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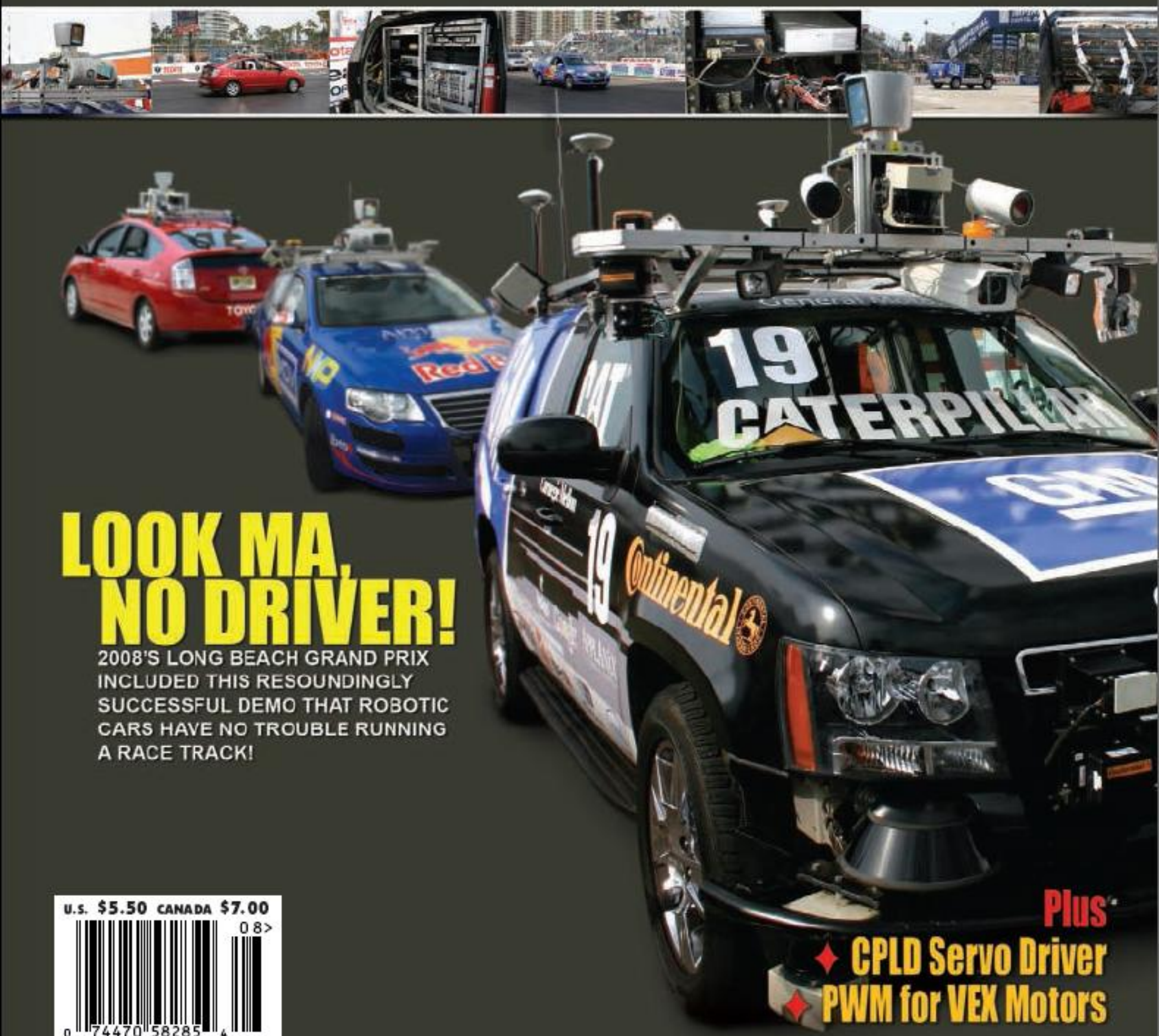

LOOK MA, NO DRIVER!

2008'S LONG BEACH GRAND PRIX INCLUDED THIS RESOUNDINGLY SUCCESSFUL DEMO THAT ROBOTIC CARS HAVE NO TROUBLE RUNNING A RACE TRACK!

