Tech Briefs

SAE International

SPECIAL REPORT: ADAS/CONNECTED CAR

DECEMBER 2018

Sponsored by

ROHDE & SCHWARZ

NATIONAL INSTRUMENTS™

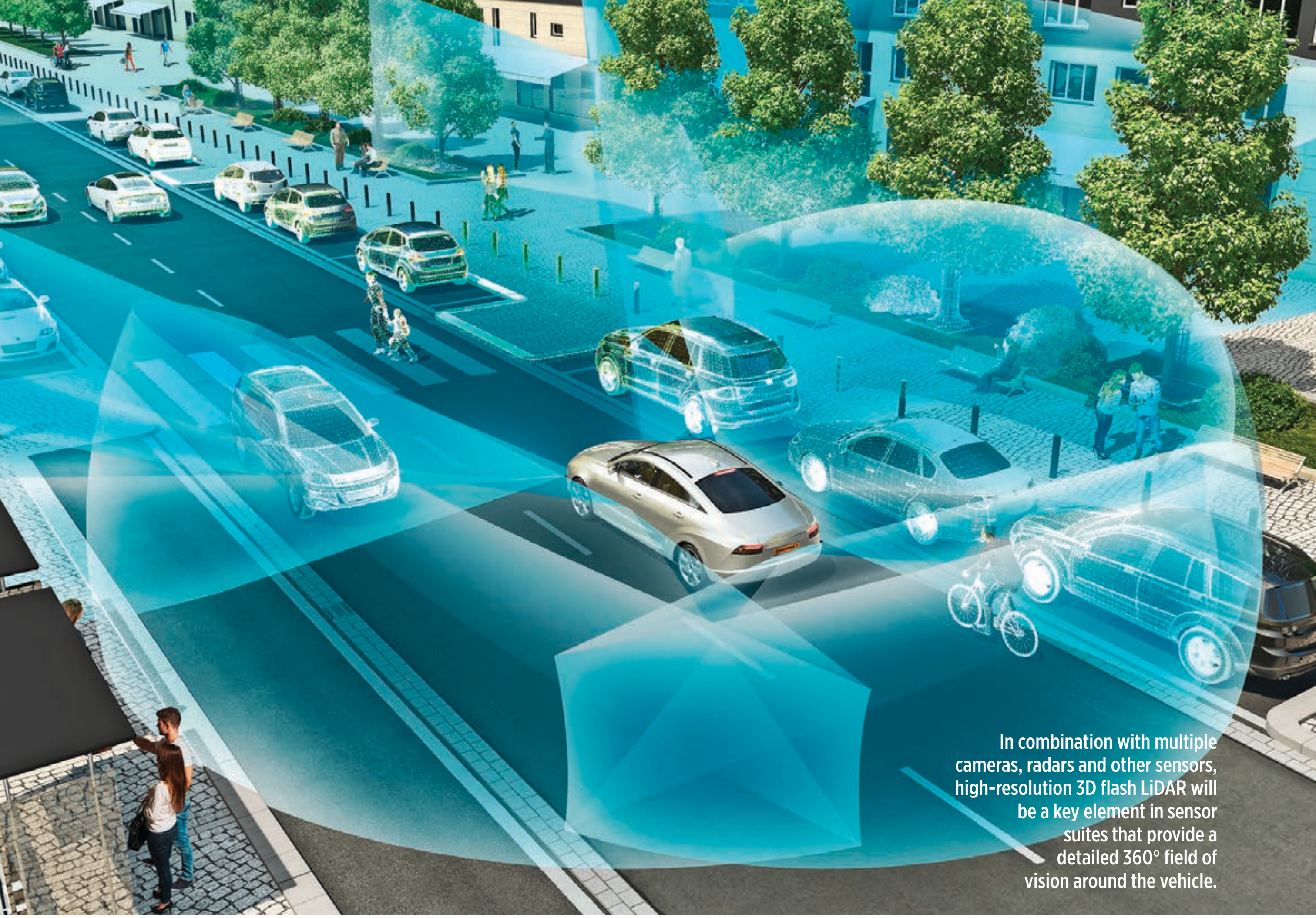
OLEA SENSOR NETWORKS™

CONTENTS

FEATURES

ON THE COVER

Cruising Chauffeur, developed by auto supplier Continental, merges camera vision, radar, and LiDAR sensing to provide SAE Level 3 automated-driving capability. Due in 2020, Cruising Chauffeur is intended for freeway driving and includes automated lane-changing and passing capability. (Image: Continental)



In combination with multiple cameras, radars and other sensors, high-resolution 3D flash LiDAR will be a key element in sensor suites that provide a detailed 360° field of vision around the vehicle.

The **Building Blocks** of Autonomous Tech

Sensors, processors, architecture and communications trends for the self-driving future.

by Terry Costlow

Mimicking the many things humans do while driving requires a complex blend of technologies. An array of several sensors per vehicle is needed to monitor a 360° field of view around the car. Fast networks that send data to the electronic controls are required to analyze inputs and make decisions about steering, braking and speed.

OEMs, Tier 1s and other suppliers are vying with and in some cases partnering with and acquiring a relentless wave of start-ups and industry disruptors including Apple and Google, as they race to develop tomorrow's mobility solutions. Their keys to winning reside in the following technology areas.

Processing power

The processors that analyze sensor data and make steering, braking and speed decisions will undergo major changes. Today's safety systems use a range of conventional multicore processors from companies like NXP, Infineon, Renesas, STMicroelectronics and Intel. But the extreme challenges associated with autonomy will require a range of processing technologies.

Nvidia's highly parallel graphic processing units, each with thousands of small processing cores, burst onto the automotive scene in recent years. GPUs excel at processing

CONTINENTAL

multiple tasks simultaneously, like analyzing the many pixels streaming in from sensors. Nvidia's latest multi-chip platform for SAE Level 3 through 5 driving, code-named Pegasus, is the size of a car license plate and delivers data-center-class processing power—up to 320 trillion operations per second.

Mobileye, now owned by Intel, has also developed a dedicated image processor. Specialized parallel devices can be made using field programmable gate arrays (FPGAs) from Xilinx, Intel (nee Altera), Lattice Semiconductor and Microsemi. FPGAs let designers create chips that are optimized for a given task. Mainstream suppliers like NXP and Renesas have licensed programmable technology from Tensilica that is being expanded from infotainment to safety systems.

Conventional CPUs won't disappear. They are best at sequential processing techniques used to make decisions. They'll help fuse sensor data after it's processed by various dedicated processors housed on sensors or in the ECU.

Most systems today link a processor to each system—for example, lane departure or adaptive cruise control. It's likely that a large control unit will collect all relevant data and decide how to navigate. That will push the demands for more cores, faster clock rates and a low power budget, especially in EVs.

Radar and cameras

Humans only need two eyes and some mirrors to drive safely, but autonomous vehicles will need as many as 30 sensors to match the performance of an attentive person. Many of them will look forward, working together to identify objects and watch roadways. Additional sensors will be employed to provide a 360-degree view of the vehicle's surroundings.

The radar component market is now dominated by established chipmakers like NXP and STMicroelectronics, which are pairing microcontrollers and radar devices. A similar integration path is being undertaken by partners Analog Devices and Renesas as well as Imec and Infineon. For example, an IHS Markit teardown of the 77-GHz radar sensor supplied by Delphi for the 2015 Volvo XC90 revealed Infineon's receiver and transmitter, and a TI apps processor among the unit's bill of material. Infineon SiGe HBT-based receiver and transmitter are also used in Delphi's pioneering RaCam radar + vision sensing technology.

A few start-ups including Oculii, Omniradar and Artsys360 are attempting to gain a foothold in radar. Most Tier 1s such as Bosch, ZF, Delphi and others are employing radar in safety systems.

Many of these companies also develop camera technologies, a field in which Intel's Mobileye has made a major impact—its EyeQ3 video processor also is part of the Delphi RaCam. Magna International, Bosch, Valeo, Continental and Denso are among suppliers that focus on vision systems. Chinese suppliers like Stonkam are making a major push into cameras, as are Panasonic Automotive Systems and airbag-supplier Autoliv.

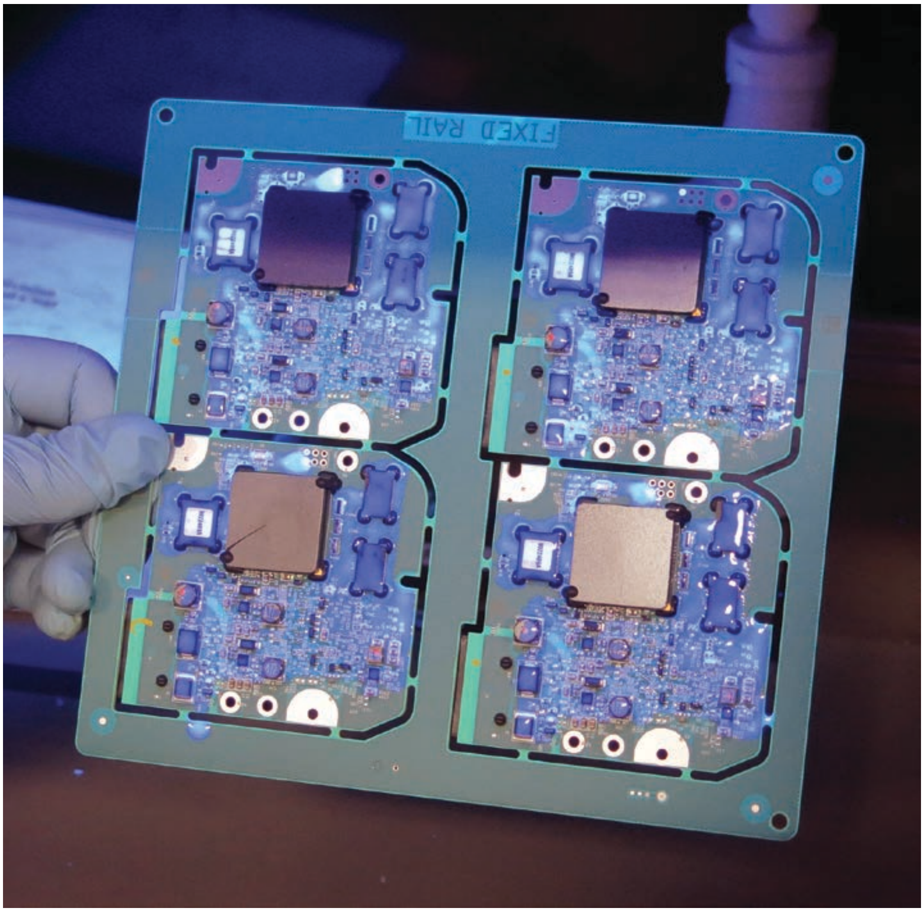
Another growing camera application is driver-alertness monitoring and cabin sensing, vital to safe SAE L2 through L4 vehicle operation, as proven by GM's Cadillac SuperCruise system. Tech collaborations are core to this emerging supply area; Denso has partnered with Xperi Corp., a Silicon Valley-based tech company whose FotoNation group specializes in image recognition technologies. Since 2014, Denso has provided a Driver Status Monitor for over-the-road trucks and large tour buses. Its system employs a cabin camera to capture images of the driver and computer vision technology to detect the driver's face angle to determine the level of drowsiness.

Cameras and radar currently work together to identify objects, and it's likely that LiDAR will be added when solid-state devices meet automotive requirements. Multiple overlapping sensors can safely identify objects without falsely sending alerts. Multiple radars are being used to provide 3D capabilities. The need for precise 3D images is behind a shift to 77-GHz radar, which offers more bandwidth than 24-GHz devices. Advanced techniques for sending and receiving signals are helping radar identify objects instead of simply providing range information.

GM CRUISE

GM purchased Strobe Inc. for its super-compact frequency-modulated (FM) LiDAR technology (prototype shown with a Sharpie for scale) that enables faster data processing than time-of-flight LiDARs. GM's Cruise Automation subsidiary is aiming to reduce solid-state LiDAR costs to under $100 per unit.

The **Building Blocks** of Autonomous Tech



LINDSAY BROOKE

Exponential growth in automotive on-board cameras has driven production efficiencies and greater scale. Shown are a quartet of image sensor boards at Magna's Holly, Michigan, camera plant.

Increasing resolution is a key factor for cameras. Higher resolution adds clarity and helps extend range, helping systems identify far-away objects. Resolutions of 8-10 Mpixels will become common, displacing today's 2-4 Mpixel cameras.

