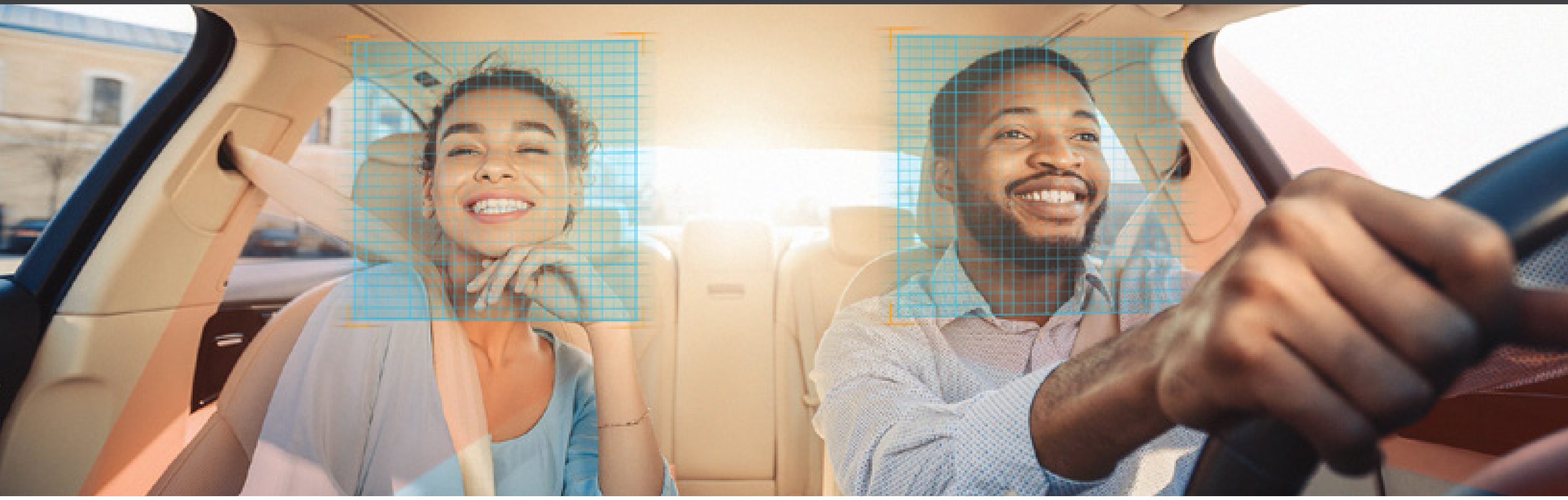


Interior Sensing Platform Enables Wealth of Innovations

Much of the attention on improving vehicle safety is directed outward from the vehicle. When people think about safety today, they often think about helping motorists avoid collisions, with artificial intelligence interpreting signals from radars, cameras and other sensors scanning the surrounding environment.

But what happens inside the vehicle is just as important as what happens outside, and the potential for safety innovation through interior sensing is just as great. OEMs have begun mounting cameras inside the vehicle in anticipation of upcoming driver state sensing regulations, but such moves are really just the start. Interior sensors open a wealth of exciting possibilities to improve safety, comfort and convenience for the driver and passengers, while simultaneously helping to drive down costs.

To realize the benefits to the in-cabin user experience, what is needed is a comprehensive interior sensing platform, integrated with the larger user experience system in the vehicle. The right platform will scale — from basic functionality that ensures safety and meets regulations, to premium functionality that recognizes passengers and customizes the experience accordingly, to functions that are necessary to enable higher levels of automated driving.

INTEREST IN INTERIOR SENSING

OEMs are racing to develop and deploy interior sensing systems for a variety of regulatory and competitive reasons.

Advanced safety

Inattentiveness, fatigue and distraction play a major role in road accidents. The U.S. National Highway Transportation Safety Administration estimates that 14 percent of all police-reported vehicle crashes and 8 percent of all fatal crashes in recent years have been due to distracted driving. Drivers were using cellphones in 13 percent of those fatal crashes.

In an aging society, "sudden medical incapacitation is also a growing cause of road crashes," according to the European New Car Assessment Program (Euro NCAP), which conducts testing and issues all-important vehicle safety ratings. While accident statistics aren't broken down by the age of the driver, the population of those aged 65 years or more in the European Union (EU) will increase from 90.5 million in 2019 to 129.8 million by 2050, and the number of people aged 75 to 84 years is projected to expand by 56.1 percent.

