A Sporting Chance
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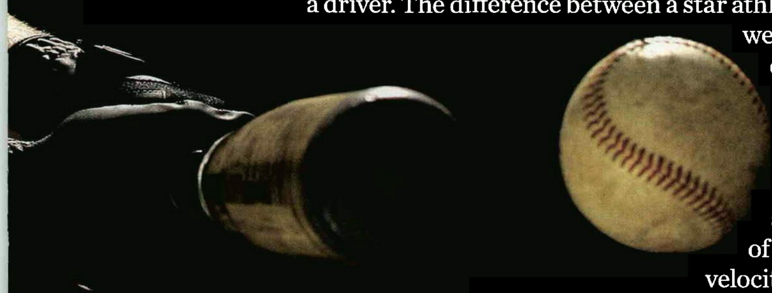
Chance

Coaches and athletes can use data from wireless sensors to improve sports training.

By Noel C. Perkins, Kevin King, Ryan McGinnis, and Jessandra Hough

Some sports focus on the pure motion of an athlete: the gymnast performing a floor exercise, say, or the sprinter dashing down the track. Other sports require the skilled use of a piece of equipment. A baseball player wields a bat, a quarterback throws a football, a golfer swings a driver. The difference between a star athlete and weekend duffer can be measured in angles as small as a couple of degrees and velocities measured in small fractions of meters per second. With practice and innate skill, an athlete can learn to achieve those motions, but it is hard for the naked eye of a coach or trainer to see the difference in real time. Because few athletes have access to the



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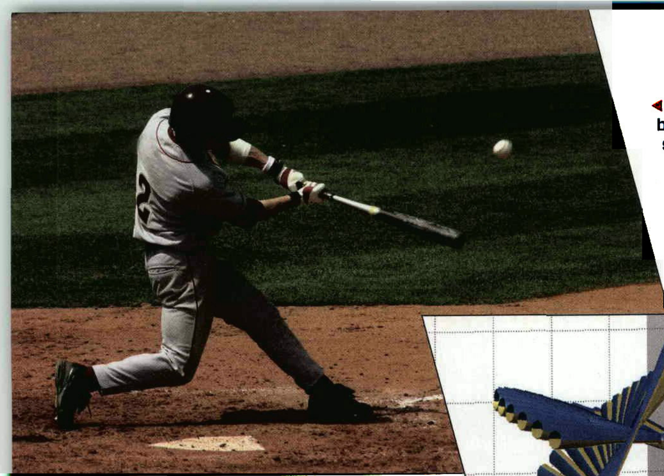
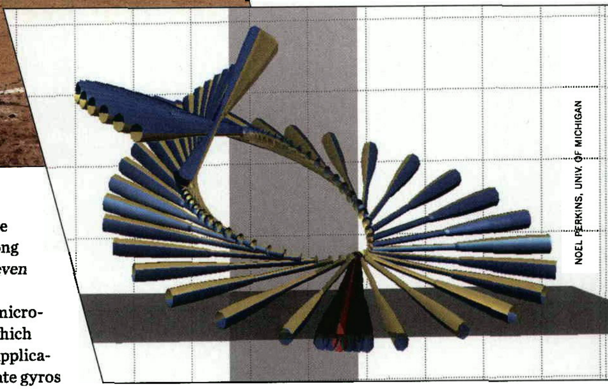


◀ Hitting a fastball requires both sharp reflexes and a good swing. Beginning with the bat almost vertical, the batter accelerates the bat down and through the horizontal plane of the "hitting zone" (shown below with black and red bats). A less than level swing can cause the bat to miss the ball.



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specialized motion-capture cameras and three-dimensional image analysis needed to augment the coach's eyes, an athlete might wind up spending long hours honing techniques that are poor at best, or even counterproductive.