As more sensors are added, the volume of data they send to controllers is rising sharply. Integrating data processors is one solution but it's not a universal view.

"Adding a processor in the sensor induces latency and adds to the bill of materials," said Glenn Perry, General Manager of the Mentor Graphics Embedded Systems division. "When you have all the LiDAR, radar, cameras needed for SAE Level 5, I'm not sure this works. It will be expensive and consume an extraordinary amount of compute power."

LiDAR

Many automotive engineering managers consider Light Detection And Ranging (LiDAR) sensing, which combines a laser and camera, a necessity for SAE L5 driving. Operating much like radar, laser light goes out to objects and bounces back. Distance is measured by analyzing the time of this return, augmenting the camera data.

Various smaller companies now make electro-mechanical LiDAR systems, but they're all developing solid-state LiDAR, which is needed to meet automotive reliability requirements. The auto industry's interest is backed with hefty funding. Delphi, Ford and ZF invested in Innoviz Technologies, Velodyne and Ibeo, respectively. Quanergy's investors include Delphi and Daimler. Continental acquired Advanced Scientific Concepts; Analog Devices Inc. acquired Vescent Photonics. And in October 2017, General Motors' autonomous-tech subsidiary Cruise Automation purchased Strobe, a tiny firm that had been quietly developing next-generation LiDAR sensors.

Cruise boss Kyle Vogt wrote in a blog post that collapsing the entire sensor down to a single chip will enable his engineers to reduce the cost of each vehicle LiDAR "by 99%."

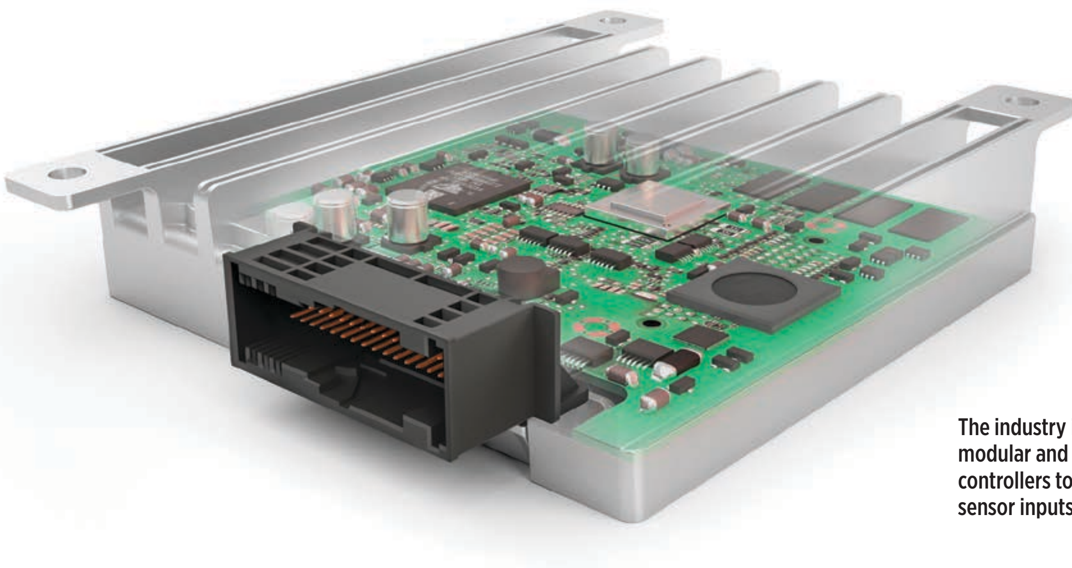
Some LiDAR chips are ready, but they're mostly for short-distance applications like lane departure. Most research focuses on getting automotive-grade solid state devices that combine 200 to 300-m (656 to 984-ft) distances with high resolution. This combination will let the systems identify objects before they get too close to the car.

"Resolution is key," said Anand Gopalan, CTO at Velodyne LiDAR. "If you're trying to see something small like tire debris that is far away, you want enough laser shots to hit it so you can recognize it and take evasive action."

Architecture

The architecture is the foundation that supports all the pieces that comprise driverless cars. It encompasses many elements: how sensor data is collected and fused to create a single view of the surroundings, how data is shared throughout the vehicle, how decisions are made and cross-checked, to name a few.

Software will play a huge role as electronic controls determine actions in response to what's happening around the car. Hardware must be powerful enough to make computations in time to avoid accidents. Today, hardware and software are often provided by the same supplier, though the Automotive Open System Architecture (AUTOSAR) has enabled some separation between hardware and software.



The industry is moving steadily toward modular and scalable multi-domain controllers to manage increasingly complex sensor inputs and processing.

CONTINENTAL

That trend may take off as carmakers search for continuously better autonomous software.

"Most people now understand that hardware and software should be abstracted from each other," said Karl-Heinz Glander, Chief Engineering Manager for ZF's Automated Driving Team. "This makes it easier to bring third-party software in. OEMs can benefit from working with pure software companies like Apple or Google or with companies like Nvidia or Mobileye that put algorithms on their chips."

One critical architectural aspect is whether the processing power is centralized in a powerful ECU or distributed. Many ADAS systems distribute processors in smart sensors to process raw data before sending it to the controller. This pre-processing trims the central controller's processing task while also reducing the amount of data sent over networks. Some system architects think it's more efficient to send raw sensor data to powerful centralized ECUs, eliminating the processors in sensors. Some OEMs may opt for a mixture, with some "smart" and some "simple" sensors.

It's nearly impossible to create software that will respond correctly to the unlimited possibilities that autonomous vehicles will see on roadways. That's sparking a huge investment in creating artificial intelligence programs that 'learn' as vehicles are driven. AI is already driving big advances in voice recognition and image analysis.

Communications

If vehicles can share information, they can get information on-board sensors can't get, such as emergency braking by a car hidden by a tractor-trailer rig. Vehicle-to-infrastructure communications to roadside beacons can also aid in safety and traffic flow. This information can be a treasure trove for autonomous vehicles. However, deployment of the two technologies often jointly called V2X is still in question.

Delphi V2V controller as used by Cadillac.

LINDSAY BROOKE

The **Building Blocks** of Autonomous Tech


CONTINENTAL

AI- and camera-based driver monitoring systems are vital for SAE Levels 2 through 4 operation.

NHTSA and automakers have worked for years to create standard dedicated short-range communication (DSRC) technologies that facilitate this communication, but there's no implementation mandate yet. There's skepticism that DSRC won't be deployed unless it's required. Cadillac has deployed V2V, but no other OEM has followed suit.

While regulators mull over factors like security, automotive and cellular suppliers are devising V2X communications that use 5G cellular technology. 5G's emergence date and actual performance are still in question, but next-generation cellular modems will probably be on most cars once 5G pricing comes down. Cellular bandwidth may let these 5G modems handle many aspects of V2X, including black-ice notification that doesn't require real-time performance.

For warnings that might cause autonomous cars to steer or brake, DSRC's low latency is critical. On-highway tests have proven DSRC's performance with large numbers of vehicles, so its rollout could be quick once NHTSA moves or a couple major proponents agree to start using it on passenger cars or commercial trucks. While some 5G proponents feel cellular can displace DSRC, many feel both may share roles.

"The industry should call for collaboration and how the two technologies should co-exist without sacrificing safety scenarios," said Raed Shatara, Senior Principal Engineer, Business Development, at STMicroelectronics. "FM did not replace AM. HD did not replace AM or FM. Satellite radio did not replace AM, FM or HD. They all co-exist in vehicles today."

Whichever technology is used, these benefits may be slow to come to fruition. V2X communications rely on being able to send messages to many vehicles, and it will take a long time for V2X-equipped vehicles to displace older cars. Aftermarket systems can't offer many safety features, since it's difficult to verify that messages are coming from a verified vehicle, not a hacker. ■

Expanding the Role of FPGAs

New demands for on-vehicle data processing, and over-the-air updating, are expanding the use of these programmable semiconductors in production vehicles. The recent Daimler-Xilinx linkup shows the way forward.

by Terry Costlow

The increasingly varied nature of data tied to safety systems and connected cars and trucks is altering electronic architectures, putting more emphasis on adaptability during design phases and after new vehicles enter the field. Field Programmable Gate Arrays (FPGA) are increasingly seeing use in production vehicles, with expectations that usage could grow as artificial intelligence (AI) and over-the-air updating become more commonplace.

FPGAs are semiconductor devices that are based around a matrix of configurable logic blocks, connected via programmable interconnects. They can be reprogrammed to desired application or functionality requirements after manufacturing. In this way FPGAs differ from Application Specific Integrated Circuits (ASICs), which are custom manufactured for specific design tasks.

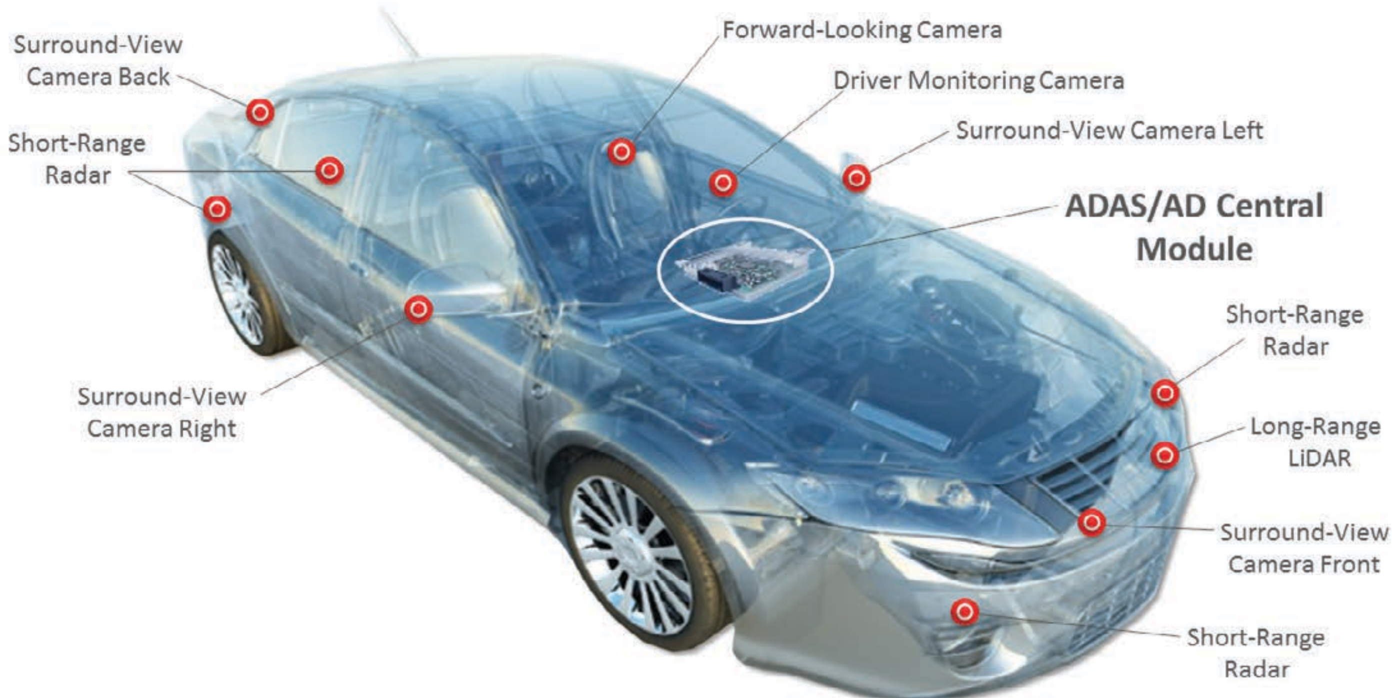
In new vehicles going forward, inputs now come from multiple sensors and wireless links, areas where changes occur far more regularly than in conventional automotive systems. AI also requires the ability to adapt to changing patterns. These shifting demands for data processing are helping FPGAs expand their role in production vehicles.

Programmable devices from Xilinx and Intel/Altera migrated beyond prototyping a few years ago, largely in rapidly-changing infotainment systems. Now, the image processing requirements of cameras, radar and LiDAR provide a boost for FPGAs, as does the looming implementation of AI.

