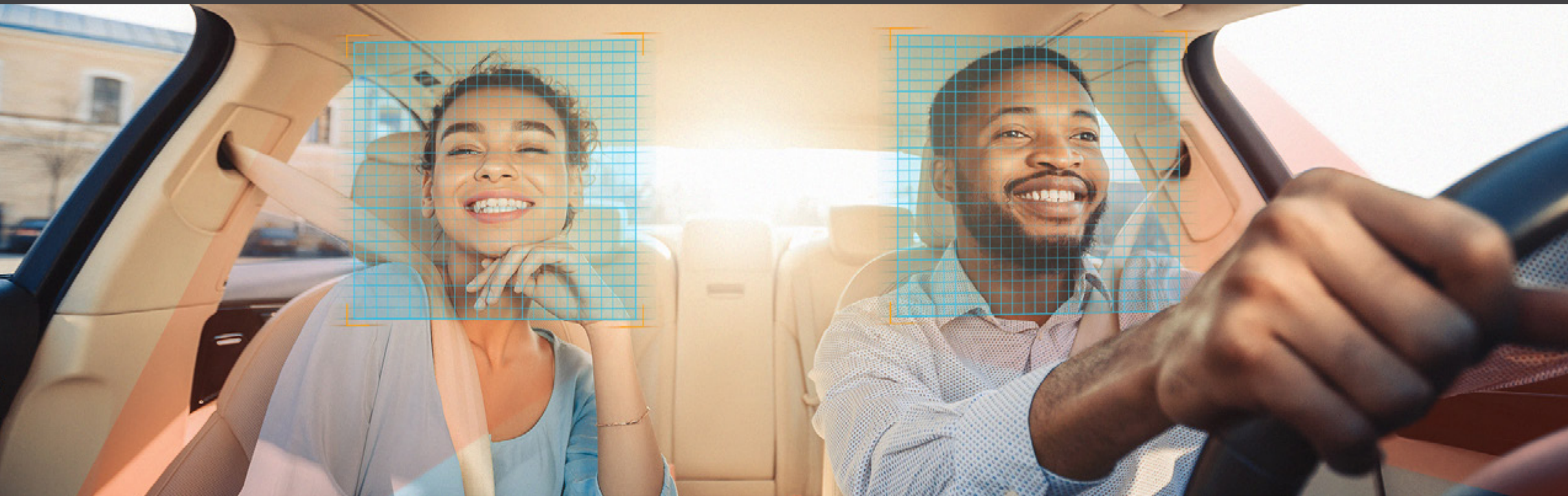


In-Cabin Sensing Platform Enables Wealth of Innovations

OEMs have installed cameras inside vehicle cabins to meet safety regulations, but such moves are really just the start. Driver and cabin monitoring open a wealth of exciting possibilities to improve safety, comfort and convenience for the driver and passengers in real time, while simultaneously detecting risk conditions early to prevent incidents before they occur.

To realize the benefits for the in-cabin experience, what is needed is a comprehensive 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.

Updated Sept. 2026

INTEREST IN INTERIOR SENSING

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

Advanced safety

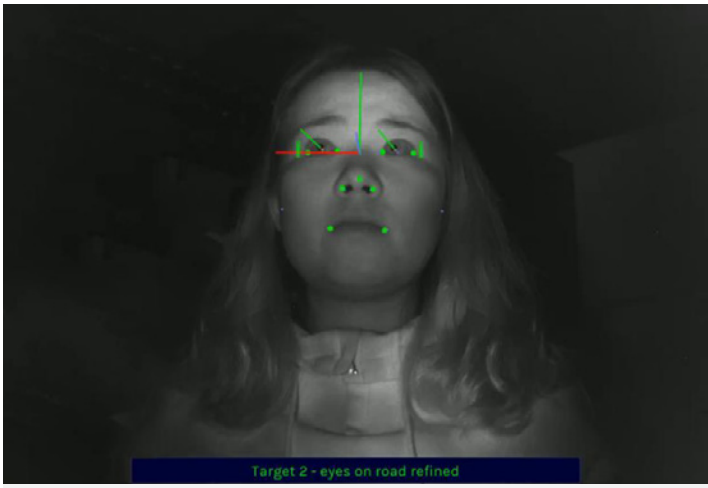
Inattentiveness, fatigue and distraction play major roles in road accidents. The U.S. National Highway Transportation Safety Administration estimates that 315,000 people were injured and 3,200 were killed by distracted driving in 2024.

