Angular velocity measurement

Angular rate sensors are helping researchers to capture critical data to deepen the understanding of brain injuries

Traumatic brain injury has become what many call the signature wound of recent wars. It's also one of the most common injuries and causes of death resulting from motor vehicle crashes. In Europe, traffic accidents involving autos, trucks, motorcycles, bicycles and pedestrians account for 50% of traumatic brain injuries (TBI). In the USA, the Centers for Disease Control and Prevention (CDC) states that traffic accidents are the second-leading cause of brain injuries, resulting in one-third of injury-related deaths. With an estimated 10 million people affected annually with TBI, the World Health Organization predicts that TBIs will likely surpass many diseases as the major cause of death and disability by 2020.

What's more sobering is the fact that these statistics are in the wake of ongoing efforts to improve vehicle designs, including new passive and active safety features. There have also been a slew of governmental safety regulations implemented including FMVSS, NCAP and consumer-level promotion of the five-star ratings by the Insurance Institute for Highway Safety (IIHS). Yet despite efforts from both manufacturers and regulatory bodies worldwide, brain injuries are still on the rise.

For many years, the head injury criterion (HIC) has been used to measure the likelihood of head injuries in several important areas from automobile frontal and side impacts, to the safety of playground equipment. And, there are even smartphone apps for sports coaches that track individual players and send warnings of a possible head injury. The HIC calculation is based on three accelerometers mounted in the head of a crash test dummy. A resultant acceleration waveform is calculated and then the area under the curve for a specific time is calculated. A score above 1,000 is definite cause for concern, and for a human, this likely includes a trip to the emergency room.

While an impact stops the skull, it's the continued movement of the brain inside that's caused much concern and debate – especially if there are rotational components in the mix. Recently NHTSA developed another injury calculation intended to be used in conjunction with HIC. The Brain Injury Criterion (BrIC) focuses on the rotational aspect of the impact and is based on animal data that's been correlated to humans through computational modeling. While HIC uses triaxial accelerometers to measure impact acceleration, BrIC uses three angular rate sensors (ARS) to directly measure angular velocity. Measured in degrees or radians per second, the captured data is compared to critical values for each axis

Tri-axial linear accelerometer array

$$\boxed{HIC} = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}_{max}$$

Three angular rate sensors

$$\boxed{BrIC} = \sqrt{\left(\frac{\omega_x}{\omega_{xC}}\right)^2 + \left(\frac{\omega_y}{\omega_{yC}}\right)^2 + \left(\frac{\omega_z}{\omega_{zC}}\right)^2}$$

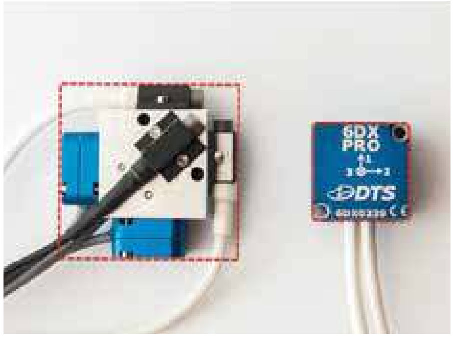
HIC and BrIC calculations work together to capture both impact acceleration and angular velocity for more accurate brain injury analysis

and then a resultant of these values is calculated.

Scientists continue to analyze field data or the latest research that may link integrin proteins or virtually anything that may help solve the TBI puzzle. Some researchers have even studied how woodpeckers are able to withstand 1,200g impacts (80-100g is concussive for a human) nearly 12,000 times per day, without sustaining head, brain or eye injuries. Not surprisingly, researchers found that the birds have a unique combination of skeletal features and special brain padding. But what is interesting is that the bird's pecking motion is all linear. The fact that the bird experiences virtually no head rotation may provide clues that could help reduce human injuries.