According to Grand View Research, automotive is now the third largest global market for FPGAs, after industrial and telecom. Another analysis firm, Markets and Markets, predicts FPGA revenues will rise from $5.83 billion in 2017 to $9.5 billion in 2023, noting that rising vehicle volumes in the Asia-Pacific region will drive rapid FPGA growth in automotive.

> *FPGAs "provide an extra layer to defense-in-depth protection schemes."*
>
> ***—Willard Tu, Xilinx Senior Automotive Director***

Xilinx, which has shipped over 40 million parts to OEMs and Tier 1s, is



FPGAs can be used in a range of vehicle sensors and in safety modules.

claiming significant progress in full-run vehicle shipments. In 2013, its chips were in 29 production models made by 14 OEMs. This year, they are in 111 production models from 29 OEMs.

Recently Daimler announced it is teaming up with Xilinx so its deep-learning experts at the Mercedes-Benz Research and Development centers in Germany and India can develop AI algorithms on an adaptable Xilinx platform.

"Through this strategic collaboration, Xilinx is providing technology that will enable us to deliver very low latency and power-efficient solutions for vehicle systems which must operate in thermally constrained environments," said Georges Massing, Director User Interaction and Software, Daimler AG.

Xilinx is competing with Nvidia graphical processing units (GPUs), Intel's Mobileye vision processing devices and the FPGAs Intel gained by acquiring Altera. Willard Tu, Senior Automotive Director at Xilinx, said Xilinx devices provide more transparency than Mobileye's black box approach. If there are problems, that makes it easier to debug. He added that FPGAs can be faster than GPUs.

"GPUs batch parallel tasks, holding some until a set number arrive. That introduces latency," Tu explained. "We do parallelism, running batchless processes where each input is an independent piece of data. There's no queueing, so all elements have the same latency."

He noted that as connectivity brings security concerns, FPGAs provide an extra layer to defense-in-depth protection schemes. Tu compared silicon to a door lock, saying that once hackers find an opening, they can continue to exploit it even after software has been updated.

"Hardware is the lock, once hackers figure out how to defeat that lock, they know how to get in. You can change the software, but they can still get in. With FPGAs, you can change the lock, closing that vulnerability for good," he asserted.

While conventional processors scale by moving to higher clock rates or adding cores, FPGAs can be upgraded without major redesigns. When alterations are needed, programmable logic can be upscaled by adding more fabric, which is simpler than redesigning a processing unit or waiting for faster parts. That is important as more factors change as OEMs move towards autonomy.

"When you look at data aggregation and pre-processing and distribution, it's hard to predict how many cameras, what type or radar and the style of LiDAR will be used," Tu said. "There are a lot of variabilities in sensors, and they may link to CAN or Ethernet, so there's a real need for programmability." ■

XILINX

ADAS Computing on a
Greater Scale

Samsung engineers are developing next-gen domain controllers to meet specific performance needs of automated/autonomous driving.

by Terry Costlow

Open. Modular. Scalable. Those words describe the framework of Samsung Electronic's autonomous vehicle platform currently under development.

The new compute platform "is being designed as a functionally-safe ADAS (advanced driver-assistance systems) domain controller that can be scaled for the performance needs of different autonomous driving levels," noted Dave Anderson, Director of Samsung Electronics' Autonomous Driving Program, during a recent interview with SAE's *Autonomous Vehicle Engineering*.

Called DRVLINE, the modular architecture is interconnected with multiple buses, including Gigabit Ethernet and a high-bandwidth backplane leveraging Peripheral Component Interconnect Express (PCIe).

A baseboard, designed to ISO 26262 ASIL D standards, serves as the gateway to the vehicle. "Think of the baseboard as the safety- and automotive-interface for all the drive-by-wire functionality in the vehicle," Anderson explained. "By adding expansion boards to this baseboard, we add higher levels of compute functionality."

On-road development is being conducted in California with a fleet of test vehicles retrofitted with the new compute platform and equipped with ADAS sensor arrays consisting of LiDAR, radar, and multiple high-resolution cameras.

"The public-road testing that we're doing now is between SAE Level 2 and SAE Level 3 functionality," Anderson revealed. "We're also doing data collection and research for higher levels of driving autonomy."

DRVLINE's architecture features plug-and-play flexibility to handle hardware and software upgrades as autonomous driving technology matures. The design intent is "to provide a very solid framework that partners can use to develop applications without being concerned about the underlying technology," said Anderson.

Although several Samsung engineers are creating control code to address specific autonomous operational requirements, such as perception, the DRVLINE platform development is based on a high degree of supplier-customer collaboration.

"We want to provide solutions, but only where it makes sense to do so," Anderson said. Because vehicle OEMs want to write proprietary algorithms for their specific product applications, DRVLINE's open framework allows them to easily augment their own control strategies with what Samsung provides to complete the overall software stack.

Anderson's development team expanded from five to 72 engineers in 18 months. He expects another wave of engineers to be headed to Samsung's San Jose, California facility this year. "We're doing what we think is appropriate to aggressively build out this software solution," Anderson stated.

Samsung recently formed a strategic partnership with Vienna, Austria-based TTTech, a leader in networking and safety controls for ADAS. ■

SAMSUNG

Development engineer Matt Lewis testing the DRVLINE computing platform recently on California public roads.

Fusing Sensors for the Automated-Driving Future

Complex processing architectures, faster networks and even more sophisticated software are vital for 100% accurate Level 4 and 5 systems.

Researchers are striving to develop optimal techniques for rapidly and accurately combining sensor inputs in vehicles.

MENTOR GRAPHICS

by Terry Costlow

Piloted and autonomous driving systems depend on inputs from many types of sensors arrayed to create a highly accurate view of vehicle surroundings. Fusing all these inputs into a single image of each car, pedestrian and roadway marking takes a sophisticated architecture with hefty amounts of computing power and deterministic communications.

At highway speeds, combining inputs from multiple camera views is a complex challenge by itself. But different sensor types are needed to avoid errors, so vehicle controllers must blend inputs coming from multiple sensors and multiple modalities.

"Camera data comes in at 30 frames per second," said Kay Stepper, Vice President for Driver Assistance and Automated Driving for Bosch North America. "Radar can have 20 to 50 or even 100 data sets per second, and LiDAR has a different time cycle all together. The first challenge is to bring all these data sets together to represent a single point in time, which requires some complex software."

The challenge of merging multiple inputs will only get more difficult as the trek to autonomy continues. As vehicles advance to higher levels of the SAE automated driving scale, more sensor inputs will be needed. Some architectures may use more than two dozen sensors to create the 360° view needed for fully autonomous driving.

"Going from [SAE] Level 1 to Level 5, the sensor count goes from one or two up to 30 or more," said Wally Rhines, CEO of Mentor Graphics, acquired by Siemens in early 2017. "To fuse all those inputs, you need software that lets you look at thousands of variations to get to an optimal design."

Those programs will be complex, so techniques for continuing upgrades will need to ensure that much of the software can be reused. These programs will need to run on successive generations of hardware that will be deployed over many makes and models for years. Today, much software is written by the teams that create the hardware. Going forward, many planners want to move away from that model so it's easier to upgrade and make changes like switching suppliers.

"Software reuse and hardware-software separation are becoming major issues," said Paul Hansen, Editor of the respected *Hansen Report on Automotive Electronics*. "AUTOSAR and Automotive Grade Linux can help companies separate hardware and software so they can more easily switch vendors."

More power

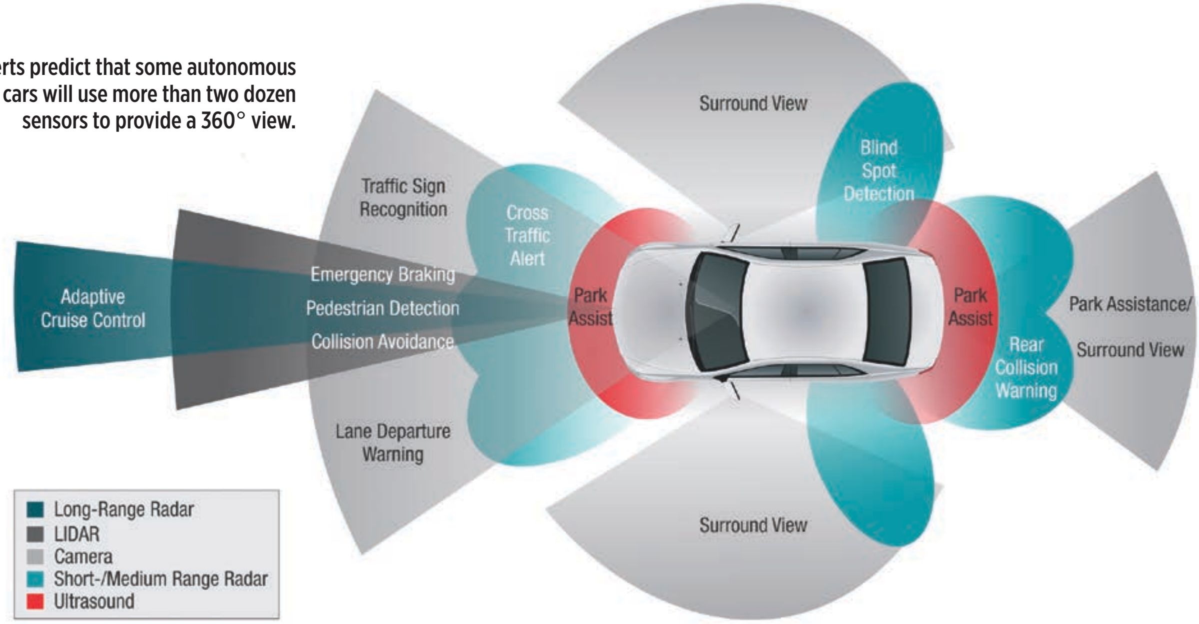
It will take a lot of computing power to collect all these inputs, analyze the data and make life-and-death decisions. The microcontrollers that have dominated electronic designs for decades will soon become one element in controllers that add graphics processors and custom devices that use parallel processing to handle images.

Many suppliers have partnered with Nvidia, which popularized the concept of graphics processors. However, Nvidia faces competition from FPGA suppliers like Xilinx and Intel, as well as mainstream automotive CPU suppliers like NXP and Renesas. They have licensed Tensilica's programmable technology, planning to move it from infotainment applications to safety systems.

Once these devices are combined with conventional controllers, the ongoing advances in microprocessors should provide the processing power needed for successive generations.

"Graphic processing algorithms need very high-performance processors or specialized processors, which opens the market for companies known for gaming processors like Nvidia and Intel," said Karl-Heinz Glander, Chief Engineer for ZF's Automated Driving

Experts predict that some autonomous cars will use more than two dozen sensors to provide a 360° view.



MENTOR GRAPHICS

Team. "Devices that were used in infotainment are now going into safety applications. Given the advances tied to Moore's Law, computing power will not be a limiting factor."

These advanced architectures rely on real-time communications. The volume of data from sensors is a key factor that will drive a change in networking architectures, but it's not the only aspect. Complex algorithms use concepts like occupancy grids, which consume bandwidth. Understanding where components are and routing the right data to them also increases bandwidth and timing requirements.

"The choice of bus communication depends strongly on the chosen vehicle architecture, number of sensors and fusion approaches taken. Additionally, the communication of occupancy grids and high definition maps between components, if necessary, enlarges the bus load requirements," said Aaron Jefferson, Director, Global Electronics Product Planning at ZF. "We see a likely preference for CAN, CAN-FD and Ethernet."

Going beyond CAN

Properly combining all the inputs to create a cohesive image requires exacting precision. Networks need to ensure that latency and other issues don't cause timing glitches.

"CAN is no longer sufficient; you need a time triggered network," Stepper said. "CAN-FD has time triggering, but there's a clear migration to Automotive Ethernet because it has deterministic behavior and has the speed and bandwidth."

BOSCH

Cyclist and pedestrian detection is a focal point for sensor-fusion development.

