http://www.analog.com/industry/*i*MEMS/markets/industrial/machine.html for more information about machine health. *Go to next question.*

[1]http://www.analog.com/industry/iMEMS.
[2]http://products.analog.com/products/info.asp?product=ADXL105.

**His photo and a brief biography appear in Analog Dialogue 33, page 72.*

C. *Automatic leveling:* **Real to Fantasy** (depending on the application). There are some applications where this is practical and currently in production. Others are too demanding for current products.

Self-leveling is a very demanding application, as absolute precision is required. Surface micromachined accelerometers have impressive resolution, but absolute tilt measurement with high accuracy (to better than 1%) requires temperature stability and hysteresis performance that today's surface-micromachined accelerometers cannot achieve. Applications needing absolute accuracy to within ±3° or more are currently possible and a few such applications are in production. *Go to next question.*

D. *Scroll control:* **Real**. This application is currently (or almost, depending on press time) in production.

A PDA (like the 3com Palm Pilot) is incredibly handy, but almost impossible to use one-handed. Like when you're driving, or on the phone. Adding an accelerometer lets the PDA accept gesture inputs, like tilting up or down, to control the cursor or page up/down control. See http://www.analog.com/industry/*i*MEMS/markets/consumer/peripherals.html if you are interested in game controllers or are a Palm Pilot user and want to see how to add a tilt function to your PDA. *Go to next question.*

E. *Car alarm:* **Real**. This application is currently in production in OEM and after-market automotive anti-theft systems.

One of the most popular methods of auto theft is where the car is stolen by simply towing it away. Conventional car alarms do not protect against this. Shock sensors cannot measure changes in inclination, and ignition-disabling systems are ineffectual. Here is an application where the high-resolution capabilities of the ADXL202 are used to advantage. The accelerometer measures if the car's inclination is changing by more than 0.5° per minute. If so, the alarm is sounded, hopefully scaring off the would-be thief. Absolute stability is not required here (unlike automatic leveling systems) as temperature does not change significantly in a minute or less. See http://www.analog.com/industry/*i*MEMS/markets/automotive/car_alarms.html if you're interested in car alarms. *Go to next question.*

F. *Ski bindings:* **Fantasy**. This is a practical accelerometer application, but current battery technology (particularly low temperature performance) makes it impractical.

All mechanical ski bindings are highly evolved, but limited in their performance. Measuring the actual shock experienced by the skier would be a much more accurate way to determine if a binding should release. Intelligent systems could be developed that could take each individual's capability and physiology into account. Smaller and lighter batteries that perform well at low temperatures will, eventually, enable this application. *Go to next questio*n.

G. *Personal navigation*: **Dream Land.** Long term integration results in the accumulation of error due to small dc errors in the accelerometer, integrator input circuitry, wiring thermocouples, etc. Double integration compounds the errors (t^2). Without some way of "resetting" the actual position from time to time, huge errors result. This is analogous to building an op-amp integrator by simply putting a capacitor across it. Even if the accelerometer's accuracy is improved by ten or one hundred times better than currently available, huge errors would still eventually result. It would just take longer to happen.

Accelerometers can be used in conjunction with a GPS system when the GPS signals are briefly unavailable. Integration over a short time (a minute or so) can give satisfactory results. See http://www.analog.com/industry/*i*MEMS/markets/consumer/car_nav.html for more information about navigation. *Go to next question.*

H. *Subwoofer servo:* **Real**. Several active subwoofers with servo control are on the market today.

Servo control of subwoofers has several advantages. Harmonic distortion, as well as power compression, can be greatly reduced. In addition servo control can also electronically lower the *Q* of the speaker/enclosure system, enabling the use of smaller enclosures[3]. The ADXL190[4] is small and light; its mass, added to that of the loudspeaker cone, does not change the overall acoustic characteristics significantly. See http://www.analog.com/industry/*i*MEMS/markets/consumer/subwoofers.html for more information about active subwoofer applications, and http://www.analog.com/industry/*i*MEMS/markets/consumer/subwoofers/Subwoof.html#cir for circuits. *Go to next question.*

I. *Neuromuscular stimulator:* **Real.** This application is very near (if not already in) production.

When walking, the forefoot is normally raised when moving the leg forward, then lowered when pushing the leg backward. The accelerometer is worn somewhere on the lower leg or foot, where it senses the position of the leg. The appropriate muscles are then electronically stimulated to flex the foot as required.

This is a classic example of how micromachined accelerometers have made a product feasible. Earlier models used a liquid tilt sensor or a moving ball bearing (acting as a switch) to determine the leg position. Liquid tilt sensors had problems because of sloshing of the liquid, so only slow walking was possible. Ball-bearing switches were easily confused when walking on hills. Using an accelerometer, the differential between leg back and leg forward is measured, so hills do not fool the system and there are no liquid slosh problems. The low power consumption of the accelerometer allows the system to work with a small lithium battery, making the overall package unobtrusive. *Go to next question.*

J. *Car-noise cancellation:* **Dream Land.** While the accelerometer has no trouble picking up the vibration in the passenger compartment, noise cancellation is highly phase-dependent. So while we may cancel the noise in one location (say around the head of the driver), it will probably be increased at other locations.

CONCLUSION

Because of their sensitivity, compactness, low cost, ruggedness, and ability to measure both static and dynamic acceleration forces, surface micromachined accelerometers have made numerous new applications possible. Many of them were not anticipated because they were not thought of as classic accelerometer applications. The imagination of designers now seems to be the limiting factor in the scope of potential applications—but sometimes designers can become too imaginative! While performance improvements continue to enable more applications, it's wise to try to stay away from "solutions" that violate laws of physics.

[3]See R. A. Greiner and T. M. Sims, Jr., Loudspeaker Distortion Reduction, *Journal of the Audio Engineering Society*, Vol. 32, No. 12.
[4]http://products.analog.com/products/info.asp?product=ADXL190.