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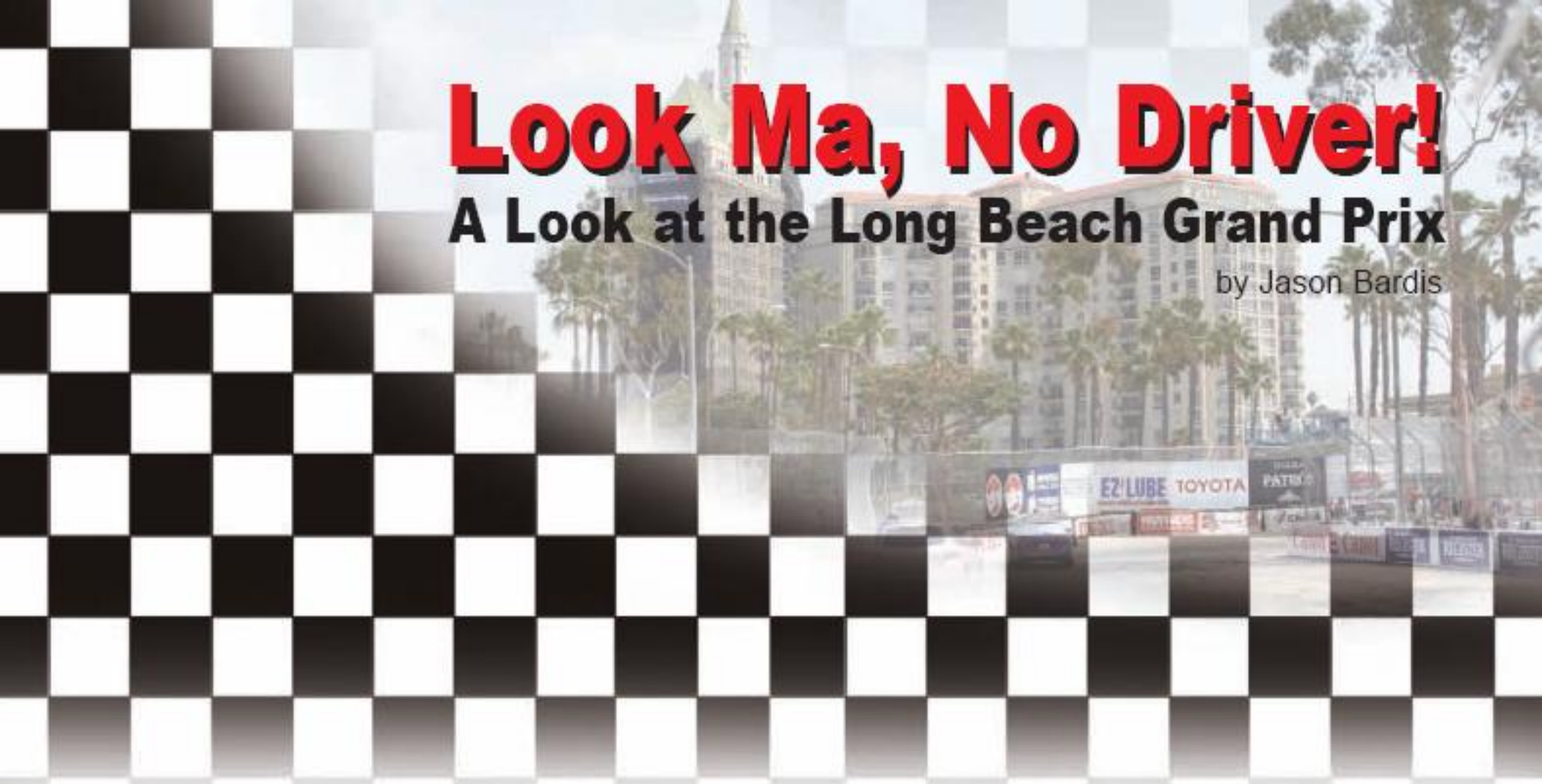
Look Ma, No Driver!

A Look at the Long Beach Grand Prix

by Jason Bardis



April 20, 2008 may be known as the turning point when robots became better drivers than humans ... or at least Lockheed Martin Advanced Technology Labs engineer Adam Solomon, when he took the wheel of an unnamed robotic Toyota Prius after its autonomous run and attempted to guide it back into the pits at the 34th Annual Long Beach Grand Prix.

Maybe the professional drivers at the race would have fared better than Adam. Then again, I'd bet dollars to diodes that none of the professional drivers had built any robot cars either, so let's call it even.

Robots? Engineers? Car race? What? According to the event's Fan Guide brochure, "... we're also going 'Green, Green, Green!' in 2008! The Toyota Grand Prix will take a giant leap into the future with an expanded Lifestyle and Alternative Energy Expo in the Convention Center and a dynamic new 'Green Power Prix-View,' showcasing hybrid, electric, and possibly even robotic cars on and off the track, as well as energy-saving devices for the home and lifestyle."

"Green" is certainly a key buzzword these days, around the world, in all industries, and now "robotic" is right up there alongside green too. Well, it's almost right up there alongside green — it still has the cautious qualifier "possibly even" preceding it.

But what was this event really all about? Three robotic cars took to the track that day, all veterans of the DARPA Urban Challenge (not just any old competitors — race fans were treated to the 1st, 2nd, and 4th place finishers out of the 89 teams that entered and 11 teams that actually qualified). They showed off by doing a hot lap of the Long Beach Grand Prix race track. Well, maybe it was more of a warm lap ... okay, how about tepid?

Compared to the deafening blurs of Champ Cars averaging 93 mph, the 30 mph max speed robotic cars seemed rather tame and pokey at best, at least to the average race fan. At worst, the average race fan just didn't get it: "Those cars must be driven by the people following in the chase cars." "No, the chase cars are there just to shut them off in an emergency — those cars are really driving all by themselves." "Yeah, I know, but, still, there's gotta be somebody driving it!" "Uhhh ... ?"

This year's Long Beach Grand Prix included this resoundingly successful

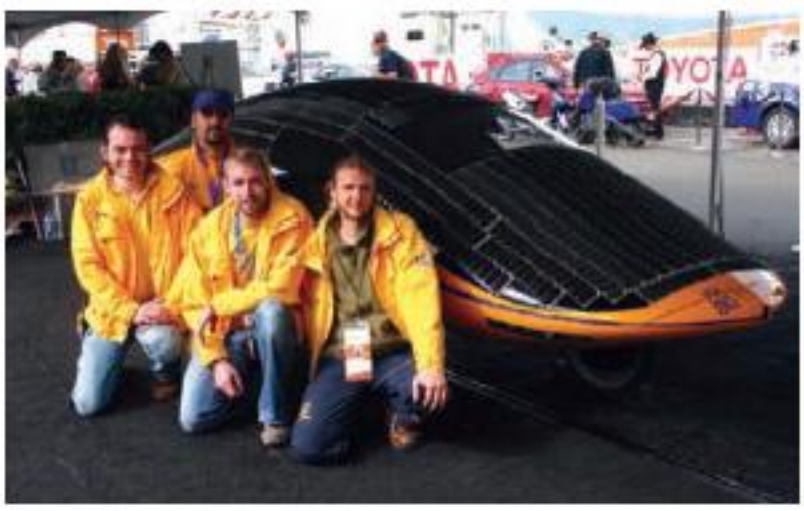
"Robot drivers are better than human drivers."