VALEO

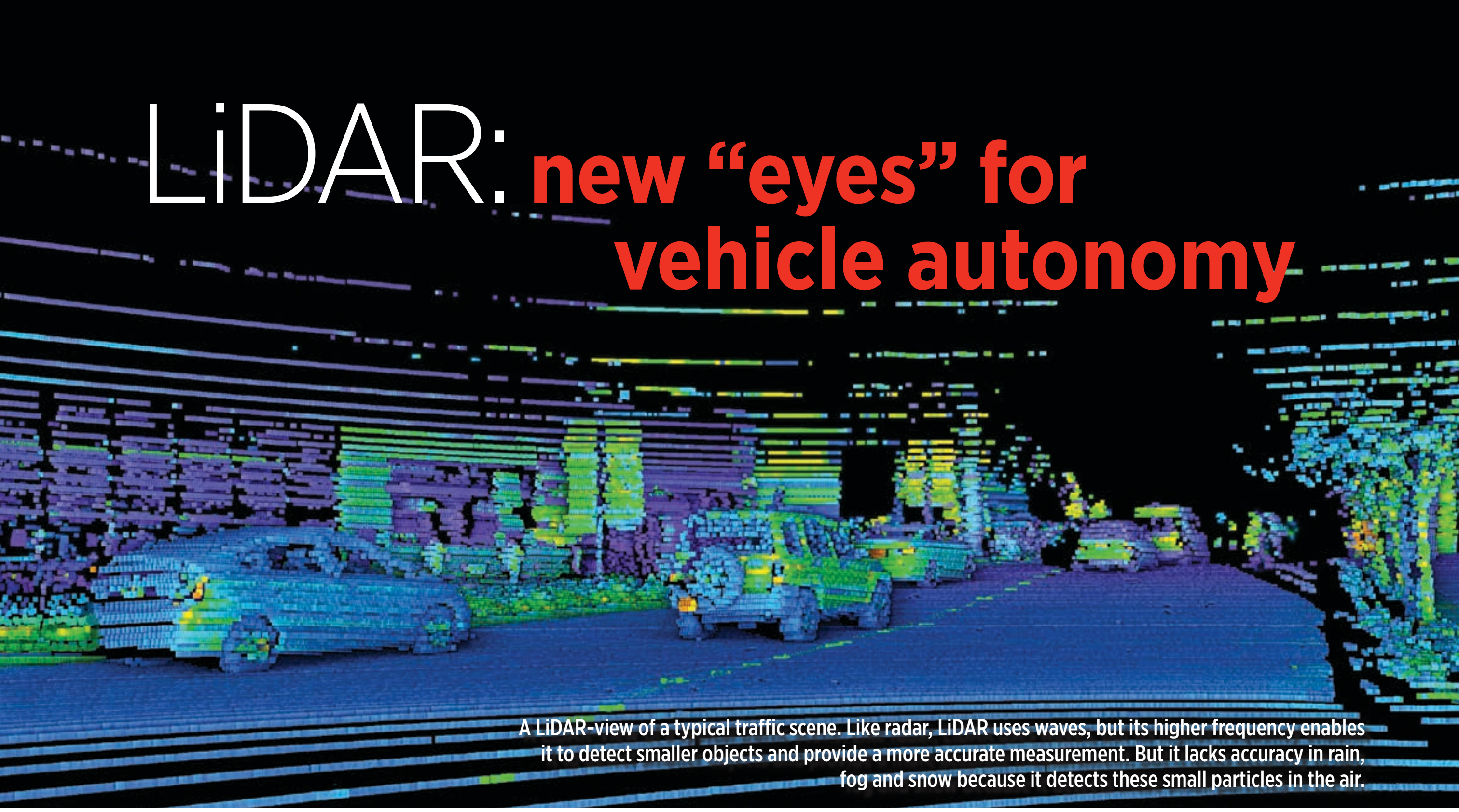
Cameras generate data at 30 fps and faster.

Many companies plan to reduce some of these communications requirements by moving everything into a centralized controller. Most systems today use dedicated electronic control modules that don't communicate at nearly the levels that will be needed by autonomous vehicles. That's prompting many design teams to look at using one very powerful ECU.

"We prefer a centralized vehicle controller with a scalable architecture that goes up to SAE Level 4 and 5," Stepper said. "Our centralized vehicle controller houses sensor data fusion and decision-making in one box."

The ability to scale is always critical, but will be especially important as technology marches forward. Sensors improve, processors get more powerful, and engineers figure out ways to do more every year. Advances in one area typically beget progress in other fields.

"3D capabilities come from different ways to create and receive signals," ZF's Glander said. "As processing power increases, we can use higher and higher resolution imagers to extract more information and get wider sensing angles. Cameras are going from two to eight and even 10 mpixel resolution." ■



LiDAR: new "eyes" for vehicle autonomy

A LiDAR-view of a typical traffic scene. Like radar, LiDAR uses waves, but its higher frequency enables it to detect smaller objects and provide a more accurate measurement. But it lacks accuracy in rain, fog and snow because it detects these small particles in the air.

The steadily evolving sensor tech offers big leaps forward in capability—once cost is reduced.

by Lindsay Brooke and Bill Visnic

The acronym stands for Light Detection and Ranging, and LiDAR first showed its potential in May 1962, when electrical engineers Louis Smullin and Giorgio Fiocca used the 12-inch telescope at MIT's Lincoln Laboratory to bounce 50-joule laser pulses off the Moon, receiving the reflected light with the lab's 48-inch telescope. Using time-of-flight calculations, the two researchers were first to measure the distance between Earth and its only natural satellite.

Four decades later, after use in meteorology and the Apollo program, LiDAR emerged as a vital sensor in robotic-vehicle prototypes competing in the U.S. Department of Defense DARPA Challenge. With up to 64 lasers and sensors packed in large, roof-mounted cylinders, the ungainly canisters resembled spinning soup cans when operating. The sensors swept a 360° field of view around the vehicle, firing thousands of light pulses. Objects that reflected light within the sweep were identified as a cloud of points, complementing imaging from the multiple radars and cameras also fitted to guide the driverless vehicles.

By 2007, the annual event's fourth year, the winning vehicle and five of the six finishers had early LiDARs from technology pioneer Velodyne Acoustics (the company's original name) mounted atop their roofs. Each unit reportedly cost nearly $80,000.

Today's steadily evolving LiDAR typically functions in a similar fashion as the early units, albeit with new hardware and software. The proven mechanical-scanning types are in the practical lead for automotive use, experts say, while new solid-state (no moving parts) devices are expected to deliver greater reliability and dependability. They also offer a compact form factor—crucial for integrating the sensors within the car's exterior skin. Solid-state types typically have a more limited field-of-view (FOV). Their lower cost, however, offers the possibility to employ multiple sensors to cover a broader area.

Depending on exterior vehicle geometries determined by styling, a typical car or truck could need up to eight compact LiDAR units of narrower acceptance angle—120° on the front and rear, 90° on the side—compared with the big 360° unit on the roof. Range can be reduced; engineers are aiming for 30 meters on the side, 200 meters to the front, 50 meters to the rear, depending on how microwave radar is integrated into the vehicle's safety suite.

LiDAR development is booming, as start-ups and established Tier suppliers race to enable SAE Level 3, 4 and 5 automated-driving capability in future vehicles. The technology is also in big demand for 3D mapping.

Frost & Sullivan forecasts sales of 6 million LiDAR units in 2025—half of them for use in autonomous vehicles, for a projected $2-billion market. Automotive Engineering counts more than 30 start-ups in the field, along with market leader Velodyne and some Tier 1s including Bosch, Valeo, and Continental. Aptiv and Magna are among top suppliers that are partnering with LiDAR specialists. OEMs continue to acquire and build ties with LiDAR developers, including BMW

GM Cruise AV rooftop sensor array shows current state of integration and packaging used by on-road test fleets.

GM

(Innoviz via Magna), GM (Strobe), Toyota (Luminar) and Ford (Princeton Lightwave and Velodyne).

While some advocates have dubbed LiDAR "the essential piece of the puzzle for self-driving cars," it is certainly the most discussed and perhaps controversial sensor technology related to autonomous vehicles.

"Every couple of weeks a new company is touting new LiDAR technology adaptations," observed veteran mobility-tech consultant Gerald Conover. "Many of their claims are based on lab-project results, so designs producible in high volume may still be some years away." Only those that deliver high performance at low cost will survive. Depending on the uptake for autonomous vehicles in SAE Levels 4 and 5, however, "the demand for LiDAR devices could be significant," Conover noted.

Cost remains the nagging impediment to the mass deployment of automotive-grade units. Development units still cost $10,000 or more—"not a sustainable number for automotive production," Conover quipped. "The thing standing in the way of this is the necessary expertise to produce working LiDAR, which is in the hands of only a few supplier firms." OEMs eventually expect a steady cost-reduction path to commodity status, similar to those of onboard radar and cameras.

Since late 2017, Quanergy has been producing a 905-nanometer solid-state LiDAR with a range of 150 meters at 8% reflectivity. An optical phased-array type, it can scan half-a-million points per second with a spot size of 3.5 cm at 100 meters, the company claims. While single-unit samples are priced in the thousands, Quanergy believes high-volume scale will drive per-unit cost below $300. Velodyne's lowest-priced 16-laser unit costs $4,000 per unit.

Horses-for-Courses Tech Choices

While the automotive LiDAR space is white-hot, not all OEMs see the technology as an imperative. Tesla's Autopilot system uses camera-based optical recognition, and company boss Elon Musk appears unconvinced that LiDAR is a game-changer. "Once you solve cameras for vision, autonomy is solved; if you don't solve vision, it's not solved," Musk said during a TED Talk in 2017. "You can absolutely be superhuman with just cameras," he added. He obliquely labeled LiDAR "a crutch."

Honda North America is "doing development and testing with LiDAR," noted Jay Joseph, assistant VP of Product Planning. He said Honda engineers believe LiDAR is necessary in the short term. "Longer-term, of course, we'd like to see other solutions—probably more dependent on connectivity and shared information. But until that's reliable, LiDAR is probably necessary to provide good information to the vehicle so it can make good decisions."

Assembling and integrating the sensor array into the vehicle is an important role that experienced Tier 1s including Aptiv are playing. "We understand how it works with the vehicle; some of the tech start-ups don't understand vehicles well," noted Jada Smith, Aptiv's VP of advanced technology.

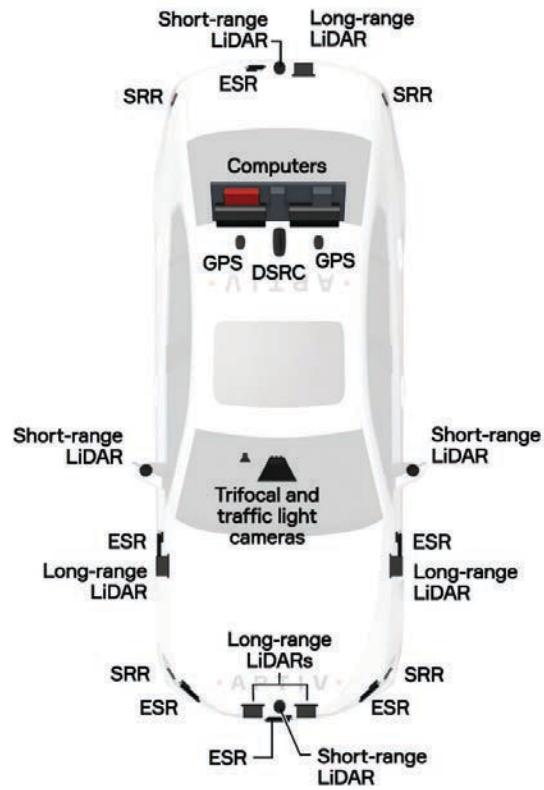
Smith said her company wholly believes in the tech triad of cameras, radars and LiDAR for vehicle autonomy. LiDAR, she said, is "a necessary piece of technology, to handle all use cases, provide redundancy, and to help the vehicle see everything going on around it." Aptiv is covering multiple technology bases with its investments in Leddartech (flash-LiDAR), Innoviz (MEM type) and Quanergy (optical phased array).

Choosing LiDAR types is a horses-for-courses engineering exercise. "What roles do we expect them to play?" Smith asked. "The longer the range, the narrower its FOV—same

LiDAR: new "eyes" for vehicle autonomy

MAGNA

LiDAR downsizing will be vital to full integration of sensor units into the vehicle. A Magna concept vehicle shows a step toward improved integration.



APTIV

Sensor layout of BMW 5-Series autonomous demo car used by Aptiv at CES17. The comprehensive array includes four short-range LiDARs, five long-range LiDARs, six scanning radars (ESR), four short-range radars (SRR), one trifocal camera, one traffic light camera, two GPS antennae, one DSRC module and two computer software stacks for redundancy.

concept as a camera. Depending on what performance we want, we may choose a flash type for one and MEMS for another. It's tradeoffs, depending on what we're trying to accomplish."

