how it works

EMBEDDED PROCESSING AND A MEMS ACCELEROMETER FORM THE CORE OF A GOLF-TRAINING AID INTEGRATED INTO AN OTHERWISE-NORMAL GOLF HAT.

Electronics module keeps you swinging straight

By David C Kehlet, SK Communications

Swinghat addresses a deceptively simple golf maxim: Don't lift your head until you hit the ball. Anyone who has ever hit a screaming ground-level worm-burner on the course or at the driving range can grasp the wisdom behind this concept. Lifting your head pulls your shoulders, arms, and the club head up from the ball, resulting in an off-center shot. SK Communications of Sunnyvale, CA, developed the Swinghat—an electronics module mounted inside an otherwise-ordinary-looking golf hat—to help golfers keep their heads level from the start of their backswings through contact with the ball to achieve consistent and effective swings (**Figure 1**).

Golf students know how difficult it is to remember all of a golf pro's instructions during the few seconds of a swing. Swinghat takes charge of watching for the fundamental error of lifting the head. If a golfer lifts up, the Swinghat immediately sounds an audio alert. Within a few strokes, the golfer generally starts keeping his or her head in the swing, freeing the golfer's brain to work on other fundamentals of the swing.

SENSING IN SWINGHAT

In developing the Swinghat concept, SK engineers and Swinghat Inc president Cliff Miller came up with several ways to detect when the head moves up and down. They considered measuring the time of flight to and from a transponder mounted on a person's shoe and looking for an increase. They also thought of triangulating from reference points mounted on poles around the golfer. And, they could have processed a real-time video image and watched for the head to move. All of these approaches, although technically interesting and even fun, suffered from user inconvenience, cost problems, or both. The designers finally recognized that it was difficult and unnatural for a person to lift his or her head without changing the head's angle of tilt. If the developers could detect the right kind of change in the angle of the head relative to vertical, they could catch the error and alert the user. So, how do you effectively and economically measure tilt?

Figure 1

The Swinghat, a module mounted inside a golf hat, helps golfers keep their heads level for more effective swings.

Two previous SK projects measured tilt using fluid-filled sensors. As the object changed its angle with respect to the direction of gravity, the electrical conductivity between the terminals of the fluid-filled sensor changed. SK built a Swinghat prototype incorporating a fluid-filled tilt sensor (**Figure 2**). However, the difficulty with using off-the-

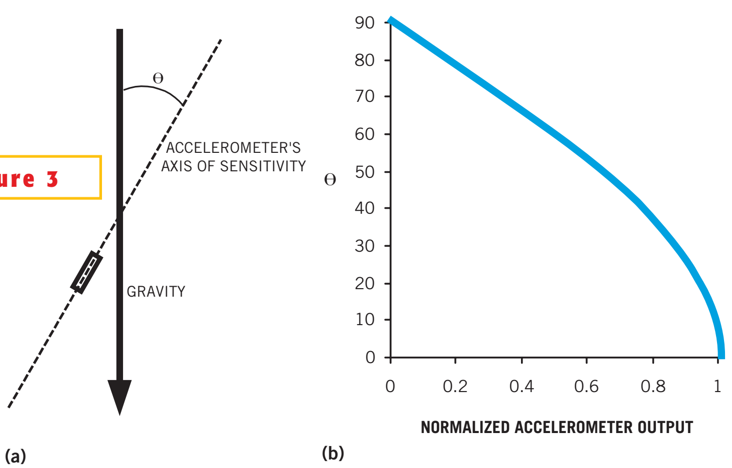
Figure 2

In an early prototype, a white clip holds a fluid-filled sensor to the module.

shelf sensors is that it is normal for a golfer to rotate his or her head during the backswing, and few sensors work with rotation. The designers filled their whiteboard with bottle and terminal sketches of tilt-sensor concepts, but, although a fluid-sensor scheme was valid both in performance and product cost, the R&D required was beyond the scope of the project.

The use of accelerometers to measure the direction of earth's gravity is well-known. Gravity is an acceleration, and an accelerometer senses its effect. With the accelerometer at steady state, you can find the angle between the accelerometer's axis of sensitivity and a line straight up from the center of the earth by calculating the arccosine of the accelerometer's output (**Figure 3**).

Figure 3



You can find the angle between the accelerometer at steady state's axis of sensitivity (a) and a line straight up from the center of the earth by calculating the arccosine of the accelerometer's output (b).

Two features of MEMS (microelectromechanical systems) accelerometers ultimately gave it an advantage over fluid-sensor ideas: First, several accelerometers are considerably smaller than off-the-shelf fluid sensors. Second, and more critical for the Swinghat application, was the ADXL202E's insensitivity to rotation around the axis of acceleration sensitivity. During a golfer's backswing, the golfer's head usually rotates around the axis formed by the spine and then counter-rotates as the forward swing progresses. The tilt sensor's output must be indifferent to how the head rotates. Although the designers conceived of fluid-filled tilt sensors that would be insensitive to rotation around their axis of sensitivity, the off-the-shelf sensors did not share this crucial property.