"Which human?"

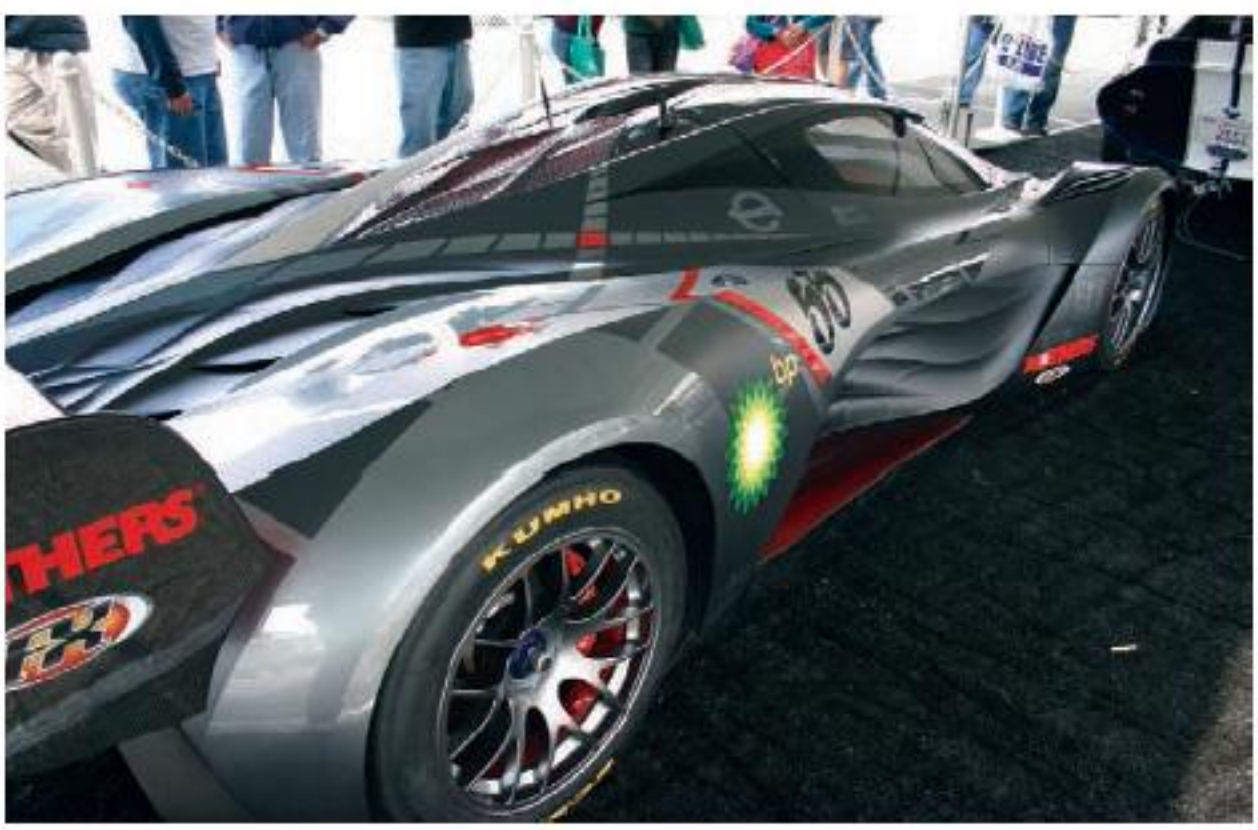
"Uh, that would be me."

"What happened?"

"We finished an autonomous run and we switched out of autonomous into manual drive, and ... uh ... kinda kept going. What we did was we warmed up the rail on the straightaway for the rest of the drivers. So, we know it's good. We tested it — it's solid."



demo that robotic cars have no trouble running a race track. Most *SERVO* readers know of the DARPA Grand Challenge and Urban Challenge, and are happy to see another successful autonomous course completion. However, most typical race fans got their first taste of robot cars and, hopefully, their appetites have been whetted. The fans saw drivers pilot two green electric race cars and a green (well, it was bright yellow ...) solar-powered car run a lap (a relatively warmish lap at that!). Sadly, the I-look-far-cooler-than-anything-that-Batman-has-ever-driven Mazda speed alternative energy rotary engine car never got out of the pits. These cars were followed by a big Chevy SUV and a VW wagon navigating the course smoothly, confidently, and precisely. They also saw a little Toyota Prius navigate the course with some timidity, trepidation, and nervousness. But which one won the race?