Automotive Engineering recently spent time with a group of LiDAR innovators and brings the following insights into their backgrounds and technologies.

Innoviz Technologies

Like so many sensor-tech developers, Innoviz is based in Israel and several of its principals have specialized-electronics background with the Israeli Defence Forces. Innoviz was founded three years ago and has about 150 employees globally. The company has garnered more than $80 million in investment funding, including stakes by Aptiv, Magna and Samsung.

The foundation technology is a microelectromechanical systems (MEMS)-based design in which movement of the mirror that projects the scanning lasers comes from a solid-state chip. Critically, Innoviz promotes laser scanning at 905 nm, a long-established wavelength that Aditya Srinivasan, general manager, North America, said allows the company to keep a lid on cost—to the point at which Innoviz can offer its first automotive-grade LiDAR sensor, InnovizOne, starting in 2019 at a cost in the hundreds of dollars.

There may be some contention about whether the Innoviz design should be defined as solid-state, since the system uses a moving mirror, but, "Rightly or wrongly, we're calling this 'solid-state,'" said Srinivasan.

The InnovizOne is "designed for seamless and easy integration into any mass-market vehicle," the company's literature describes. The system delivers 120°-horizontal and 25°-vertical FOV for high-definition resolution of 7.5 million pixels/sec; the frame rate is 25 frames/sec. Claimed range is up to 250 m (820 ft). The unit's footprint measures 50 mm high by 110 mm wide by 100 mm deep (2 x 4.3 x 3.9 in.). Data is managed by a proprietary signal-processing chip that's been developed with "a partner" that Srinivasan chooses not to name.

The company also claims its system is adept at identifying objects with extremely low reflectivity—a performance aspect that to now has been a challenge for many LiDAR developers.

In April, Innoviz announced a supply agreement with BMW through Innoviz' supplier partner Magna. BMW said it intends to offer an SAE Level 3 autonomous ride-hailing service in 2021 and Innoviz-derived LiDAR apparently will be a key component.

Aptiv and Samsung also are partnered with Innoviz for automotive LiDAR development and in June the company said it formed a partnership with Chinese Tier 1 HiRain Technologies, which supplies several major Chinese automakers and is integrating the components for its own autonomous-driving platform.

TetraVue

The primary differentiation point for TetraVue's solid-state "flash" LiDAR technology is high resolution—as well as reliance on long-proven and relatively-inexpensive sensor technology derived from the digital-camera world. In fact, the company refers to its automotive LiDAR as a "high-definition 4D camera" that essentially fuses mega-pixel digital video capture with LiDAR for long-range sensing with pixel-level depth information.

Resolution is everything to TetraVue founder and executive VP Paul Banks, who has a Ph.D in applied physics but explains the company's presumptive technology advantage in plainspoken terms. Banks removes his eyeglasses, saying the state of California would not certify him to drive without them—yet most competing LiDAR technologies "see" with less resolution than the state's minimum vision requirement for humans to legally drive.

"For us, that's what's important," Banks said flatly. "High resolution. We actually use the same (image) sensor that's in your cell phone. We cheat," he deadpanned.

His argument is a compelling one that's interested investors such as Bosch and Samsung. Appropriating the well-developed and extremely cost-driven complementary metal oxide semiconductor (CMOS) and charge-coupled device (CCD) sensing technology of digital cameras, TetraVue's LiDAR flashes the environment at up to 30 fps with lasers operating at the invisible-to-the-eye 800-nm wavelength. This "illumination" is merged with the high-resolution video-capture to derive depth information at the pixel level.

Banks' demonstration borders on amazing, as he shows a data scene of a dancer seen with "conventional" LiDAR and TetraVue's LiDAR; the additional perspective and depth from the TetraVue image is patently startling.

"It looks and feels more like a video camera," Banks said. And he does not exaggerate—showing up to 60 million points per second, the images from the company's system make the techy-but-still-scratchy visual representations from competitors seem like the visuals from an ancient video game.

The current downside to Vista, California-based TetraVue's LiDAR may be a comparative lack of range. The current design, Banks said, has a range of about 150 m (492 ft)—Velodyne's latest system, for example, boasts a range twice that far. TetraVue's range may be improved, he said, "but for us, it all comes down to cost." He said the company is intent on delivering its advanced technology at a price conducive to mass-market application.

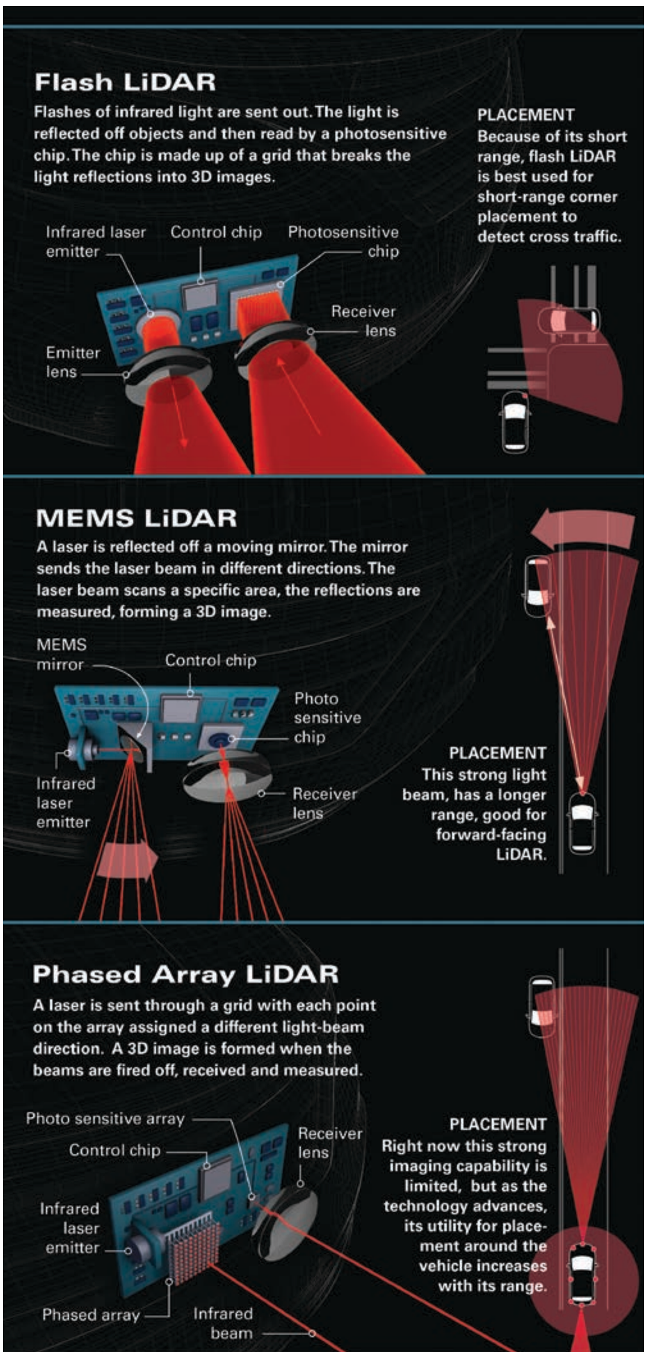
Ouster

Founder and CEO Angus Pacala's Ouster could be the tech age's embodiment of the military doctrine of the Civil War's Nathan Bedford Forrest: "Get there firstest with the mostest."

LiDAR: new “eyes” for vehicle autonomy

Pacala extols one of his company’s market advantages as just that: Ouster is shipping automotive LiDARs today, he said.

“We let our products do the talking,” he boasted of the “smartest, lightest 360-degree, 3D sensing in the market.” He also said his company is the only one to openly and transparently price its technology for any buyer.



Solid-state LiDAR types as used by Aptiv.

APTIV

Pacala, formerly the director of engineering at Quanergy, said Ouster’s OS-1 is the highest-resolution LiDAR currently commercially available, and it has best-in-class power consumption, size and weight. The system measures 1.3 million points per second, yet consumes less than 15W. And like TetraVue, the company’s technology is rooted in comparatively low-cost, highly-developed CMOS technology used for years in ever-advancing smartphones and digital cameras.

To keep costs reasonable, the OS-1 lasers operate on the 850-nm wavelength; cost is “laddered” to some degree according to the customer’s need for channels: the highest-cost versions use 64 emitters to deliver each vertical field-of-view “slice,” while lower-performance requirements can cut cost with just 16 channels. Pacala said the company expected to ship 10,000 to 20,000 units by the end of 2018

The roughly double-puck-sized OS-1 weighs just 330 g and is 2.5 in (63 mm) tall and 3.14 in (80 mm) in diameter. It is not solid-state: the unit spins to emit over the 360° coverage range and nearly 32° vertical FOV. Its accuracy is about 3 cm (1.3 in)—but range is a comparatively abbreviated 120 m (394 ft).

Range is improved with the coming OS-2, which Ouster indicates will have a 200-m (656 ft) range and 64 channels spaced at 15.8°, although the unit is correspondingly larger and heavier. Pacala said the OS-2 would be available in the third quarter of this year.

Valeo

French Tier 1 supplier Valeo late in 2017 achieved the distinction of supplying what is believed to be the first LiDAR sensing system to be deployed on a series-production vehicle, Audi’s A8 sedan, widely described as using SAE Level 3 driver assistance. The A8’s Traffic Jam Pilot system controls the A8’s acceleration, braking and steering at speeds up to 37 mph (60 km/h), using the company’s Scala LiDAR.

Scala, a solid-state design developed in cooperation with ibeo, won a 2018 PACE award for supplier innovation. Valeo said Scala has a 145° horizontal field of view and range of 150 m. As is typical for many sensing technologies, LeddarTech says its advances are largely in proprietary processing and algorithms: “essentially an ensemble of software, algorithms and know-hows that are used to design or optimize various types of solid-state LiDAR sensors,” according to company literature.

Some anxious early-adopters won’t find Traffic Jam Pilot and the Valeo/LeddarTech LiDAR array just yet, however; the system initially is not available in many countries. Audi was reluctant to introduce the technology in the U.S. and other markets that do not have clearer legal and regulatory frameworks to address conditional autonomy.

In May, Valeo announced a “strategic cooperation” with Apollo, the open autonomous driving platform created by China’s Baidu in 2017. The company said in a release it will contribute to the Apollo project its expertise in sensors, not to mention its “skills in sensor cleaning systems and connectivity between autonomous vehicles.” ■

Seeing Through Fog

Fog, rain and snow are big challenges for optical sensors, particularly active systems. Engineers need to understand the impact of fog conditions on cameras and thermal sensors used in AVs.

by Art Stout

As the mobility industry advances with ADAS and autonomous vehicle (AV) operation, the safety challenges of applications involving nighttime warning systems, pedestrian detection and driver situational awareness will surely warrant redundant systems. Thermal sensors will continue to be an important component of the sensor suite that makes safe autonomy a reality.

A 2006 example of the notorious and deadly Tule fog in Bakersfield, Calif.

WIKICOMMONS

Although the value of thermal sensors is widely acknowledged for nighttime driving, a key issue that has limited their full-scale adoption has been cost. It is important to note that infrared imaging sensors are semiconductors, so the same economics of scale apply to infrared sensors as apply to other silicon-chip products. The costs for high resolution thermal sensors are projected to decline to well under $250 with their large scale adoption in ADAS systems.

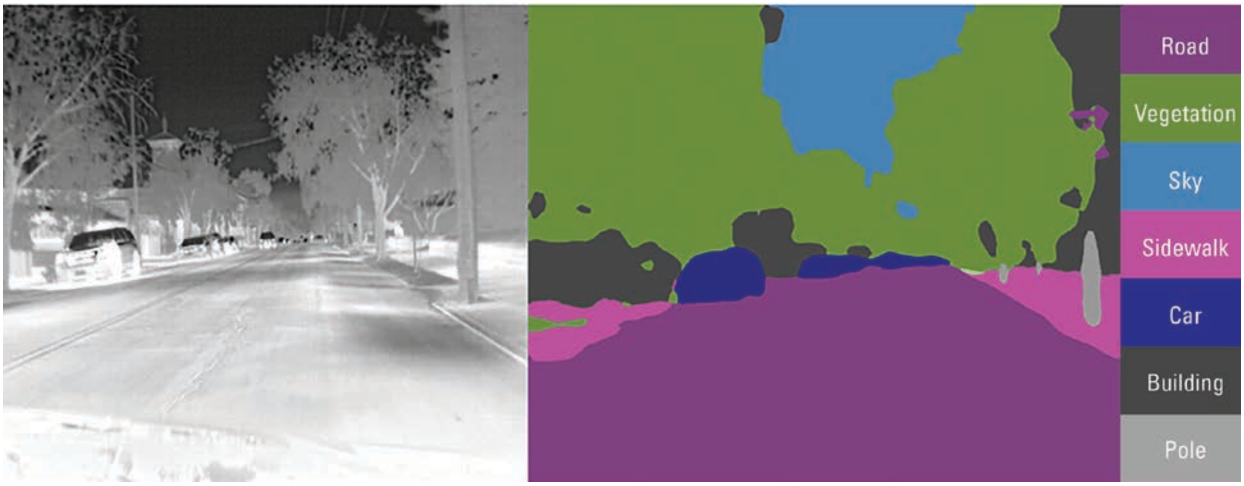
As the price enables developers to include thermal sensors, it is important to identify why they are needed and where they complement the ADAS sensor suite to make roads safer.