But what eyes can miss, MEMS can see. Among micro-electromechanical systems are inertial sensors, which were first developed for automotive and military applications. They are tiny accelerometers and angular rate gyros that can be combined to form a complete inertial measurement unit. An IMU detects the three-dimensional motion of a body in space by sensing the acceleration of one point on the body as well as the angular velocity of the body. Incorporated in our IMU design are a microcontroller for analog-to-digital conversion and a low-power radio frequency transmitter for wireless data transfer to a computer. The resulting design is as small as a postage stamp and has a mass of merely three grams; a rechargeable lithium-ion battery adds just 1.5 grams to the unit. To our knowledge, we developed in our lab the smallest wireless IMU yet produced.

When this small, but rugged device is mounted on or embedded within sports gear, such as the shaft of a golf club, the IMU provides the essential data needed to resolve the motion of that equipment.

This technology—and sound use of the theory of rigid body dynamics—is now being developed and commercialized as the ingredients in new sports training systems. It won't be too long before MEMS-based hardware and sophisticated software combine to enable athletes at any level to get world-class training.

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To get a sense of what impact MEMS sensors can have on sports training, it's good to look at some specific case studies. For instance, it has been said that one of the most difficult feats in sports is to hit a major league fastball, which can cross home plate at more than 100 miles per hour. But even if a player has the requisite reaction time to hit the pitch, a sub-par hitting motion could cause him to foul off the ball, even if he can make contact at all.

IMU technology can assist in correcting a swing. A single IMU can track the motion of a bat, enabling trainers to piece together a three-dimensional view of the swing. In our lab working with college athletes, we've done just that, and have carefully resolved three distinct phases of the bat swing: the start of the swing, where significant acceleration develops; the so-called hitting zone, where one would expect to strike the ball; and the follow-through, where the bat experiences smooth deceleration.

Following the start of the swing, the bat conforms to a well-defined swing plane in the hitting zone. This swing plane is rarely level and can typically cut an angle a few tens of degrees below horizontal. The precise location of the bat at impact with the ball within this plane reveals where the bat was "aimed" and thus where the ball would be directed on the field. You can best see this so-called aim angle from a bird's eye view looking directly down at the three-dimensional swing from above. If at impact the bat makes a small angle with respect to the line perpendicular to the pitch, the resulting hit will send the ball more or less up the middle.

A side view of bat-ball impact is worth noting, too. By tracking the end of the bat in this view during the hitting zone, you'll see whether the hitter's swing is level, which is desirable. Alternatively, less accomplished batters will exhibit a distinct "upper cut"—where the end of the bat rises through the hitting zone, or a distinct "chop"—where the end of the bat falls through the hitting zone.

In addition to visualizing these highly useful measures of bat orientation, a coach or trainer may further quantify the bat swing using numerous other metrics derivable from the sensor data. Trainers can, for instance, check for bat speed and momentum at impact, the maximum acceleration during the swing, and the time from swing start to ball impact as a measure of reaction time.

Comparing these metrics for players of all abilities provides a rational basis for determining skill level, assessing a particular player's technique, and pinpointing what parts of that technique should be targeted to maximize improvement. Pinpointing the problem within the swing enables the focused practice that truly does make perfect.

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A good swing is also critical for a golfer. But where a baseball player generally stays with a bat of similar weight and composition, a golfer must handle drivers, irons, and putters—clubs of widely varying design, weight, and function—virtually every hole. The voluminous literature describing golf swings and the proliferation of swing training aids, videos, golf schools, and academies are all testimony to the significant challenges in perfecting swing skills.