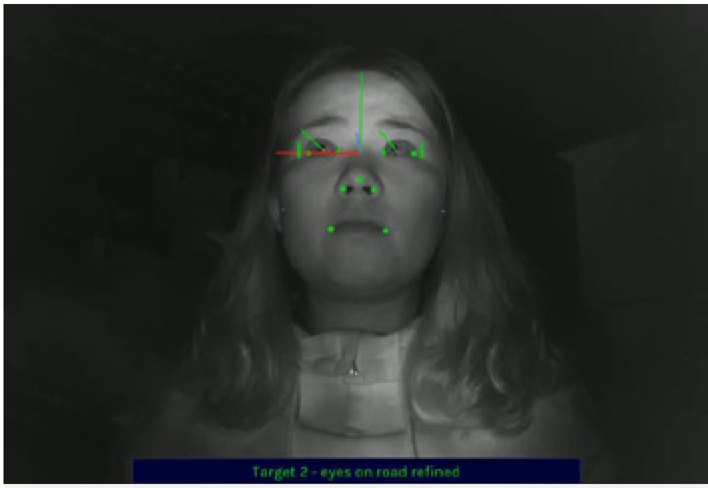
Meanwhile, the pandemic has accelerated the trend of consumers ordering more goods online, leading to an increase in delivery vehicles on the road and the potential for drivers of those fleet vehicles to be overworked or drowsy.

In an effort to reduce accidents caused by these and other factors, Euro NCAP is incentivizing vehicle manufacturers to deploy driver state sensing systems that detect impaired and distracted driving, give appropriate audio and visual warnings, and take effective action, such as autonomously initiating an evasive maneuver or safely pulling the car over to the side of the road in the case of a medical event.

The timeline for implementation of Euro NCAP standards for driver state sensing systems has been pushed back by one year due to the COVID-19 pandemic. But the latest guidance calls for NCAP to begin grading carmakers on their implementations of basic driver monitoring for fatigue, distraction and alcohol-induced impairment between 2023 and 2025.

Similarly, NCAP is expecting car makers by 2023 to deploy systems that can detect and monitor the presence of a child in the vehicle, and alert the car owner or emergency services if the child has been left unattended.

In addition, the European Commission's General Safety Regulation, slated to be released in 2022, piggybacks on the Euro NCAP standards, requiring vehicles sold in the EU to have advanced driver distraction warning for all vehicles and driver availability monitoring for Level 3 vehicles, by 2024 in new models and by 2026 in all vehicles.



DRIVER STATE SENSING FEATURES

- Distraction Recognition
- Drowsiness Detection
- Sudden Sickness Detection
- Driver Readiness Monitoring
- Driver Identification
- Eye Gaze Region of Interest
- Blink Rate
- Eye & Head Tracking
- Driver Activity (talking, yawning, eating, smoking, using phone, etc.)

Autonomous driving

The same interior sensing technology that uses cameras to monitor the driver for fatigue and distraction dovetails nicely with the requirements of autonomous driving systems.

At Levels 2+ and 3 (see: What Are the Levels of Automated Driving?), there is a complex, real-time interplay between the driver and the vehicle in which control is handed back and forth, depending on the situation.

At Level 3, drivers can fully disengage, but only for specific situations, vehicle speeds, road types and weather conditions. For example, drivers can sit back, relax and check their phone while the vehicle is driving along on the highway, but the handover occurs when approaching an exit, construction zone or other situation the car is not equipped to handle. At this level of automation, the vehicle needs to know that the driver is physically ready to resume control, has their hands on the steering wheel and is focused on the task at hand.

Comfort and convenience functions

Interior sensing systems represent an opportunity for OEMs to deliver features that will impress their customers and provide a competitive advantage. With interior sensing systems, OEMs will be able to offer drivers and passengers the ability to control certain vehicle functions via multimodal, human-machine interface approaches, including eye gaze and gesture recognition.