Delivering high-quality data and images to the 'brains' of autonomous vehicles in low light and under poor driving conditions is a major challenge for ADAS developers. Fog, rain and snow are big challenges for optical sensors, particularly active systems. Engineers need to understand the interaction of light energy across the visible and infrared spectrum with water vapor—specifically, the impact of fog conditions on optical systems such as visible cameras and thermal sensors.

Modeling with MODTRAN

Fog is a visible aggregate of minute water droplets suspended in the atmosphere at or near the surface of the earth. When air is almost saturated with water vapor, the relative humidity is close to 100% and fog can form in the presence of a sufficient number of condensation nuclei, which can be smoke or dust particles.

There are different types of fog. Advection fog is formed through the mixing of two air masses with different temperatures and/or humidity. Radiative fog is formed in a process of radiative cooling of the air at temperatures close to the dew point. Some fogbanks are denser than others



FLIR

Semantic segmentation classifier using thermal sensor.

FLIR

Oncoming headlight effect on visible and thermal camera comparison in nighttime foggy driving conditions.

because the water droplets have grown bigger through accretion. The question whether scattering is less in the IR waveband compared to the visible range depends on the size distribution of the droplets.

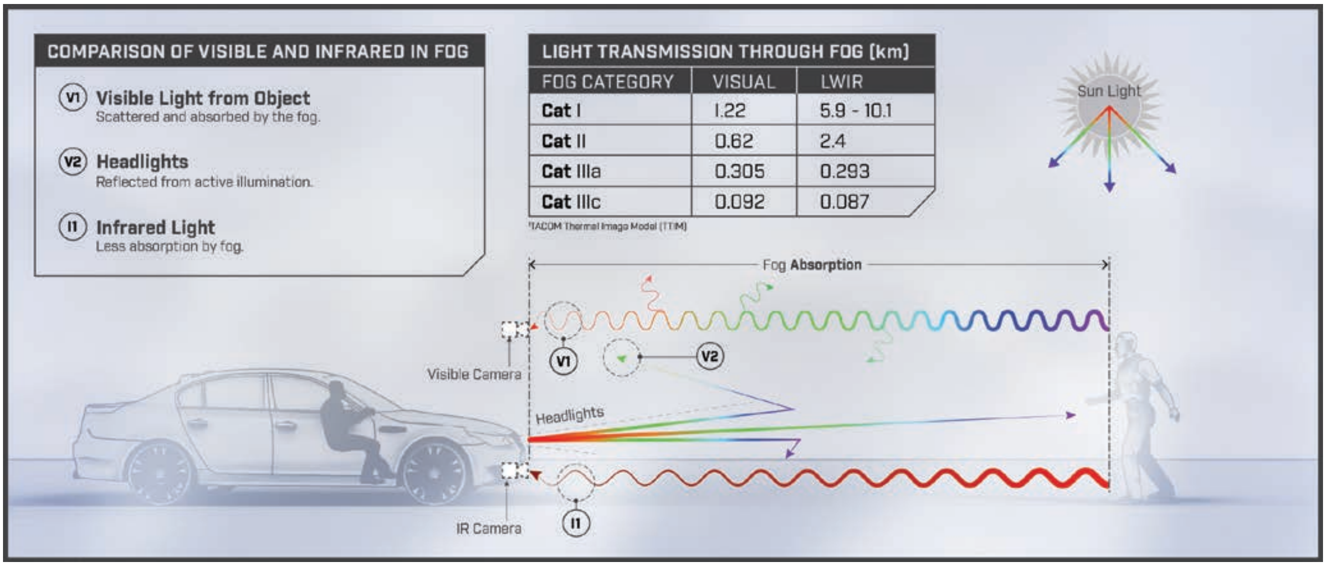
MODTRAN is used to model the atmosphere under a variety of atmospheric conditions. Developed by the U.S. Air Force, it can predict atmospheric properties including path radiances, path transmission, sky radiances and surface reaching solar and lunar irradiances for a wide range of wavelengths and spectral resolutions. MODTRAN offers six climate models for different geographical latitudes and seasons.

The model also defines six different aerosol types which can appear in each of the climates. Each of the climate models can be combined with the different aerosols. The distance an optical sensor can see will also depend on the climate and the type of aerosol which is present in this specific climate.

The spectral transmission of the atmosphere for varying ranges enables a simple qualitative comparison of the visible (0.4 to 0.75 microns) and thermal (8 to 12 microns) transmission in different atmospheric conditions and fog type. The International Civil Aviation Organization (ICAO) classifies fog in four categories:

- **Category I:** In fog in mid-latitude summer and rural aerosols, the visible spectral waveband demonstrates significantly lower transmission than in thermal IR wavelengths.
- **Category II:** Radiative fog is used in this category and the model predicts that transmission in the thermal band is superior to the visible band.

Seeing Through **Fog**



FLIR

Pathlength losses for visual and thermal energy in fog.

- **Category IIIa and Category IIIc:** The model states that transmission in the visible and thermal wavelengths are essentially equivalent.

The model compares the detection range in kilometers through fog with the naked eye and an LWIR camera, given a temperature difference of 10°C between the target and the background and a detection threshold of 0.15 K. The graphic on p. 17 includes the qualitative results of the model.

The model and data provide transmission performance, which is driven by several factors. The reason for degradation of visibility in a foggy atmosphere is the absorption, reflection and scattering of illumination by water aerosols. All drivers have experienced driving in heavy fog and poor visibility when using headlights. The light photons from headlights immediately begins to scatter and reflect.

The limited light, if any at night, coming from the driving scene is absorbed and scattered, so the main visible photons the visible camera collects are of the fog itself.

While thermal light photons exhibit the same basic characteristics as visible light, the thermal energy is emitted by the surroundings so the path the thermal light energy takes between an object and the camera takes only one pass. There are loses due to scatter and reflection, but in most fog conditions the transmission is higher in the thermal bands than in the visible spectrum, so the losses are much lower.

Thermal imaging, Machine learning

The addition of thermal sensors to the ADAS sensor suite will clearly increase safety on the road. Thermal sensors see in darkness and challenging lighting conditions such as fog. As the photos on p. 16 illustrate, a vision-based autonomous system will simply become blind in a frequently experienced driving condition. They can detect and classify objects in a cluttered environment. The next challenge is to integrate thermal sensors into the fused detection and classification algorithms.

An additional promising area for thermal sensors, beyond seeing at night and through poor visibility situations, is semantic segmentation or dense labeling, a deep learning technique that describes the process of associating each pixel of an image with a class label (structure, person, road marker, animal, road or car). Initial results demonstrated by FLIR Systems, which has delivered more than 500,000 longwave infrared (LWIR) thermal cameras to date, indicate that thermal images can produce accurate classifications of most of the object classes of interest.

The ability to classify complex automotive driving scenes quickly and accurately using thermal imagery is a key part of increasing safety of ADAS and future autonomous vehicles. While open-source visible light training data sets exist, publicly-available thermal image training data sets do not, making the initial evaluation of thermal imaging more challenging. An annotated training data set from FLIR will create the opportunity for developers to more quickly test and integrate thermal sensors into their ADAS sensor suites.

Thermal cameras are and will become even more affordable with additional manufacturing scale. They deliver high resolution data and fill significant sensor gaps that exist in current ADAS approaches, especially in challenging lighting conditions. ■

Art Stout is Director of Business Development, Office of the CTO, FLIR Systems OEM Division.

TAKING AIM AT THE DROWSY-DRIVER THREAT

Hyundai Mobis is leveraging SAE Level 4 autonomy tech to move 'departed' drivers safely off the road.

by Ian Adcock

DDREM "rescue" scenario. Most situations where DDREM is active would involve the vehicle taking over for less than one mile.

HYUNDAI MOBIS

Semi-autonomous technology designed to significantly reduce the 7000 annual fatalities in the U.S. attributed to driver drowsiness has been developed by Hyundai Mobis North America. A "low-cost" production system is being readied for 2022.

"By narrowing our focus to the safety aspects of autonomy, we can quickly bring life-saving [SAE] Level 4 into passenger cars," said David Agnew, Director of Autonomous Vehicle Development.

"Everyone talks about autonomous Level 4 where you don't depend on the driver to take over; what we're doing is using autonomous just for safety," Agnew told *Automotive Engineering*. He claimed that current driver-alert systems "just detect and then give a warning" which is often ignored.

"People don't perceive themselves as being on the cliff-edge between being alert or drowsy; they want to reach their destination," he opined. The new Hyundai Mobis system takes over the driving to safely move the vehicle out of traffic, slowly bringing it to a halt before transmitting an emergency call.

The system, known internally as DDREM (Departed Driver Rescue & Exit Maneuver), is now undergoing road testing in prototype vehicles. It employs standard brakes, stability control and electronic power steering. There's a production long-range radar, a forward-looking monocular camera and short-range radars, with modified software. Mobis engineers are not using LiDAR or redundant systems.

Monitoring the driver are three interfused sensor systems. An infrared camera focuses on the driver's face to observe eye closing and which direction the face is looking. Fused into this are control inputs from the steering wheel and pedals. The third set of inputs detects vehicle wandering.

"We take it to almost a point of no return and then retake control of the vehicle," Agnew explained. "Ultimately, we end up with a low-cost, low-tech Level 4 system that is a highly-effective solution for 'departed' drivers."

He said much of the research done to date is based on data from industries such as mining, where huma drowsiness-detection is vital to worker safety. While the Mobis system currently does not employ physiological sensors such as heart rate, body temperature and brain function, these are being investigated for future development.

Agnew claimed that for vehicles already equipped with ADAS, the Hyundai Mobis system would represent a "low-cost" investment for OEMs. The implementation of the DDREM technology could save up to 85% of the drowsy-driver-related fatalities per year, he said.

"We are now trying to get into production as soon as we can, not necessarily with Hyundai or Kia," he added. ■

Sensing Changes in Autonomous Trucks

Requirements for sensors and controls for commercial vehicles differ significantly from those used for cars.

Daimler's road tests examined automated braking that is needed when sensors spy a car (being pulled by first truck) cutting in between trucks.

DAIMLER

by Terry Costlow

Driver shortages and rising demand are fueling interest in technologies that let commercial trucks navigate with minimal to no human input. Many of the sensing systems being designed into trucks are borrowed from passenger cars, but commercial vehicles have many different requirements.

Radar, cameras, LiDAR and control technologies for automated vehicles are all advancing quickly, giving commercial vehicle engineers a number of tools to work with. Highway speeds are largely universal, but many factors change when these electronic systems migrate from cars to trucks. The systems and their software will have to be honed to operate with vastly different parameters.

"The sheer size and weight differences between a passenger car and a commercial vehicle at 80,000 pounds mean the actuation systems for acceleration, braking and steering are of a different magnitude as well," said Derek Rotz, Director of Advanced Engineering for Daimler Trucks North America. "Stopping distances vary from cars to trucks, so the need for earlier warning of objects becomes more critical. Trucks operate under a wide array of conditions, from fully loaded to empty. These differences cause vehicle dynamics to vary, which must also be considered."

The vagaries of commercial environments also pose major challenges for design teams. Over their operating lifetimes, tractors will haul loads of widely divergent weights and sizes, factors which impact braking and steering.

Additionally, most autonomous programs call for 360-degree views around the vehicle, so sensors will have to be mounted on trailers. The electronic links between trucks and cargo carriers need to facilitate frequent configuration changes. Connections and communications between tractor and trailer will work best if they're simple and universal.

