Electronic systems have been major contributors to the success and popularity of all types of auto racing, from basic stock cars to the highly modified dragsters or Formula 1 machines that stretch the limits of engine and chassis design. As fans enjoy their favorite motor-sport competition at the track or on television, they see the culmination of years of research, data collection, and refinement that designers base on embedded-system technology. From prerace optimization to postrace analysis, auto-racing teams increasingly rely on mounds of engine and mechanical data to refine designs and increase performance. In the event of a crash, embedded recorders capture multiple data streams to identify mechanical failures or driver errors. But many of these electronic systems are controversial, and racing officials must continually update the rules to balance driver safety, fan enjoyment, and competitiveness.

Electronics in auto racing: FRIEND AND FOE

BY WARREN WEBB • TECHNICAL EDITOR

ALTHOUGH EMBEDDED-SYSTEM TECHNOLOGY IMPROVES ALMOST EVERY ASPECT OF MOTOR SPORTS, RACE OFFICIALS OFTEN BAN IT DURING COMPETITION IN THE INTEREST OF FAIRNESS.

Motor sports have inspired numerous embedded-electronics innovations that have eventually found their way into production automobiles. Embedded processors gather and exchange information to control, optimize, and monitor many of the functions that just a few years ago were purely mechanical. Power-train computers examine multiple sensors in real time and adjust fuel mixtures, ignition timing, and the transmission for the best performance. Designers base antilock-braking, traction-control, and stability-control systems on embedded electronics. In racing-specific applications, embedded systems can adjust the body configuration to improve aerodynamics and tune active suspension systems to a specific track. With real-time communications, pit crews can monitor and adjust engine performance, and fans get a view from the cockpit. Ironically, few motor-sport events allow many of the advanced electronic subsystems that racing teams have developed and refined. Officials may bar any subsystem that compensates for or assists driver actions in the interest of competition.

Individual sanctioning bodies, such as NASCAR (National Association for Stock Car Auto Racing), the Indy Racing League, or the FIA (Federation Internationale de l'Automobile), maintain rule books detailing the requirements for participation in racing events. NASCAR dates back to 1948 and claims to be the No. 1 spectator sport. It boasts 17 of the top 20 most-attended sporting events in the United States and is No. 2 in worldwide regular-season television sports, with broadcasts in more than 150 countries. The FIA, which centers itself mainly in Europe but hosts events worldwide, sanctions Formula 1 or Grand Prix racing with highly customized cars designed for high-speed competition. Designers fully instrument most Formula 1 vehicles to deliver a real-time stream of car and driver information to the racing team, broadcasters, and spectators. The Indy Racing League is the governing body for another open-wheel, single-seat-style race car that the Indianapolis 500 features.

PRERACE OPTIMIZATION

Teams make many of the racing decisions and refinements long before the car ever touches the track. For example, Penske Technology Group works with motor-sport teams to predict vehicle performance before an event. Penske offers a computer-controlled shaker table along with analysis services it bases on software from The MathWorks to determine the best adjustments to vehicle-damping characteristics (**Figure 1**). The shaker rig provides seven hydraulic actuators, including four for road simulation and three that connect directly to the body of the car to simulate banking, cornering, and wind loads. Racing teams use prerecorded data from the track to tune vehicle dynamics by adjusting spring and shock parameters. Penske also uses The MathWorks' Simulink simulation tool to model aerodynamic loads that determine the proper download force for the actuators.

AT A GLANCE

- To ensure that race-car drivers–not clever computer programs–win races, competitions sometimes ban embedded electronics.
- Auto racing provides a test environment for high-performance vehicle- and safety-enhancement systems destined for production automobiles.
- In the event of a racing accident, event-data recorders capture the real-time sensor information to deliver immediate medical support.
- In the interest of fairness when employing embedded systems, some racing venues plan to supply racing teams with standardized engine-control units.