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 vehicle safety ratings. The population of those age 65 or older in the European Union is expected to increase from 99 million in 2025 to 147 million by 2050.

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 safety actions, 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.

Euro NCAP has begun grading carmakers on their implementations of basic driver monitoring for fatigue, distraction and alcohol-induced impairment.

Euro NCAP's 2026-2028 regulations have put more emphasis on the importance of in-cabin sensing, with driver and occupant monitoring functions now accounting for more than half of its Safe Driving assessment points. The organization will continue to raise Safe Driving thresholds by 10 points each year through 2028, giving OEMs time to adapt to expanding requirements around driver monitoring, occupant monitoring and cabin awareness.



DRIVER STATE SENSING FEATURES

- Distraction Recognition
- Drowsiness Detection
- Sudden Sickness Detection
- Impairment & Intoxication 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.)
- Seat Belt Usage

Looking ahead, discussions around Euro NCAP's 2029 regulations suggest closer coordination between driver-monitoring systems and ADAS features. Future requirements may place greater emphasis on how vehicles use information about driver attention and awareness to improve safety system performance and reduce unnecessary warnings.

Discussions also include expanded seat-belt monitoring, detection of seat-belt misuse, monitoring of extreme front passenger seat recline positions, more advanced occupant classification and adaptive restraint strategies.

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, where 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 a 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 (HMI) 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 rearview 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, returning 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 saying, "Turn the left passenger climate control to 68 degrees," a person could say, "Turn it down to 68 degrees" while looking at the corresponding seat.

With an advanced infotainment system, a driver could connect seamlessly with digital systems both inside and outside the vehicle. For example, the vehicle could automatically illuminate rear cabin lights when a passenger reaches into the back seat, initiate a parking maneuver through a simple gesture or voice command, or open the sunroof based on recognized user intent. Occupant-aware displays could also enable content to move seamlessly from one screen to another as passengers change seating positions or direct their attention elsewhere in the cabin. If an infotainment system were connected to a smart home system, a driver could remotely switch on houselights and turn up the heat while on the road, so everyone would return to a warm, safe home.

Vehicle simplification and revenue generation

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

For example, the camera's ability to "see" whether a person or a package is in a seat could enable OEMs to eliminate dedicated hardware such as passive occupant detection systems, reducing system cost and complexity. Using vision-based sensing, vehicles can now support Advanced Occupancy Classification (AOC), which uses AI and computer vision to accurately classify occupants based on height, size, weight, posture and seating position, enabling safe and reliable airbag deployment and seat-belt tensioning. It can also detect whether an occupant is wearing a seat-belt in the first place and — most critically — whether a child has been left behind in a car seat.

Face identification would allow the system to confirm transactions — say, at a parking garage, or when placing an order 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 calls.

The platform could also gather enough data to understand how occupants are feeling. By examining the human face at the pixel level, the software can analyze information on the position of a person's eyebrows, eyes, mouth and nose to determine whether they are 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 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. The ability to identify pain points in on-road situations could help OEMs create more user-friendly features in the future.