Read on as I introduce you to the players:

BOSS

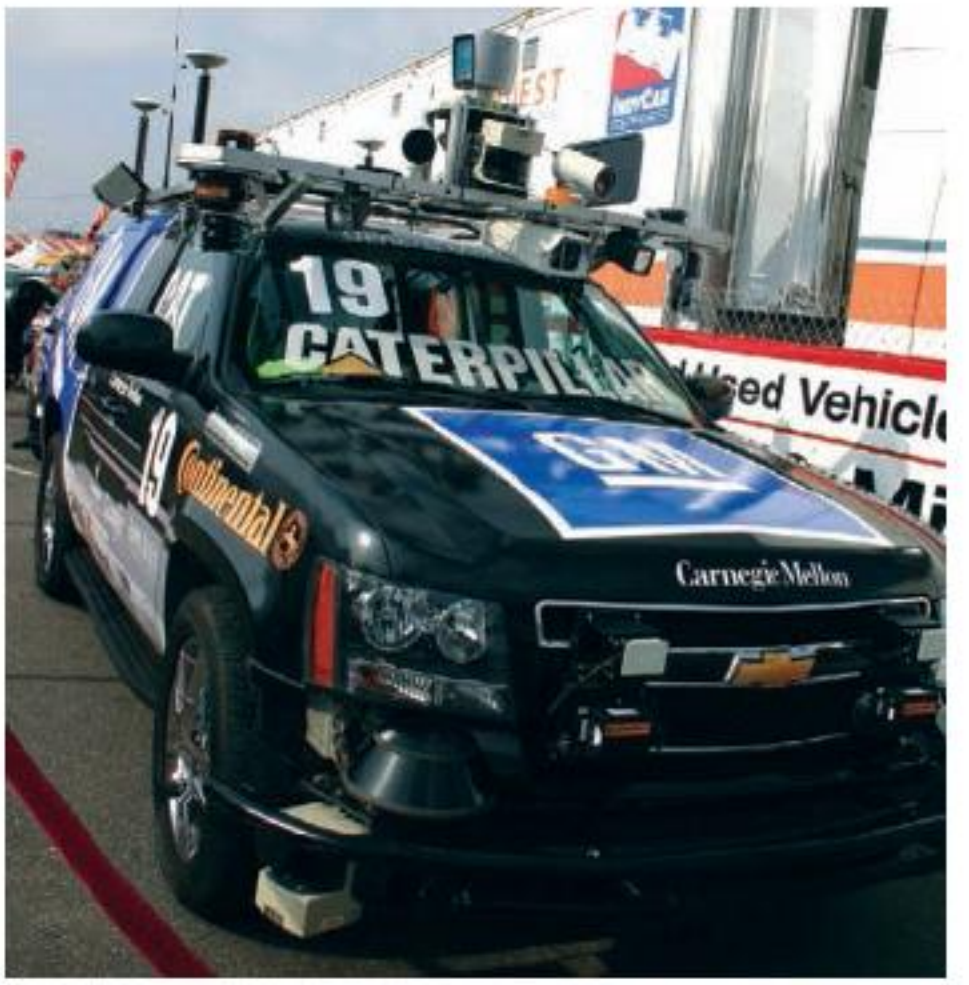
Named After: Charles "Boss" Kettering, founder of General Motors R&D (Nothing to do with Bruce Springsteen.)
Former Life: 2007 Chevy Tahoe
Pedigree: 1st place in 2007 DARPA Urban Challenge
Team: Tartan Racing @ Carnegie Melon University, with General Motors, Caterpillar, Intel, and Continental
Build Time: 14 months between receipt of the vehicle and the DARPA Urban Challenge
Cost: "Well, the prize for winning the challenge was $2 million. We were very happy to receive that." "Aaaaand, that went somewhat towards recouping your costs of —" "WE WERE VERY HAPPY TO RECEIVE THAT!"
Turn-Ons: More is better!
Turn-Offs: Subtlety

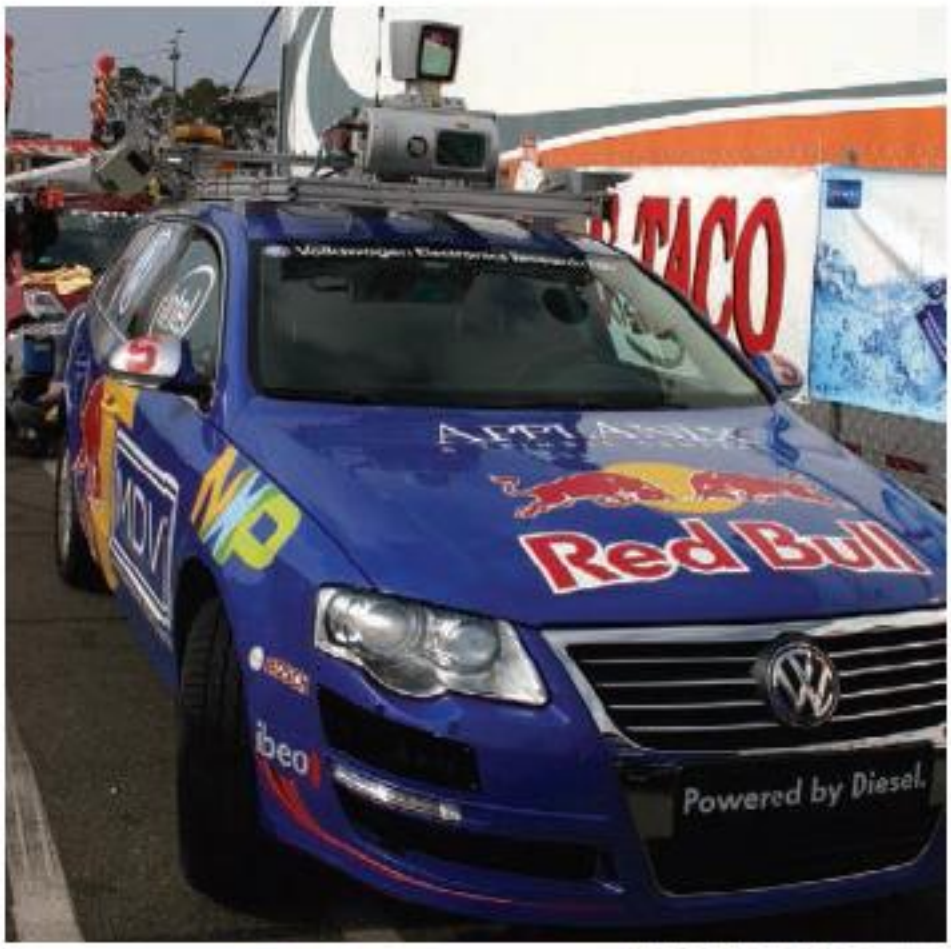
What has room for four programmers, a table with cupholders and power outlets and Ethernet jacks, and 10 bays of Intel dual-core processors? Oh, and it goes 30 mph, so the answer is not "the server room down at corporate." It's Boss. Aptly named, as it won the 2007 DARPA Urban Challenge ... by a 20 minute margin. Note that a two-second lead in a normal car race is a healthy margin! A 6,000 lb Chevy SUV with such impressive performance could be misconstrued as a bully, but it ran the Long Beach Grand Prix track almost as smoothly as the human drivers. I spoke with test lead Bot Bittner about the past and future of Boss.