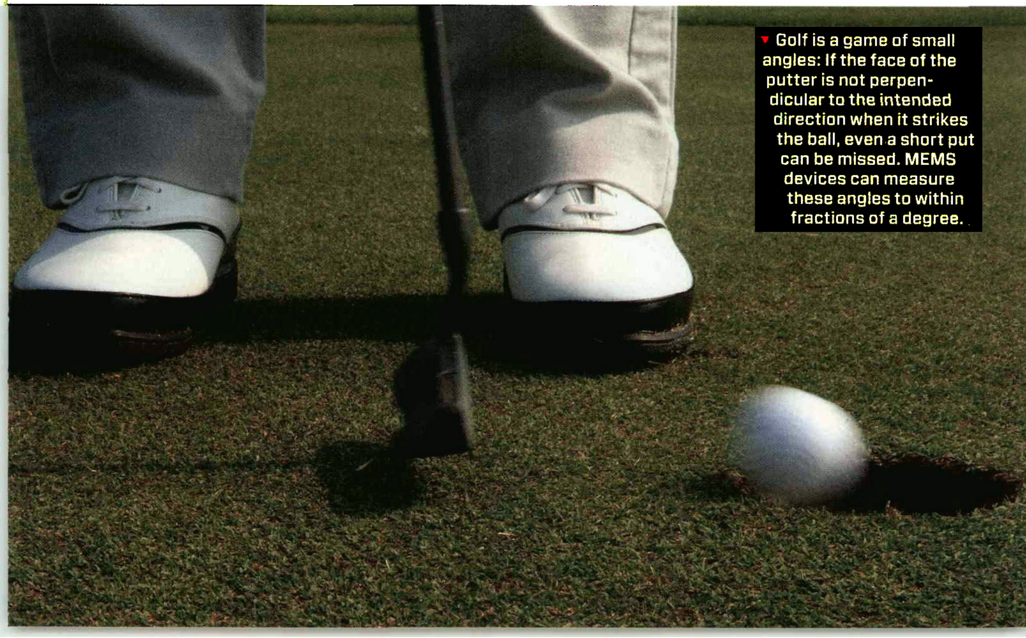
At present, the most advanced technology commonly used to measure swing skills uses high-speed video with or without motion capture. Such camera-based measurement systems precisely track club motion, though typically their use is limited to specialized indoor facilities.

By comparison, the highly portable MEMS inertial measurement unit also precisely measures club motion, both indoors and on an outdoor course. And because of the miniature electronics and simple computer software involved, this technology promises to do the job at a much lower cost.

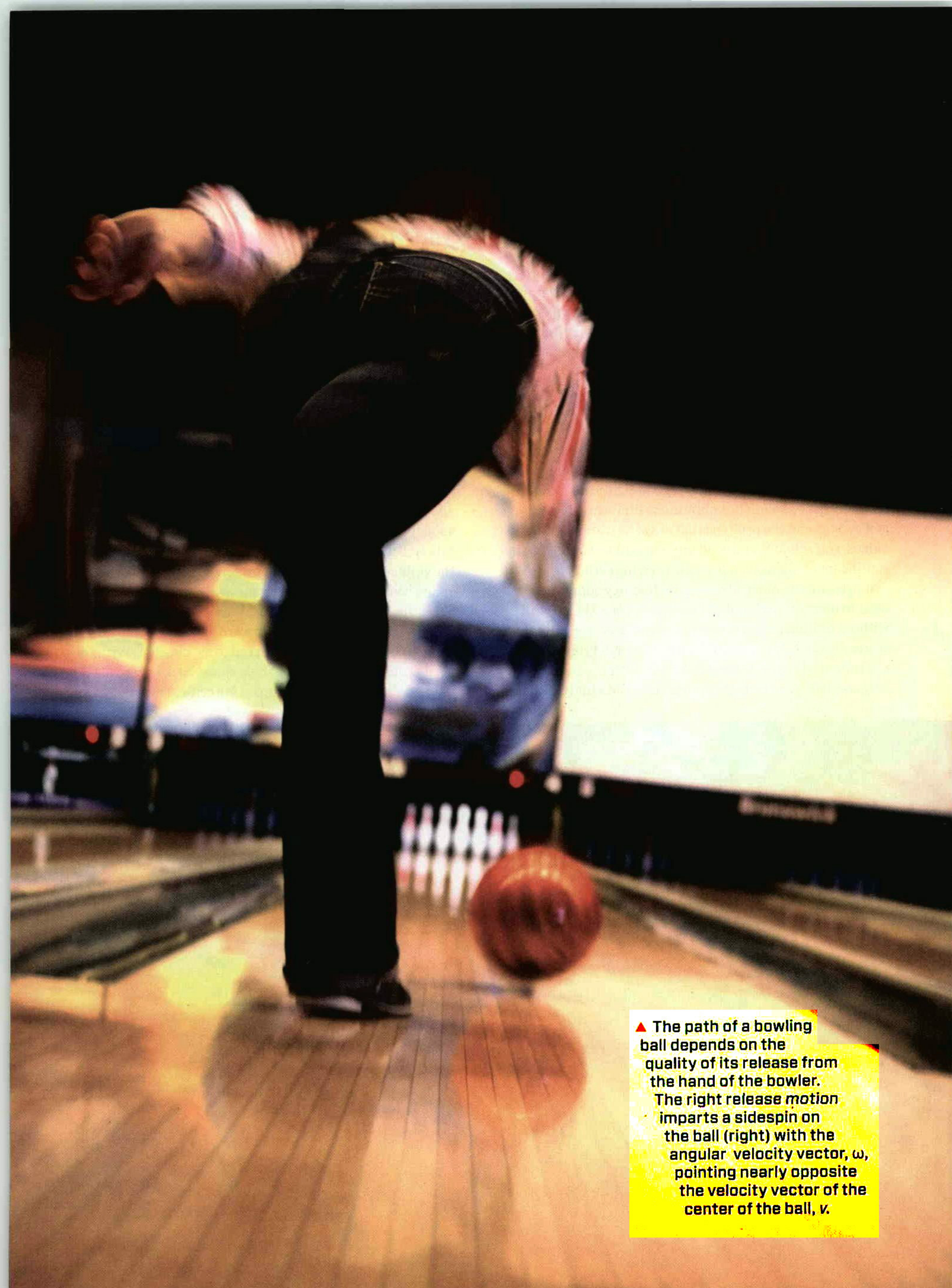
A way to illustrate the potential of this technology for golf swing analysis is to examine the challenges inherent in the putting stroke. The most common putting stroke is aptly described as a "gate swing." In this swing, the path of the club head describes a portion of a circular arc in the plane of the green similar to the path of a gate swinging open and then closed. During address when the club is still, the orientation of the club face defines the intended target line, which is perpendicular to the face of the club. But if the club face does not return to this orientation when the ball is impacted, the ball won't travel along the intended path but along a direction defined by the angle of the club face at impact.