"Tractor-trailer combinations are not a given during equipment lifetimes—there will be a lot of swaps," said Dan Williams, Director, ADAS and Autonomy, at ZF Commercial Vehicle Technologies. "That creates a demand for standardization."

Several sensors

A range of sensors will be needed to provide the input needed by autonomous control systems. Though the number of radars, cameras and LiDAR and their locations will vary widely depending on vehicle types and loads, all of them will be needed regardless of how they are configured. The technologies all have different traits, so using a mix provides more certainty about what's in the vehicle's purview.

"We feel it is critical that a comprehensive approach is taken as each of these types of sensors play a specific role," Rotz said. "When deployed together, they can collectively improve overall safety performance."

Multiple sensors complement each other, providing information that can be combined to improve identification and avoid false positives. Using many sensors also provides redundancy for a range of failures. Radar and LiDAR can provide results when a camera can't see through snow, for example, letting the systems understand the surrounding environment.

"Automation requires more and more situational awareness and redundancy," Williams said. "We need a wider field of view and redundancy, to be robust when one sensor fails. That redundancy includes having different sensor technologies."

LiDAR is the new technology in this mix. Solid-state LiDAR systems are still in their infancy, with several suppliers vying for what's expected to be a huge automotive market. These cameras add lasers to work much like radar, adding distance capabilities to identification skills.

"LiDAR can provide very accurate measurements, especially in comparison to radar," said Chris Woodard, Business Development Manager for Autonomous Machines, Danfoss Power Solutions. "Rain, snow and dust can all take a toll on LiDAR, where it doesn't bother radar at all. From a safety standpoint, LiDAR is a great solution and complementary sensor to other available technologies."

Off-the-vehicle input

Sensors are typically mounted on the vehicle, but in some commercial environments it may be more beneficial to install sensors in the infrastructure. In warehouse docks or a mining

ZF

Standards may be needed to let autonomous trucks freely change trailers.

site, fixed infrastructure sensors can determine where vehicles are. Locational data can be transmitted to the vehicle, where it can be treated like any other sensor input. That can keep costs down.

"Automated behavior in freight yards, which extends to outside operations like pit to port, has very different concerns because operating environments are more controlled, vehicles are not exposed to the general public," Williams said. "One great advantage is that you can put instrumentation in the freight yard so the back of every trailer doesn't have to be covered with sensors that cost more than the trailer and its freight."

Remote controls are another way to gain the benefits of autonomy without making the investment needed for fully

Sensing Changes in Autonomous Trucks

Off-highway environments are simple—but not

It is the best of environments and the worst of environments for designers of autonomous off-highway vehicles. Freight haulers and some agricultural equipment are in some ways easier to automate than passenger cars, but many construction machines pose extremely vexing challenges.

Mining companies have been using autonomous trucks for a few years, with a number of users saying efficiency gains average 15-20% over conventional trucks. In many ways, hauling freight from mines to ports or rail depots is far simpler than autonomously driving trucks on highways.

"The mine might be 20 miles from the rail head," said Dan Williams, ADAS and Autonomy Director at ZF Commercial Vehicle Technologies. "The driving path is very predictable—they run the same route every day, often in a remote environment where there aren't a lot of intersections and they don't have to deal with many drivers or pedestrians."

Passenger cars usually drive forward from point to point, so most of their sensors face forward, with comparatively few facing rearward. But any construction vehicle equipped with a backup alarm requires extensive sensing technologies on the front and back to provide autonomy.

The Danfoss Autonomous Vehicle Integration System provides a platform for combining sensors that will help the vehicle perform a range of off-highway tasks.

"While off-highway machines are trying to get from one spot to another, they're also performing work functions," said Chris Woodard, Business Development Manager for Autonomous Machines, Danfoss Power Solutions. "You may have a wheel loader that's transporting material or an excavator that's digging. Or, all the work may be happening behind the machine, like planting or tilling. These all require different sensor systems and configurations. In short, the flexibility and adaptability of autonomous systems for the off-highway market is much higher than in the automotive industry."

Another difference is that while off-highway vehicles may need more sensors, they may not need the high resolutions used for autos. For many tasks in construction and agriculture, distances are only a few meters and fewer objects are important, so the high-resolution cameras used in cars aren't necessary.

"We've worked with lower-resolution cameras as well as different filtering technologies—infrared, for example—to pick out important pieces of data, as well as high-resolution cameras that can pick out the finer details of objects" Woodard said. "The trade-off is processing requirements, which impacts the processor cost."

"We're working with different types of cameras and backend processing for different tasks, so there isn't a 'one size fits all' solution. The type of application can determine which configuration works best. For example, a lower-resolution camera is used for sprayers or mechanical weed removal to differentiate between a plant or a weed simply based on the area it takes up," he added.

However, Woodard noted that as automotive volumes for high-resolution cameras rise, it's likely that prices will fall to levels that make high-resolution cameras viable for off-highway systems. That will increase computing requirements, but processor prices are also likely to decline over time.

Terry Costlow

Radars from suppliers like ZF will be a mainstay of sensor arrays that include cameras and LiDAR.

Redundancy is needed to ensure that a tractor's sensors don't miss vehicles that impact the truck's ability to switch lanes.

autonomous vehicles. In environments like mining and agriculture, a single remote operator can monitor a few semi-autonomous vehicles, taking control mainly when systems aren't able to make a decision based on the sensor input. This technology may help companies take steps towards autonomy while developers are working to bring driverless vehicles to mainstream applications.

"We see remote control systems as an important piece on the path to full autonomy and will play a critical role in developing an overall machine control package," Woodard said. "In the future, I can see this technology evolving to more 'tele-operation' applications, where operators can control machines through a long-range radio link or over an internet connection." ■

CLOCKWISE FROM TOP RIGHT: ZF; DAIMLER; DANFOSS

SEARCH WITH A PURPOSE

IN SAE'S MOBILITY TECHNOLOGY SOLUTIONS GUIDE

The **Mobility Technology Solutions Guide** enables mobility engineers to meet their technology challenges and design the next generation of vehicles.

INTUITIVE DESIGN

Simplistic layout makes it easy to find the relevant information you're looking for.

POWERFUL SEARCH FUNCTIONALLY

Search keywords, categories, companies and products.

MOBILE-RESPONSIVE DESIGN

Search the directory anywhere, on any device.

ENHANCED COMPANY PROFILES

Learn more about the companies serving our industry.

COMPANY REFERRALS

Referrals build confidence and credibility for potential buyers.

START YOUR SEARCH TODAY!

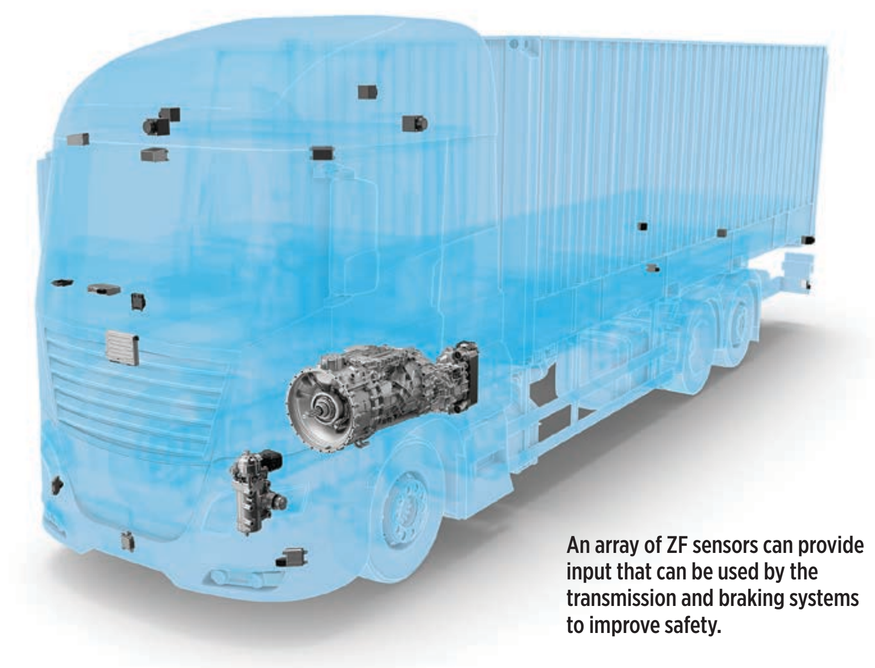
mtechguide.com

SAE has partnered with MultiView to provide advertising opportunities in the **Mobility Technology Solutions Guide**. For more information about advertising, email **salesinquiries@multiview.com**, or call **972-402-7070.**

MULTIVIEW

ADAS Features Expand Role, V2V Looms

by Terry Costlow



An array of ZF sensors can provide input that can be used by the transmission and braking systems to improve safety.

ZF

Truck owners and commercial-vehicle suppliers are ramping up their safety efforts, making more advanced driver-assistance systems (ADAS) standard while looking at the potential benefits of vehicle-to-vehicle (V2V) communications. Though V2V can bring many benefits, widespread usage remains shrouded with questions.

Support for improved safety comes from some of the top executives of the largest vehicle fleets. FedEx CEO John Smith repeatedly commented on the need for improved safety during a recent Volvo Trucks-FedEx V2V demonstration. Associates detailed the push to fully equip the FedEx fleet with safety systems.

"By the end of the year, we will have collision mitigation, rollover stability control and lane-departure warnings on all our vehicles," said FedEx Communications Director Michele Ehrhart. "We already have adaptive cruise control on all but the oldest vehicles."

Truck makers are moving in lockstep, noting that it's easy for buyers to justify the cost of safety systems. Safeguarding human lives is priceless, but protecting vehicles and cargo has a definable financial payback.

"There's a very strong business case for improving safety," said Kary Schaefer, General Manager of Strategy for Daimler Trucks North America's Freightliner Trucks. "Every accident that safety systems prevent provides more uptime for the fleet. Active safety is one of three major areas of investment for the industry, along with propulsion and connectivity."

As suppliers and owners move to equip more vehicles with ADAS, researchers are also exploring the potential benefits of V2V. The industry has standardized 5.9 GHz dedicated short-range communications (DSRC) to let vehicles talk to each other and communicate with roadside beacons. Many companies are testing V2V's benefits for platooned convoys. When vehicles can tell each other when they're braking, safety can be improved. Tightening distances between trucks can bring fuel savings up to 10%.

"The first use of V2V communication will be platooning," said Dan Williams, Director of ADAS and Autonomy, Commercial Vehicle Technologies, at ZF. "Vehicle-to-infrastructure communication could allow more cost-effective information in a restricted area environment."

Safely shortening following distances means ensuring that trucks slow down synchronously. Volvo provides redundancy by closely linking adaptive cruise control (ACC) with V2V communications. That helps ensure that all vehicles immediately react when the lead vehicle slows.

"Active safety is one of three major areas of investment for the industry, along with propulsion and connectivity."

—Kary Schaefer, Freightliner Trucks

VOLVO TRUCKS

Platooning brings many benefits, but regulations for certifying V2V remain elusive.

"We're using our standard ACC and adding a layer on top, using V2V," said Keith Brandis, Vice President for Product Planning at Volvo Trucks North America. "Cooperative ACC uses DSRC to let trailing vehicles know immediately when the lead truck is slowing or braking."

Researchers feel V2V brings major financial benefits, but its usage remains in question. Platooning brings benefits even if the operating fleets are small. Greater benefits occur when more trucks can communicate, bringing broader safety improvements. It can be difficult to justify connectivity costs when only a few vehicles can talk to each other.

"In a mixed environment where sometimes this information might be available, sometimes not, it can become a source of potentially useful information, but if it is unreliable you may not want to base safety decisions on this data source," Williams said.

The National Traffic Highway Safety Administration's (NHTSA) tardiness in mandating a rollout date has created questions around adoption. Cellular promoters say that 5G connections provide enough bandwidth to provide many of the benefits.

Called C-V2V, it is gaining some interest from automakers who feel they can eliminate the cost of a DSRC link by using cellular modems that are likely to be on most cars in a few years. Given the lack of usage in cars and trucks, some groups have discussed selling some of the 5.9-GHz DSRC spectrum. That's not palatable for most DSRC proponents.

"We're working with the FCC to protect our wireless spectrum," Brandis said. "If we get narrower bandwidth, it will restrict the amount of data we can send. That's important for the future, when even more data will be sent."