Because they tried so many tests to compare different subsystems and components, they didn't have time to integrate the large racks of components seamlessly into the vehicle. Boss' future lies in using its successful technology not to make fleets of robotic cars but to integrate various subsystems into consumer and military vehicles: "What you'll see is a lot of the subsets of the technology pulled out and introduced into the vehicles that we're driving every day. You'll end up with a lot of early warning for accidents ... be able to tell us about lane departure, accident avoidance, obstade avoidance, defensive driving ... Right now, I don't think people are ready to see a car just driving itself down the road."

How many more DARPA "Blank" Challenges (where you can fill in "Blank" with some sort of extreme-sounding adjective) are in store for Boss? Carnegie Melon is pursuing many related projects, but "We don't expect to see any more of this type of challenge out of DARPA. But, what it has done is excited the community, generated an interest in vehicle safety, autonomous driving, and all the benefits that can come from this technology bringing it to society." One example is the "panheads" mounted on the sides of the roof, which look downward and left/right. At an intersection, these sensors are used to monitor side traffic and obstacles and help Boss decide when it would be safe to pull forward into an intersection. I am so looking forward to these sensors being commonplace automobile options, stuck up there on the roof next to the satellite radio antennas!

As a mechanical engineer, I deal in the tangible; having trouble grasping the movement of electrons in circuits or





appreciating the elegance of a really efficient gosub routine (heck, they probably don't even have gosubs in modern programming languages, do they?). So, I asked Bob what all the cool sensors on Boss' roof and bumpers were:

• *Roof*: Three GPS antennas to determine not only location but also orientation of Boss; Velodyne HDL-64E 64-laser LIDAR rotating at 10 Hz.

• *Roof Sides*: Panheads for monitoring side traffic and obstacles.

• *Roof and Inside*: Big red panic buttons to shut down and stop the car.

• *Back Bumper Sides*: Two close-range radars.

• *Back Bumper Center*: Planar LIDAR and long-range radar.

• *Front Bumper*: More radar and LIDAR short- and long-range sensors.

• *Junk in the Trunk*: Racks with 10 Intel dual-core processors, data-logging equipment, a Planix that processes the GPS data and also takes inertial motion and encoder data to determine location when GPS signals are not available, the remote kill device (contrary to the saw blade deployment components on a BattleBot, this box is used simply to pause and unpause Boss), and a whole lot of cable ties to keep it all tidy.

I asked Bob if they've ever gone on joyrides faster than the 30 mph speed limit imposed by the DARPA Urban Challenge rules. I got the boiler plate "I can neither confirm nor deny ..." routine, but he did point out that they've set up the hardware and software to work and react at 30 mph. So, we've probably got a few years until these smart guys can get their robot cars up to typical Champ Car speeds.

To make its driving look effortless and professional, Boss uses prior knowledge of the course combined with on-the-fly decision-making. The course can be outlined from satellite images or by driving the course prior to the event and recording waypoint locations. Of course, the more prior information known, the more successful the course navigation will be. Don't roll your eyes — the same applies to us fleshy and indecisive humans too! For the DARPA Urban Challenge, they were provided with a sparse set of waypoints, so Boss proved that it was versatile and robust by still navigating DARPA's course (and the Long Beach Grand Prix race course) excellently, although they still deferred to a human driver to drive Boss to and from the track. Boss probably would not have dealt well with the dozens of people crowding around him, as well as the strange obstacles (tents, strollers, golf karts, swing-out race track entry/exit barriers, etc.) creating mayhem in and around the pits.

"WE'RE WORKING ON THAT"

(No, that's not its real name — it truly does not have a name — call Marketing, quick!)