IMU-based analysis can uncover very small deviations from the perfect swing. For instance, it can record the path of the club head as the putter undergoes the backswing followed by the forward swing, measuring displacements in fractions of an inch. Such small displacements can be enough to move the point of impact away from the sweet spot of the club face.

As well, the MEMS-based device can measure the angle of the clubface in relation to the preferred target line, the so-called "face angle." During a gate swing, as the club is pulled back, the club head rotates clockwise, which is referred to as "opening up." During the forward swing, the club head rotates counterclockwise referred to as "closing." With the perfect gate swing, the face angle closes back to zero at ball impact. This face angle at impact is a critical measurement,



Golf is a game of small angles: If the face of the putter is not perpendicular to the intended direction when it strikes the ball, even a short put can be missed. MEMS devices can measure these angles to within fractions of a degree.



▲ The path of a bowling ball depends on the quality of its release from the hand of the bowler. The right release *motion* imparts a sidespin on the ball (right) with the angular velocity vector, ω, pointing nearly opposite the velocity vector of the center of the ball, *v*.

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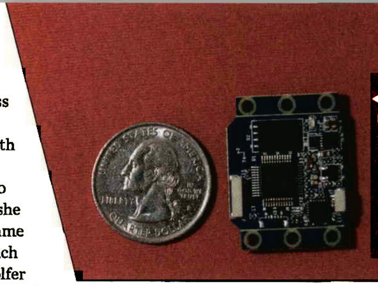

◀ The inertial measurement unit (shown at actual size) is small enough to sit unobtrusively on common sports equipment.

since an error of only 2 degrees may be enough to miss a five-foot putt.