Having a communications infrastructure capable of handling lots of data is viewed as an important element in the drive to automate all driving. Data on road and weather conditions can help autonomous vehicles navigate safely. Vehicles could also share information about pedestrians near roadways, as well as providing real-time traffic info. V2V input is often viewed as sensor information that extends farther than on-board sensors. Increasing the volume and confidence levels of environmental data will be important as autonomous trucks move from limited applications to mainstream driving.

"Further out, we will use more sensing to identify safety issues all around the vehicle, and combine longitudinal and lateral control," Williams said. "These associated functions will help to improve safety and efficiency of commercial vehicles, and lead to increasing levels of automation. The first automated vehicles will appear in duty cycles that are relatively easy to navigate, such as hauling from a mine pit to a railhead on a remote road, or maintaining a lane on a limited access highway." ■

Big Data,
Big Challenges

Cloud services and multiple partnerships are issues the mobility industry grapples with as it expands outside the vehicle.

by Terry Costlow

AIRBIQUITY

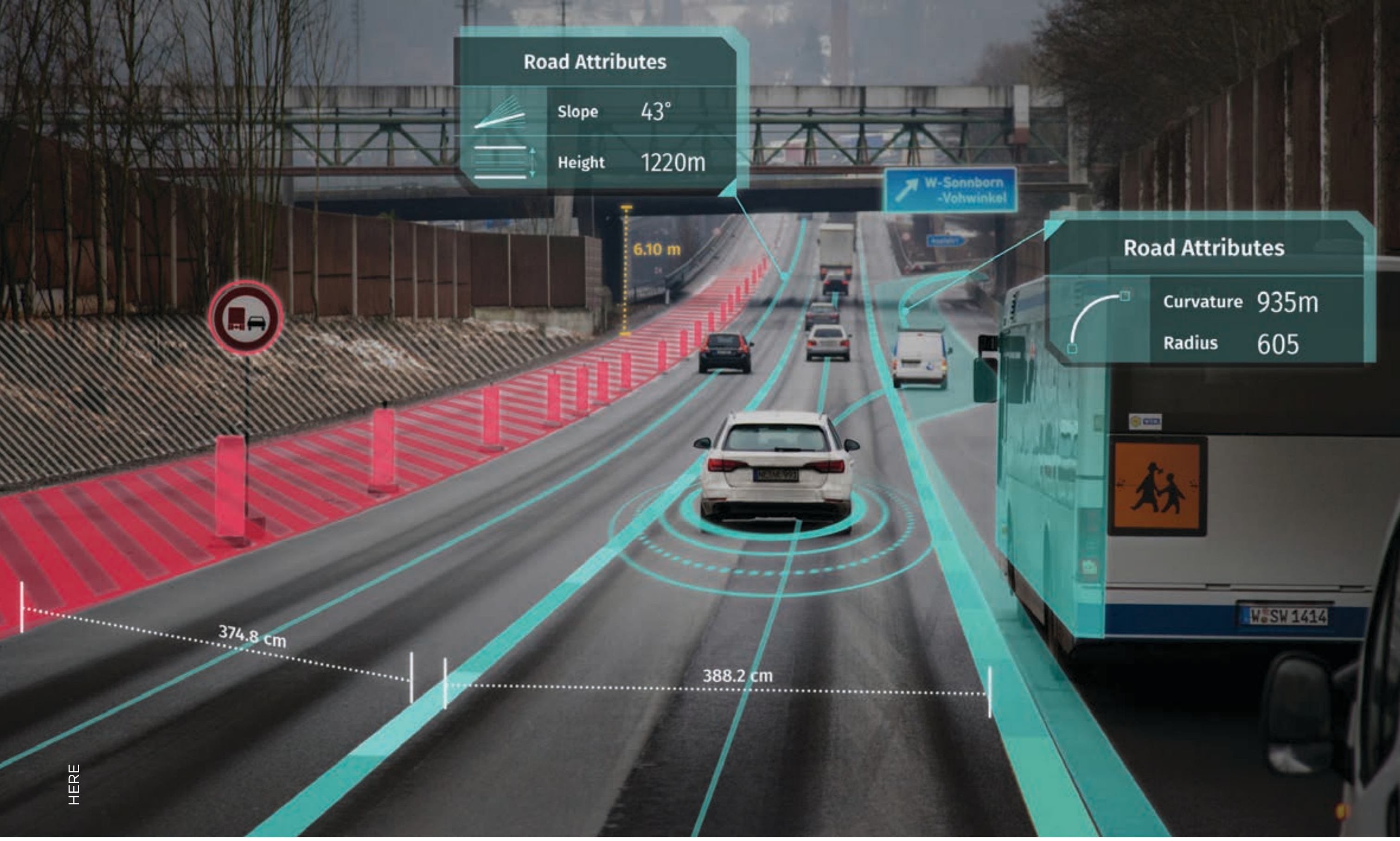
'Cloud computing' lets OEMs and suppliers gather copious amounts of data from vehicles.

Connectivity lets automakers and service providers collect tons of valuable data from vehicles and their operators, but it also brings the challenge of finding ways to glean useful information from huge databases. After controlling everything built into cars and trucks for more than a century, OEMs are moving outward to a murky world with multiple partners and 'cloud-computing' networks that are spread across the planet.

Companies throughout the automotive supply base—which now includes a growing number of startups and new players—are rushing to build profitable models based on data from vehicles. The OEMs who decide when and where to market connected cars will be able to quickly justify their investments.

"Companies can do a lot to drive new services," said Scott Frank, an executive at Airbiquity. "OEMs can understand the condition of the vehicle and how particular parts are performing. If there's a new part on a vehicle, they may check its performance data every minute. If they see an issue, they can go to the supplier and set up steps to resolve the issue."

OEMs aren't the only ones planning to make use of vehicle data. Service providers and app developers are racing to help end users take advantage of all the data that's available. Retailers want to connect with drivers in search of food and fuel, roadway managers



Real-time digital maps provide a wealth of information, built with petabytes of data.

want information on traffic flow, and drivers want infotainment such as real-time maps and navigation services.

Map maker Here is busily creating maps that include updates as detailed as where road signs have been knocked down. The company already has hundreds of cars collecting geospatial information, with LiDAR, high resolution cameras and other sensors. Although data transmission is limited to roadway traits that have changed, these specialized vehicles are collectively sending tons of data.

"We're collecting petabytes of data on a monthly basis," explained Sanjay Sood, Vice President of Highly Automated Driving at Here. "It's processed with machine learning algorithms."

Transmitting this data efficiently requires a well-planned architecture. The easy part is sending data to vehicles. Map updates and other data sent down to vehicles are small compared to the volumes being uploaded to the cloud.

Data overload

Cameras and other elements of the vehicle's fused-sensor array will generate large volumes of data that OEMs and Tier 1s can use to analyze usage and provide predictive diagnostics. However, input from large vehicle fleets can challenge the data 'pipes' that send bits and bytes to the cloud. Intel estimates that a single autonomous vehicle will generate 4 terabytes of data every 90 minutes.

Though connected vehicles won't reach such levels for a few years, the data volumes sent by thousands of vehicles operating in a big city during rush hour quickly add up. Many techniques can help make data collection and analysis more manageable. Data compression is an obvious choice.

Overhead can also be reduced by using on-vehicle systems that decide what's essential and useful. For example, cameras collect lots of information that isn't needed for real time mapping.

"We want vehicles to do a lot of the computing, so they only send important data," Sood told SAE's *Autonomous Vehicle Engineering*. "When the safety and driving systems process the scene, they can pick out the important elements, things that have changed. That doesn't require a lot of overhead, and the OEMs get better maps as a result, so they're open to collecting the data and sending it to us."

Automakers aren't interested in collecting and storing all this data by themselves. The industry is moving quickly to devise strategies for working with huge databases. Last year Toyota, Intel, Ericsson, Denso, and telecommunications firm NTT DoCoMo formed the Automotive Edge Computing Consortium.

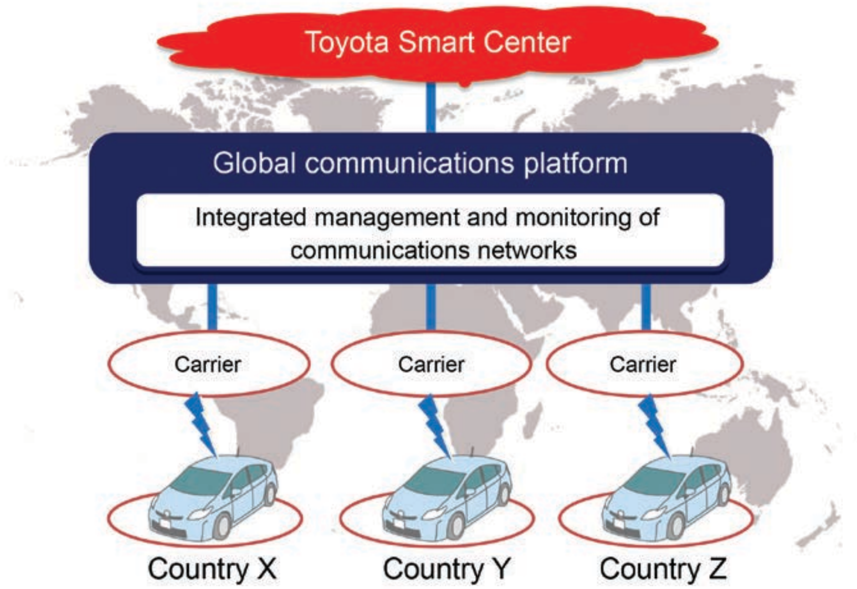
The companies estimate that data sent to the cloud will reach 10 exabytes per month by 2025—10,000 times what's being collected in 2018.

Toyota also partnered with Microsoft, which handles cloud computing for Toyota Connected. Microsoft is making a strong push in automotive, teaming up with Baidu, BMW, Ford, Renault-Nissan, Toyota, ZF, Harman, IAV and Volvo. Existing cloud service providers like Microsoft and Amazon are expected to handle

Big Data, **Big Challenges**

most auto industry programs, since the far-flung nature of global cloud coverage brings many vagaries.

"Automakers now have to deal with large amounts of data and work with a lot of partners," said Sanjay Ravi, Managing Director Automotive at Microsoft. "They also need to deal with varied data collection and usage in many different countries, where privacy and other regulations are very different."



Toyota has forged partnerships to bring data to vehicles around the globe.

Partners galore

The industry's focus on collecting and sharing data has made "ecosystem" an industry buzz word. Many different entities play a role in helping companies turn data into useful information. These partners need a common technical base if they're going to work together efficiently. These relationships can extend into areas like banking, so there's little chance that different partnership groups will be able to use proprietary versions of standards.

"We want to have a unified platform," said Mamatha Chamarthi, ZF's Chief Digital Officer. "That will let us harvest what we have from existing programs and innovate with new things like Car eWallet, which lets vehicles pay for electric charging, parking and tolls without human interaction."

Such developments give rise to considerable security and privacy concerns. The incentive to manage anxieties over these issues will come not only from a desire to fulfill customer expectations. There's also the potential for regulators to step in and establish minimum requirements.

"The industry needs to create standards, or we will be legislated by people who do not understand our challenges," observed Chris Moyer, CTO at DXC.

Public trust takes other forms. When people give corporations access to some of their data, many will want to know what's being done with that information and how it is being shared.

"One factor that may impact success is how many people and organizations trust those who collect data," said Steve Crumb, Executive Director, GENIVI Alliance. "People need to feel that data collectors will keep it safe and many will want to know how they're using it."

As a supplier of consumer electronic products as well as mobility systems, Bosch is making compatibility between vehicles, homes and 'smart city' networks a centerpiece of its strategies.

Growing challenges

If the challenges of handling data related to vehicles seem simple, automakers can also look at their role in the many 'smart city' programs advancing around the globe. Integral to these programs is keeping commuters informed, in real time, about the best combination of transportation options for reaching their destinations.

That requires combining information on traffic volumes, impending congestion, driving (and walking) times, public transportation schedules and access to bikes, taxis and ridesharing Those who drive the first portion of their travel routes will also want to know about parking availability and cost. Many executives feel that this type of data sharing is mandatory as more people migrate to large cities.

"We need a new conception of the city," said Bosch management board member Stefan Hartung. "One key factor here is technologies that make cities smart and worth living in. In the long run, cities without intelligence will not survive, but succumb to gridlock." ■