Former Life: 2006 Toyota Prius
Named After: See above
Pedigree: Riding on the coattails of its twin "Little Ben" (fraternal twin, not identical twin, as Little Ben's brother has only two-elevenths as many sensors as Little Ben), who placed 6th in the 2007 DARPA Urban Challenge, unless you ask somebody on Little Ben's team, who points out that Little Ben placed 4th out of the teams that finished within the rules. "What rules were broken?" "They collided with other vehicles. One in particular had it out for us, it seemed — they tried to hit us twice."
Team: Ben Franklin Racing Team: University of Pennsylvania, with Lehigh University and Lockheed Martin
Build Time: 18 months between initial concept and DARPA Urban Challenge
Cost: $250,000 of parts, and "a lot of free student labor"
Turn-Ons: KISS (the acronym, not the band with their own army)

Turn-Offs: Human drivers

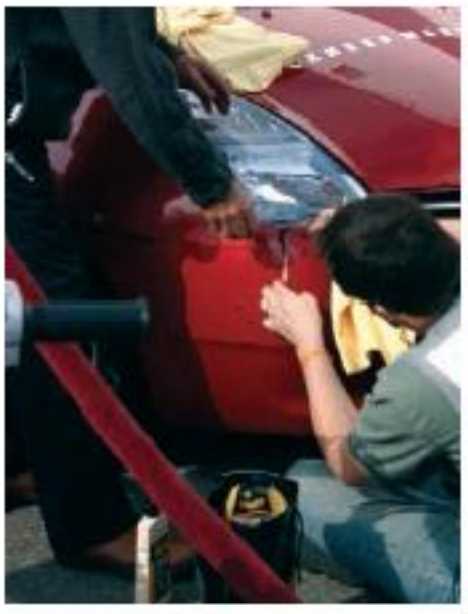
Adam Solomon, Lockheed Martin engineer and race track barrier strength-tester, gave me the scoop on their Prius.

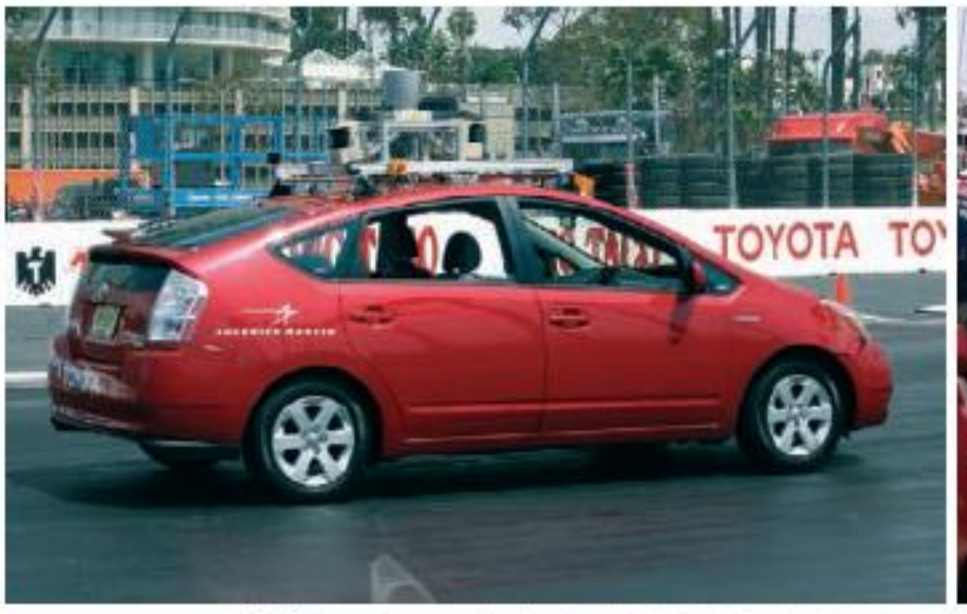
The first thing that jumps out and slapped me in the face is the fact that this car looks so *normal*! I couldn't help myself: "This car looks kinda boring. But that's a backhanded compliment! Honest!" Just as Toyota set to achieve (and did so) utter normality with the Prius to not freak out potential customers who fear change and abnormality in their daily drivers, so did the Ben Franklin team also achieve remarkable normality with their robot car.

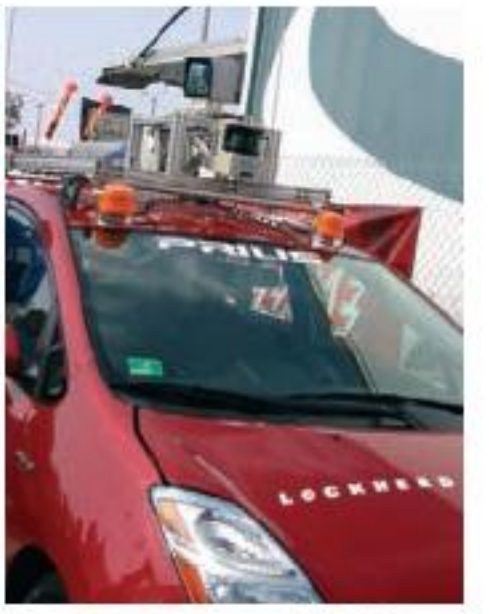
This was the backup car ("backup" not as in "it goes in reverse," but "backup" as in "if we total Little Ben, we've got a spare!") for Little Ben at the DARPA Urban Challenge. Little Ben ran so well that this vehicle wasn't needed for that event. In its understudy role, as on Broadway, it wasn't equipped as well as the top-billed star was in order to put on a standing ovation, throw-the-roses-on-the-stage performance. This car had only two main sensors vs. Little Ben's 11. This bears repeating. According to Adam, with only 18% of the hardware bolted to the outside of this car, it could perform at 95% of the capacity of Little Ben. The 5% shortcoming is in this robot car's inability to perform sensing of extremely close objects — the Prius' roof eclipses the field-of-view of the one centrally-mounted roof sensor, casting the area immediately around the car into "shadow."