It takes excellent coordination to control both the path and the orientation of the club head during a putt. For instance, a golfer may be able to return the club head to within a tenth of an inch of its starting position, but if she does not rotate the head on the forward swing at the same rate that it rotates on the backswing, the ball won't reach the hole. The use of IMU technology would enable a golfer to quickly discover and pinpoint this problem, provide quick feedback, measure and track improvement. This concept can be applied not just to putting, but also to full swings.

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Bowling is another sport where the swing of an arm and the twist of a wrist have to be calibrated to within a few degrees. Although the main action in bowling—the impact of the ball against the pins—occurs 60 feet away from the bowler, that action is determined by the way the ball is released from the fingers (as well as by the distribution of oil in the lane). Fortunately, wireless IMUs are capable of recording and transmitting that data.

Bowlers develop enormous rates of spin on the ball at the very end of their forward swing just prior to ball release. This spin, known as the rev rate, can be 350 revolutions per minute or higher for balls bowled by professionals. High rev rates, in the form of sidespin, generate sideways friction forces on the ball. This friction is what causes the ball to turn, or hook, toward the end of its run down the lane.

The angular velocity at release, together with the linear velocity of the ball center, determines if and where the ball hooks. When properly thrown, the ball will hook into the pocket between the head pin and the second row of pins, creating the ripe conditions for a strike.

A professional accomplishes this feat at the very end of the forward swing by releasing the thumb from the ball and simultaneously lifting upwards quickly with the two fingertips. Simultaneously, the bowler moves the palm from underneath the ball to the side thereby enabling this fingertip lifting action. These two coordinated movements generate a significant torque on the ball. This lift phase typically leads to a three-fold increase in the rev rate in just 50 milliseconds.

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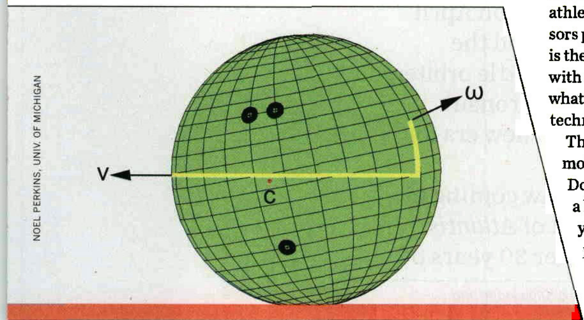

We studied this effect with a wireless IMU sensor embedded in a standard bowling ball. The entire sensor package, incorporating a rechargeable battery, was shrink-wrapped and inserted into the thumbhole.

The lift that is imparted at the end of the throw is considerable, increasing the rotation rate from 85 rpm to over 300 in the bowler we studied. But the sensor can also determine the exact time of release, because at that instant the angular velocity stops increasing. As the ball moves down the lane, the rev rate remains constant for some time, and then begins to increase as it approaches the pins (due to the transition from rolling with slipping to rolling without slipping).

The entire angular velocity vector is also measured, and for a right-handed bowler, it often points in a direction nearly opposite of the ball's velocity at the instant of release. That is, at release, the ball has sidespin or rifle spin, rotating about a horizontal axis parallel to the center of the lane. It is this large sidespin that generates the sideways friction force necessary for the ball to hook.

By measuring the linear and angular velocities of the ball at the instant of release, a bowler can understand the precise release conditions that dictate the motion of the ball in the lane thereafter. He can then experiment and precisely track improvements in these release conditions. And just as with baseball and golfing, this analysis could be conducted in real-life environments and in real time, not just in a laboratory or a specialized facility.

Indeed, highly miniaturized wireless inertial measurement units offer a scientific, quantitative way to evaluate athletic performance in a variety of sports. The inertial sensors precisely measure the motion of the sports gear, which is the bottom line indicator of athletic skill. When combined with analysis software and coaching tips specific to a sport, what emerges is a novel, highly portable and inexpensive technology for sports training.

The ability to precisely measure and decompose complex motions into a sequence of simpler skills is powerful. Doing so allows one to pinpoint those skills that can form a bottleneck, impeding improvement. Understanding your bottleneck and using quick measurement feedback promotes a more focused practice—one that truly could lead to perfection. This technology has the potential to emerge as a real game-changer for sports training in the near future. ■