To select among accelerometers, designers studied several other components in addition to the Analog Devices ADXL202E, including the Motorola MMA1260D, the Silicon Designs 1010, and the MEMSIC MXD2010A. The combination of 3V operation and compact size made the ADXL202E the best fit for the application.

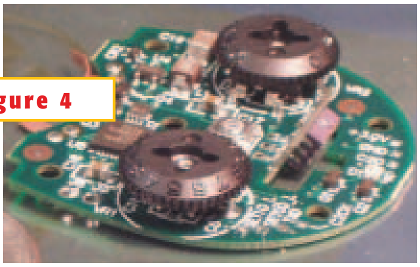
ADXL202E APPLICATION IN SWINGHAT

Figure 4 shows how the ADXL202E accelerometer fits into the Swinghat electronics. Swinghat uses only a single sensor output even as the ADXL202E and others provide dual-axis outputs. The digital PWM (pulse-width-modulated) output allows the convenience of using the microcontroller's counter hardware. A future Swinghat could easily use the analog output into a controller's ADC.

The key to Swinghat's rotation-insensitive tilt-sensing scheme is that the ADXL202E's axis of sensitivity must be parallel with the golfer's spine. The two need not be coincident but are so as a result of Swinghat's relocating the electronics away from the back of the hat and the adjustment strap. One of Swinghat's early prototypes used a back-of-the-head mounting scheme (**Figure 5**).

With the move to the top of the head, the physical size of the unit became critical. The electronics module needed to be very small. And in conflict with its size was the fact that the ADXL202E could no longer be coplanar with the pc board and other components. To keep the axis of sensitivity parallel with the spine, the Swinghat angles the ADXL202E up from the main pc board. To keep the product low cost, designers avoided using a connector by soldering between contacts of the main pc board and the ADXL202E daughterboard. Plastic wedges inside the electronics housing support the daughterboard to relieve strain on the solder joints.

Figure 4



Designers mounted the ADXL202E accelerometer at a 60° angle from the pc-board plane.

SIGNAL PROCESSING

Signal processing is the secret sauce in any sensor project. The Swinghat combines lowpass filtering for determining the tilt angle followed by highpass filtering to check for motion. This filtering combines with state processing to guard against alarms when the golfer is not actually lifting his or her head while swinging. Designers used The Mathworks' Matlab to develop the filters, choosing coefficients and cutoffs to allow integer arithmetic.

The tilt angle serves two purposes in Swinghat. Fundamentally, an upward change in the head angle indicates that the golfer has lifted his or her head. Swinghat also checks for a range of head angles that indicate whether the golfer is in the ready stance. The motion detection keeps the alert disarmed while the golfer is teeing up a ball or walking around the range. A key to this product is that it figures out on its own when the golfer is really swinging and when the golfer is doing something else. Preventing false alarms is crucial to making the Swinghat a usable training aid.

The ADXL202E data sheet's application notes recommend a standard power-supply decoupling scheme to decouple noise on V_{DD} at the accelerometer. A 100Ω series resistor and a ferrite bead from the digital supply feed the ADXL202E's V_{DD} pin with a 0.1-µF capacitor to ground. Swinghat dedicates the pc-board power plane of the accelerometer daughterboard to this filtered V_{DD}. Even so, power-supply noise from the rest of the system interfered with the accelerometer operation. A 1-µF capacitor greatly reduced the noise and was available in the 0402 size needed.

CALIBRATION

Ideally, every accelerometer part would have identical sensitivity and zero offset levels, eliminating the need for calibration. However, just like most sensors, the ADXL202E exhibits substantial variation from part to part. To facilitate calibration in production, each Swinghat unit contains built-in calibration firmware. This firmware reads the 0 and 1g values from the accelerometer and stores the result in flash RAM. The system later uses these values in operation to translate raw accelerometer values into a normalized form.

The Swinghat pc board uses ICT (in-circuit test) pads in a rotating calibration-test fixture. The ICT pads connect to I/O pins of the microcontroller, which senses their state at power-on. The ICT fixture pulls down each pin, which is normally pulled up, in succession when the board rotates to the 0 and 1g angles, respectively.□

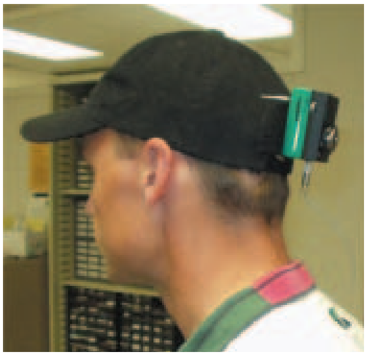


Figure 5 An early prototype that mounted on the back of the golfer's head still had the accelerometer axis parallel with the spine.

AUTHOR'S BIOGRAPHY

David Kehlet is a principal engineer at SK Communications, where he develops innovative products for engineering managers and funded entrepreneurs. He draws on 20 years of design experience for products, including medical instruments, computer and broadcast-video systems, and sensor systems. Before joining SK, Kehlet was director of hardware engineering at Sun Microsystems in the graphics and imaging group. He holds a BSEE and an MSEE from Stanford University (Stanford, CA), and his interests include Kempo karate, snowboarding, and, of course, golf.