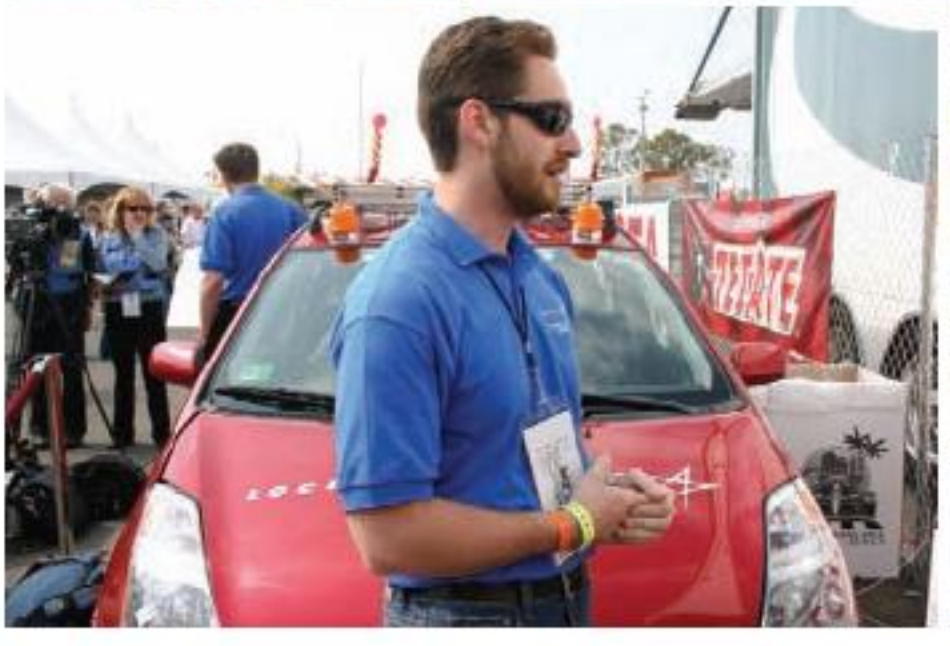
How is this possible? Software, software, software. They refined their software over and over, making it more efficient, more robust, and more powerful, until they had this impressive driving capability-per-sensor ratio (Don't ask me what the units are on that value ...). Did I also mention that the star of their robot — the software — runs on a plain old consumer MacBook Pro laptop? Their biggest problem with their whole system was not any of their components or code but the laptop's rechargeable battery, which gradually lost its capacity over the months of testing from its frequent charge and discharge cycles. They learned their lesson and now keep the laptop plugged in at all times. Lockheed Martin is also continuing to use this Prius as an active research vehicle, constantly refining their software. Why? They have plans to transition their refined software to other vehicles, including boats and military tactical vehicles. Could they end up developing a ubiquitous "operating system" for robot cars? Perhaps standardized tests of the future will include the following analogy: Microsoft is to consumer PCs as Lockheed Martin is to robot cars.

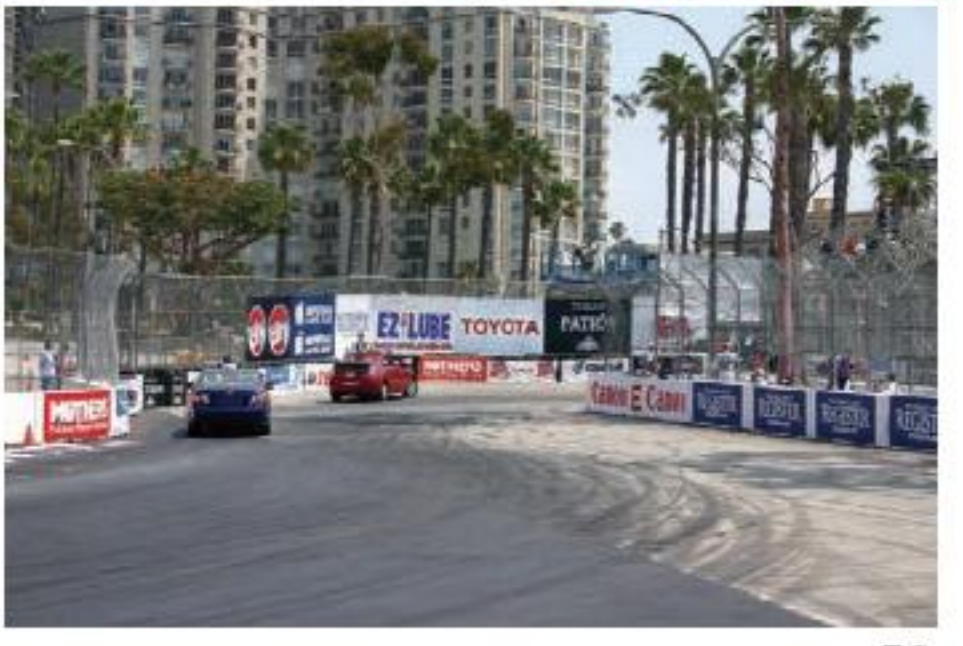
Like Boss, Little Ben's sensor-challenged brother starts with a map of the course and then uses those sensors to determine exactly when to turn, how sharply to turn, and how to deal with obstacles that can't be pre-programmed. Adam's analogy was your GPS unit in your car. It tells you