With vehicles traveling at more than 200 mph and only inches apart, auto-racing accidents are inevitable and frequent. However, only after the 2001 death of stock-car legend Dale Earnhardt did NASCAR begin collecting real-time crash data with an embedded-electronics event-data recorder from Independent Witness. NASCAR officials install the Witness—a self-contained unit with a two-year battery—next to the driver's seat. The device monitors vehicle motion and, in the event of impact, records the date, time, direction, impact, and severity, as well as a 3-D acceleration profile. Similarly, the Indy Racing League requires all cars to include the Delphi ADR3 accident-data recorder (**Figure 2**). The ADR3 can sense and record multiple vehicle parameters at 1k sample/sec before, during, and after an accident. Monitored parameters can include wheel speed, throttle position, steering angle, tire pressure, acceleration, and seat-belt loads. An ear-plug sensor that the driver wears contains embedded accelerometers that send G-force data immediately upon impact. On-site medical personnel can rapidly retrieve and analyze impact data to help them anticipate the types of injuries a driver may have suffered so they can prepare appropriate treatment. The data from multiple accidents has led to the integration of additional safety features into the cars, such as head and neck restraints to counteract impact forces.

In a move to adopt the benefits of embedded electronics and maintain fairness, the FIA has defined a standardized ECU (engine-control unit) for all Formula 1 racing teams starting in 2008.

Figure 1 Penske Technology Group offers racing teams a shaker table and software to determine the best adjustments to vehicle-damping characteristics.

Figure 2 The Delphi ADR3 can sense and record multiple vehicle parameters at 1k sample/sec before, during, and after an accident.

Figure 3 The NASCAR PitCommand feature allows fans to track race-car position, speed, and engine rpm in real time on their computers (above).

Figure 4 RaceView provides fans with 3-D animation similar to that of sports video games to track their favorite drivers during racing events (right).

The ECUs will monitor all aspects of the power train and gather data from more than 100 sensors on each car while displaying critical information to the driver. Generating as much as 500 kbytes of data per second, a single ECU can potentially gather more than 1 Gbyte of information from the sensors during a Grand Prix race. A high-speed telemetry link continuously broadcasts this data back to systems in the pit-side garage of each Formula 1 team for detailed analysis. The FIA selected McLaren Electronic Systems and Microsoft as official suppliers of the standard Formula 1 ECUs and associated software.

TELEMETRY TROUBLES

By its nature, real-time telemetry data is also controversial in auto racing. With the proper setup, pit crews or even factory specialists can monitor vehicle sensors during the race to prepare for pit stops, devise alternative strategies for fuel conservation, or even identify and troubleshoot engine or mechanical malfunctions. Typical telemetry measurements include multiaxis acceleration, temperature, rotational speeds, and mechanical displacement. With two-way telemetry, experts can tune the engine performance or adjust aerodynamic characteristic in real time throughout a race. Sanctioning organizations now standardize the type and quantity of telemetry data allowed, and most ban two-way telemetry altogether.

One of the fastest growing segments in racing for embedded-electronic systems and software is in delivering real-time race information to the fans, either through television or over the Internet. Embedded-system designers working with broadcast teams and race officials have devised a number of concepts to capture and display real-time statistics. Most of these systems require precise position-location information for each car (see **sidebar** "Real-time tracking: Where's my car?"). NASCAR has been on the leading edge of subscription-based information systems that allow fans to closely follow the action with customized views of the race on the Internet. For example, the NASCAR PitCommand subscription service is an online Java-based multimedia feature that allows fans to track car position, speed, and engine rpm on their computers for any or all of the cars with real-

REAL-TIME TRACKING: WHERE'S MY CAR?

Combining high-speed data communications, global-positioning technology, and real-time camera control, the Racef/x system from Sportvision provides graphical enhancements for live television coverage of racing events. The system allows the announcer to activate on-screen pointers to identify selected cars in the race along with an optional virtual dashboard showing vital statistics, such as speed and position in real time. The system employs an onboard telemetry system to send sensor and GPS (global-positioning-system) data to a network of receivers in strategic positions around the track. Differential-GPS techniques determine each car's position, comparing satellite-position signals to known fixed positions. Several of the broadcast cameras include remotely controlled pan and tilt heads, enabling them to automatically follow the position data from the selected car. Updated several times per second, custom software synchronizes transmissions and collects statistics from as many as 55 cars racing around the track at more than 200 mph. Sportvision introduced its Racef/x system during the 2006 Indy Racing League season, and NASCAR (National Association for Stock Car Auto Racing) is now also using the system in its 2007 Busch series season. This type of tracking system also allows sanctioning organizations to capture additional revenue with subscription-based data it delivers over the Internet so that users can follow their favorite competitors.