Both drivers and passengers could control a variety of vehicle functions in this way. With eye-gaze recognition, a driver could look at the mirror and adjust it using a gesture. Or, if the driver looks at the instrument panel in anticipation of changing the radio channel, the panel could get brighter, then go back to a less-intrusive or distracting level of brightness when the driver returns their gaze to the road. Eye gaze can also be combined with voice for more conversational control. Instead of “Turn the left passenger climate control to 68 degrees,” the command could be “Turn it down to 68 degrees.”

With an advanced infotainment system, the driver could connect with digital systems outside the vehicle, such as home automation systems. For example, imagine being able to activate the video feed from your Ring doorbell with a simple hand gesture as you are driving home. Point-to-search capabilities could be extended so that someone inside the vehicle could point at a landmark to get information about it, or point at a restaurant to reserve a table.

Indeed, if an infotainment system is fully manipulable with touchless interaction (voice, gesture and/or gaze), it opens up additional opportunities for vehicle interior design, because the infotainment screens do not have to be placed within arm’s reach of the driver and could instead be located where it is easier for the driver to quickly glance between the windshield and the screen, reducing the amount of time the driver spends looking away from the road.

Vehicle simplification and revenue generation

Importantly, an interior sensing platform opens the door for potentially removing legacy hardware and enabling new revenue streams.

For example, the ability for the camera to “see” whether someone is sitting in a passenger seat might enable OEMs to remove pressure sensors — the Passive Occupant Detection Systems, or PODS — that are part of the airbag and seatbelt system, thus removing that cost. At the same time, the platform adds functionality, as it can detect whether everyone in the car is wearing a seatbelt, even in the back seat, something that is not possible in most vehicles today.

Face identification would allow the system to confirm transactions — say, at a parking garage, or with ordering via in-vehicle personal assistants. Also, once the vehicles are equipped, these same interior cameras can be used for other productivity applications, such as conducting video conference calls or detecting objects left behind.

The platform could also gather enough data to understand how occupants are feeling. By examining the human face at a pixel level, the software can analyze information on the position of the eyebrows, eyes, mouth and nose to determine whether a person is happy, angry, surprised, disgusted, scared or sad.

The practical application of this information is most likely to be in the commercial realm of taxis, ride-sharing networks, vans and other vehicles that transport customers and would benefit from knowing those customers' emotional states.

However, emotion sensing could also let OEMs know how users are reacting to their hardware and software — that is, the system could detect users' stress or enjoyment when trying to interact with certain features. This can help OEMs create more user-friendly features in the future by identifying pain points in on-road situations.

THE INTERIOR SENSING JOURNEY

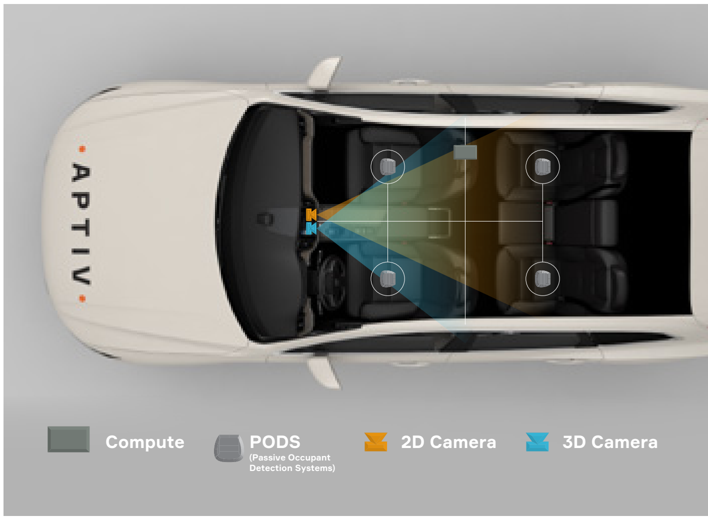
We are certainly at an early stage in the interior sensing journey, but there are clear steps ahead.

Basic driver sensing

The current roadmap for interior sensing systems starts with a low-cost implementation that meets basic regulatory requirements and can be widely deployed across an entire fleet. At this level, a single camera mounted on the steering wheel column, instrument cluster or central display will be able to detect drowsiness and distraction. If the driver takes their eyes off the road for more than two seconds, for instance, the system could sound an audio alert or flash a red light on the dashboard. To determine whether the driver is drowsy, the intelligence behind a camera can measure head position, eye movements, blink rate and how wide the driver's eyes are open. If the driver is nodding off, the system could shake the seat or sound an audio alert.