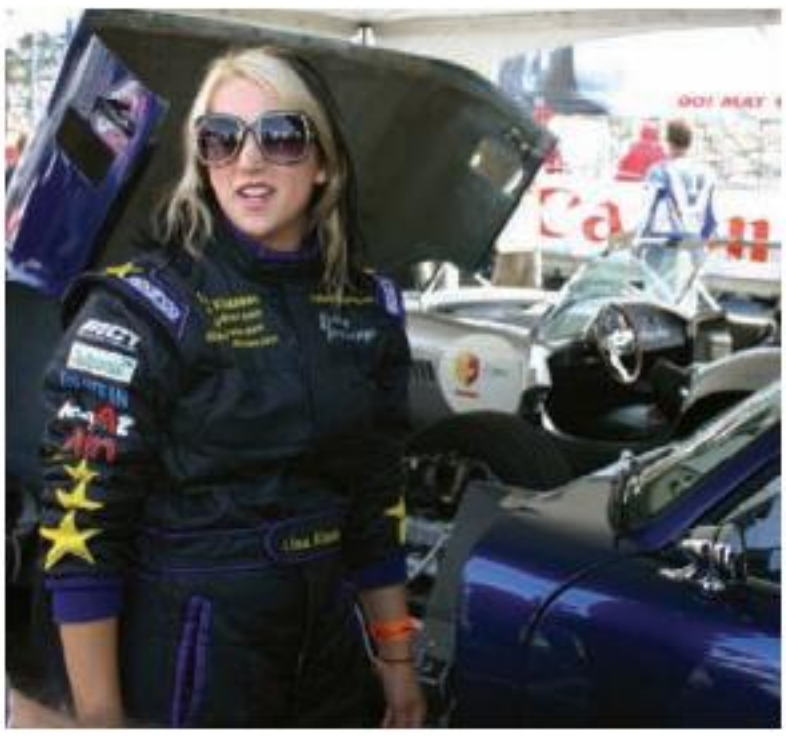












roughly when to turn and gives you a semi-detailed set of instructions, but it's up to the driver to perform the fine-tuned actions of stopping at a red light vs. going at a green light vs. flooring it at a yellow light, braking when that teenager on her cell phone cuts you off without using her turn signal, staying in your lane, and keeping on the right side of the island on that boulevard.

As far as the Prius knows ("knows," depending on how many human traits you like to attribute to your car ...), it has no idea that it was turned into a robot. That MacBook operates the car's controls (steering wheel, gas, and brake) with a drive-by-wire system, rather than interfacing into the Prius' smart hybrid computer brain.

Forget the high mileage boasted on the dealer sticker on the Prius. This vehicle averages 23 mpg in autonomous mode. Probably not too different from the smooth-driving-yet-hefty Boss Chevy Tahoe.

Adam gave me the run-down on the amusingly short list of significant sensors bolted to The Prius With No Name:

• Velodyne HDL-64E 64-laser LIDAR rotating at 10 Hz (Yes, I copied and pasted that from the Boss description — I challenge you to find a successful robot car that does *not* have one of these spinning domes bolted to its roof!).

• GPS on the roof determines vehicle location.

Also hidden in the car are accelerometers and odometry data, used when a good GPS signal is hard to find. Long Beach's skyline, intertwined with the street race course, was conspiring against the robot cars, but they didn't seem to mind very much. For the Grand Prix, the team also kicked their system up a notch by refining it to cruise at speeds up to 28 mph — up from their previous 15 mph top speed.

So, how did it work? The Prius was significantly slower than the other two robot cars, paused at a few turns, tapped the brakes as much as a cautious octogenarian on a busy street, and even added some slalom action around some imaginary cones on a straightaway. "Look! The Prius is heating up its tires on its warmup lap!" the race announcer mused over the PA. The 23 mpg mystery was solved! Although the Prius' driving performance was the least impressive of the trio, the fact that it did so much with so little was astounding. Furthermore, it could blend in as well on a normal city street as the Google Maps street view camera car or a car belonging to a serious mountain biking addict.

JUNIOR

Former Life: 2006 VW Passat station wagon
Named After: Presumably the little brother of Stanford's bigger VW Touareg — winner of the 2005 DARPA Grand Challenge
Pedigree: 2nd place in 2007 DARPA Urban Challenge
Turn-Ons: "Intel Inside" stickers on cars, not just PCs!
Turn-Offs: Fahrvergnügen
Team: Stanford University

Unfortunately, *SERVO* didn't get a chance to talk with anybody from the Stanford team. Based on the impressive operation of Junior, we're certain that they're all really smart and stuff.

Even if *SERVO Magazine* doesn't give me a free press pass to the 2009 Long Beach Grand Prix, I am so going to attend, crazy ticket prices be damned! It will be worth the price of admission just to see what sort of evolutionary leaps these robotic cars have performed during their intensive off-season training program.

What's next for robotic race cars? Adam Solomon grins: "This year was just a demo. I hear they're hoping to make this a race!" SV

Dr. Jason Bardis is a Mechanical Design Engineer for Alliance Spacesystems in Pasadena, CA. In addition to having three giant nuts from his three BattleBots championships, he designed many parts on the Phoenix Mars Lander's trench-digging arm, which is currently "making its mark" on Mars.