With the growing focus on rotational motion in 2006 NHTSA amended FMVSS 202 for rear-impact protection testing to allow the use of ARS to calculate body motion, and hence, injury potential. The standard specifies angular rate sensor model ARS PRO-1500 made by Diversified Technical Systems (DTS). The California-based manufacturer is known for its miniature rugged data recorders and also pioneered the widespread use of the MEMs-based ARS PRO for high-impact applications. "Ten years ago when we introduced the ARS PRO, gyros and

> "While an impact stops the skull, it's the continued movement of the brain inside that's caused much concern and debate – especially if there are rotational components in the mix"



LEFT: If space and weight are at a premium, the 6DX PRO 6DOF is 70% smaller and 50% lighter than a traditional triaxal block with individual sensors. Fewer cables make setup easier, plus it's serviceable if a channel gets damaged in field

RIGHT: DTS offers mounting brackets with proper CG to embed both the sensors and even Slice Nano miniature recorders in dummy heads, free motion headforms and pedestrian headforms

angular rate measurements weren't new. But when people realized how accurate the ARS PRO is during high linear acceleration, that was a game changer," says Steve Pruitt, co-founder and president of DTS. Features such as a 2,000g shock rating (there is even a 10,000g model), DC response, ranges from ±300 to ±50,000 degrees/sec, and a variety of bandwidths have opened the door for new applications. In fact NHTSA recently released a notice of proposed rule-making requiring the use of ARS in future US NCAP crash tests.

With industry trends focusing more on angular rate measurements for injury prediction, test engineers are looking for easier ways to get that data. Nine-channel accelerometer arrays are commonly used but require complex calculations that can produce inaccurate data due to small offsets or noise in the measured accelerations. There is also the issue of space constraints. Over the years, university researchers and auto manufacturers have been replacing 3-2-2-2 and 3-3-3 accelerometer arrays with sensor packages that include a triaxial accelerometer along with a triaxial ARS. Designed to maintain proper center of gravity (CG), DTS offers mounting brackets for all ATD heads. Plus the standard mounting pattern makes it easy to add to the thorax or pelvis – almost anywhere that additional injury or validation data may be valuable.

To fulfill both HIC and BrIC calculations, accelerometers can be added to a triaxial mounting block. But when space and weight are at a premium, the 6DX PRO from DTS should be the sensor of choice. Claimed to be the world's smallest 6DOF sensor, the 6DX PRO packages three ARS and three accelerometers in a tiny, rugged 19 x 19 x 14.5mm enclosure. Weighing less than 12g, it's 70% smaller and 50% lighter than a fully loaded triaxial block with individual sensors. "If you've ever had to wire up a dummy or set up a test with lots of channels, you appreciate anything that makes it easier and faster," adds Pruitt, who started his career as a crash test engineer. Not only does the 6DX PRO have fewer cables to deal with, it's also serviceable, eliminating concerns that one damaged channel may ruin the entire sensor. All of the sensor models are IP67 rated and sealed, making them also ideal for PMHS research. The complete line of DTS ARS products includes a single axis ARS PRO, a triaxial ARS3 PRO and the 6DX PRO with a triaxial ARS plus three linear accelerometers.

DTS now offers a new coplanar 6aω configuration, which uses six accelerometers and three ARS to quantify 6DOF motion, plus angular acceleration. This allows the transformation of measurements taken in one location, to another location using well-known algorithms. The DTS solution includes a 6DX PRO sensor, plus three more linear accelerometers used to calculate angular accelerations. With the old nine-channel accelerometer arrays, the complex math required to calculate angular velocities and displacements often leads to errors – and ultimately inaccurate results. The advantages of the new coplanar 6aω configuration include: angular accelerations derived from simple algebraic equations; angular velocities from direct measurement; and angular displacements and a transformation matrix from single numerical integrations. DTS offers special new coplanar 6aω mounts for standard dummy heads. There's also a turnkey package available that includes an embedded Slice Nano that is so small it fits right in the head, eliminating any trailing wires from the sensors or CG concerns.

While technology and regulations continue to evolve, the formula for safety remains steadfast. "People are always the priority," says Pruitt. "It feels good knowing that our products are helping keep people safer all around the world. That's a big deal and something to be proud of." ❮