Advanced driver sensing

Systems can build on basic drowsiness and distraction recognition with additional capabilities. They can detect voices and accurately identify drivers with cameras and biometrics such as fingerprints. They can determine whether the driver is intoxicated, stressed, lost in thought, or even trying to spoof the autonomous driving system by holding up a picture.



Cabin sensing

An evolution of driver sensing is cabin sensing, where a wide-angle camera covers a larger field of view within the vehicle, often including the passenger seat and rear seats. With this larger visible area, a system could tell if the driver has their hands on the steering wheel. It could identify the front seat passenger, adjust their seat to their specifications, and make sure passengers are wearing their seat belts properly. With full cabin presence detection, the system could determine how many people are in the vehicle, and would be able to pinpoint their mood and emotion. It would also be able to detect whether a driver has been hit with a sudden illness, which could trigger automated systems that safely pull the vehicle over to the side of the road and notify emergency services.

In addition, a wide-angle 3D camera can be mounted on the interior roof of the vehicle and directed downward, providing a view of the front seats. This enables passengers to control aspects of the vehicle with hand gestures and hand poses, in-air writing, and the point-to-search function mentioned earlier. This gesture recognition capability continues to evolve, and is on a technology path that is separate from driver state sensing.

Future innovations

As machine-learning systems become more intelligent and more powerful, they will be able to not only understand what is happening with the driver but also to take actions accordingly. For example, if the vehicle is departing its lane and the driver has their eyes off the road, the system might engage lane keeping for a few seconds, even if it is manually turned off. Or let's say the car ahead stops while the driver is distracted — the system could slow the vehicle down or start braking early in anticipation of the automatic emergency braking feature engaging suddenly.

As interior sensing algorithms improve, other safety applications become possible, such as tracking body positions to adjust airbag deployment.

Long term, full cabin sensing is key to enabling reconfigurable interior designs, and any other nonstandard interior concepts for fully autonomous vehicles, such as leisure cars where people can recline and sleep or watch videos, autonomous medical clinics for health telepresence, or autonomous shopping boutiques.

HOW IT ALL WORKS

An interior sensing platform represents a complex integration of hardware and software. On the hardware side, a basic platform would feature a 1.3-megapixel camera operating at 60 frames per second, with infrared vertical-cavity surface-emitting lasers (VCSELs) that invisibly illuminate the driver, allowing the system to see at night and to see the driver's eyes through dark sunglasses.

At more advanced levels, there could be multiple 2D and 3D cameras mounted at various locations within the vehicle, including one looking down from the roof.

For flexibility in placement of those cameras, a satellite approach can be used. In this scenario, only the camera optics and minimal hardware are placed in the cabin, and each camera transmits data on a high-speed networking line to a centralized domain controller, which hosts the vision processor that runs specific algorithms. Alternatively, the camera optics can be bundled with the processor in an electronic control unit (ECU), which would then transmit data to the domain controller. For privacy and data protection considerations, data would not leave the vehicle.

CABIN SENSING FEATURES

- Seat Occupancy Classification
- Seat Belt Usage Detection
- Hands-on-Wheel Detection
- Body Pose Tracking
- Left-Behind Object
- Video Call / Remote Snapshot
- Gesture Recognition
- Point-to-Search
- Occupant Location
- Occupant Identification

It is critically important that the interior sensing platform is developed in close partnership with the OEM and is fully integrated with other systems in the vehicle, so that alerts or other information from the camera can trigger actions such as automatic emergency braking or complex autonomous driving handoffs, and that gestures are accurately interpreted and translated into concrete actions.

So, how does the camera know whether the driver is tired, stressed, distracted or impaired? The interior sensing platform collects data points from the entire face and compares them to a baseline for that driver. Is the driver blinking more often than usual, or are the blinks lasting longer than usual? Is their head tilting at an odd angle? Are their eyes narrowing or closing? Has their facial expression changed?

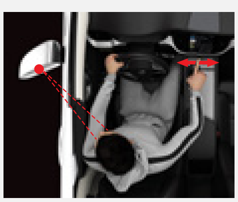
The system can follow the eyes of the driver to make sure the driver is focused on the road. In addition, the platform can spot when a driver has "spaced out" and is staring straight ahead but not really paying attention. Advanced systems will also be able to understand what might be distracting the driver and get their attention back on the road.