Figure 5 The Boss Chevy Tahoe sport-utility vehicle from Carnegie Mellon University will compete in the driverless DARPA Urban Challenge.

Figure 6 Only sunlight powered the Nuna3, which won the 3021-km World Solar Challenge in 2005 with an average speed of 103 km/hr.

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For more on vehicle electronics, see "Black boxes capture car-crash data, controversy," www.edn.com/article/CA529380.

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time data directly from telemetry boxes in every car (**Figure 3**). RaceView, another NASCAR fan-data-delivery innovation, provides a computer application that features 3-D animation similar to that in popular sports video games (**Figure 4**). Fans can select one driver or switch among the full field of drivers to follow them around the track and during pit stops, caution flags, and lead changes and view driver data, such as live position, speed, and time behind the leader. Three race views are available for each driver, including Lead View, which shows the front of the driver's car, as well as the cars in pursuit; Flyover View, an aerial view from above; and Draft View, which shows the car from behind and the field in front of the driver. PitCommand and RaceView are part of NASCAR's premium subscription service for which fans pay a monthly fee of $12.95.

Although embedded-system technology may be controversial and some venues partially ban it, other races not only allow electronic systems, but also base results solely on their performance. For example, the top 20 teams from a qualifying event will compete in the DARPA (Defense Advanced Research Projects Agency) Urban Challenge in November for cash prizes worth $2 million for first place, $1 million for second, and $500,000 for third. Driverless robotic vehicles will conduct simulated supply missions on a network of urban roads at a military training facility in Victorville, CA. Vehicles must be entirely autonomous, using only a GPS (global-positioning system) and the information it detects with its sensors. In addition, vehicles must be stock or have a documented safety record and obey California driving laws. DARPA will provide the route network 24 hours before the race starts and provide each team a file detailing the route five minutes before the race starts.

ROBOTIC SUV

Tartan Racing of Carnegie Mellon University (Pittsburgh) is representative of the teams participating in the Urban Challenge. Its entry, named Boss, is a Chevy Tahoe sport-utility vehicle with more than 300,000 lines of code to autonomously navigate in town and in traffic (**Figure 5**). Boss uses perception, planning, and behavioral software to reason about traffic and take appropriate actions while proceeding to a destination. The vehicle includes more than a dozen lasers, cameras, and radars to view surroundings. Software and sensor technology allow the vehicle to detect and track other vehicles at long ranges, find a spot and park in a parking lot, obey intersection-precedence rules, follow vehicles at a safe distance, and react to dynamic conditions, such as blocked roads or broken-down vehicles.

The World Solar Challenge is another interesting racing event that depends heavily on embedded-electronic systems. The challenge is to design and build a car capable of crossing Australia using only sunlight as fuel. The winning car from the last race in 2005 covered the 3021 km between Darwin and Adelaide in 29 hours and 11 minutes, averaging about 103 km/hr. The car, Nuna3, relied on high-efficiency, three-layer, gallium-arsenide solar cells of a type normally used to power orbital satellites (**Figure 6**). Eleven students from different disciplines of the Delft University of Technology, Netherlands, designed and built the vehicle. The 2007 event, which will take place in October, will employ new rules to increase competition. Officials will restrict entrants to 6m^2 of solar collectors, driver access and egress must be unaided, and seating position must be upright. There are also many new safety requirements. Further, competitors will have to adhere to the new 130-km/hr speed limit across a portion of the course.

Although auto racing is not always ready for the latest in embedded electronics, it provides an excellent test bed for vehicle-performance and safety-enhancement systems. Designers have used embedded devices to improve the operation of vehicle power plants, transmissions, aerodynamics, fuel economy, and safety systems. Whether the competition tests speed at the track, reliability across the desert, or egos at the next stoplight, racing enthusiasts will continue to depend on electronics technology to keep ahead of the pack. EDN

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