Gesture control is accomplished through a downward-facing camera and 3D gesture recognition intelligence that essentially allows drivers to perform sign language to communicate with the car. For example, in response to a phone call, the driver could make a simple swipe gesture to decline the call or could make a tapping motion with one finger to accept the call. Spinning a finger clockwise could indicate turning the volume up or zooming in on a map displayed on the console. Making a circle with thumb and index finger and moving to the right could signal next song or next menu item.

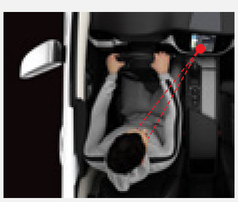
To interpret the images from in-cabin cameras, a typical interior sensing platform may use more than 20 neural networks, and that number is increasing. Together, these networks contain more than 70 million parameters that are trained and optimized.

Eventually, interior-sensing comfort and safety applications will up-integrate and consolidate onto infotainment and ADAS domain controllers, which will help to make the technology affordable for all vehicle segments. And the right software framework would allow OEMs to update individual applications over the life cycle of the vehicle via over-the-air updates.

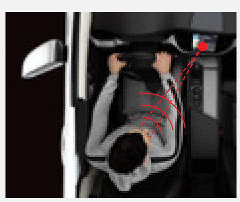
Eye Gaze with Voice and Gesture Recognition



1 A driver could look at a mirror and adjust it with a gesture.



2 As the driver looks at the center console, it brightens.



3 The driver can look at the climate controls and change temperature via voice commands.

HOW IT WORKS

❶ **Gesture control** uses downward-facing infrared lights, a camera and 3D gesture recognition software to read drivers' hand signals.

❷ **A driver state sensing system** uses a camera and infrared light to allow the system to see the driver's eyes at night or through sunglasses.

WHAT OEMS SHOULD LOOK FOR IN AN INTERIOR SENSING SYSTEM

The key considerations for selecting a partner to help develop interior sensing systems are flexibility, scalability, experience, technical know-how, cost and integration capabilities.

OEMs should choose technology providers with the expertise to develop customized systems that can scale from low-end to luxury vehicle models. Another important consideration is whether the technology partner can assemble an integrated solution that combines best-of-breed features from best-in-class suppliers, as well as the OEM's internally developed algorithms.

Rolling out interior sensing systems is a long-term proposition, so OEMs should look for companies that have a solid technology platform, a detailed roadmap and a track record of success.

Aptiv launched the industry's first integrated 3D gesture recognition system with BMW in 2015 on the 7 series, which has since been expanded to include the 5 and 3 series based on customer interest. Separately, Aptiv introduced a driver sensing system in 2018 that is currently deployed in BMW X5 series vehicles as a key part of their Level 2 autonomous driving system and is also being expanded to other models. Today, Aptiv is the leader in interior sensing technology with customer awards at five different OEMs.

Over time, as these systems become more widely deployed, vehicle manufacturers will undoubtedly receive customer feedback that will spark new applications and use cases that have not even been conceived of. Partnering with a technology provider that can help create and deliver innovation over the long haul is critically important.

SCALABLE INTERIOR SENSING PLATFORMS

DRIVER STATE SENSING
ENTRY

- Distraction Recognition
- Eye Gaze Region of Interest
- Drowsiness Detection

DRIVER STATE SENSING
MID & HIGH

- Enhanced Drowsiness Detection
- Sudden Sickness Detection
- Driver Readiness Monitoring
- Driver Identification
- Driver Activity

2D CABIN SENSING
MID & HIGH

- Occupancy & Seat Belt Detection
- Occupant Location & Identification
- Left-Behind Object Detection
- Video Call / Remote Snapshot

3D CABIN SENSING
MID & HIGH

- Body Pose Tracking
- Hands-on-Wheel Detection
- Gesture Recognition
- Point-to-Search

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Doug Welk leads global technology development for Aptiv's interior sensing products, with a primary focus on vision-based driver and cabin sensing. Doug began his career developing hardware and software for next-generation infotainment systems and has held multiple engineering positions covering diverse product areas such as navigation, in-vehicle HMI, connected vehicles, and cloud-based features. He has also held a leadership position in the GENIVI Alliance.

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