THE IN-CABIN SENSING JOURNEY

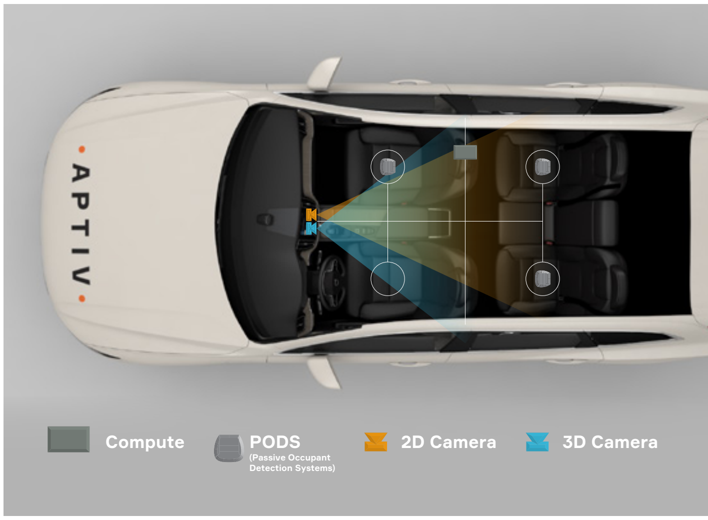
As we advance in the in-cabin sensing journey, there are clear steps ahead.

Basic driver sensing

The current roadmap for in-cabin 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 would 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 detect a drowsy driver, the intelligence behind a camera could 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 monitoring

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 monitoring

An evolution of driver monitoring is cabin monitoring, where a wide-angle camera can cover 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 all passengers are wearing their seat belts properly. With full cabin presence detection, the system could determine how many people are in the vehicle and pinpoint their moods and emotions. It would also be able to detect that a driver has been hit with a sudden illness, triggering automated systems that safely pull the vehicle over to the side of the road and notify emergency services.

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 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.

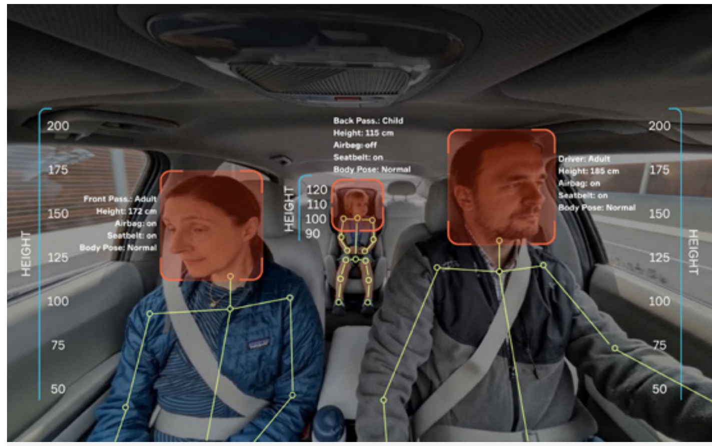
As in-cabin sensing algorithms improve, other safety applications become possible, such as tracking body positions to adjust airbag deployment.

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 in which people could 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 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 cameras mounted at various locations within the vehicle, including one looking down from the interior roof.

A satellite approach would give OEMs flexibility in the placement of those cameras. In this scenario, only the camera optics and minimal hardware would be placed in the cabin, and each camera would transmit data on a high-speed networking line to a centralized domain controller, hosting the vision processor that runs specific algorithms.



CABIN SENSING FEATURES

- Advanced Occupancy Classification (AOC)
- Driver Monitoring (gaze, attention, drowsiness, distraction)
- Cabin Monitoring
- Occupant Recognition & Personalization
- Occupant Position & Pose Tracking
- Seat Belt Usage
- Emotion Sensing
- Child Presence & Left-Behind Occupant Detection
- Gesture Recognition & Touchless HMI
- Occupant Localization
- In-Cabin Communications & Camera Services

Alternatively, the camera optics could be bundled with the processor in an electronic control unit, which would then transmit data to the domain controller. To ensure privacy and data protection, data would not leave the vehicle.

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. Doing so allows alerts or other information from the camera to trigger actions such as automatic emergency braking or complex autonomous driving handoffs and ensures 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 driver's eyes to ensure that they are 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.

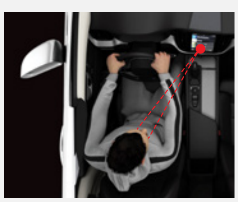
Gesture control will be accomplished through a camera and gesture recognition intelligence that essentially allows drivers to use a form of sign language to communicate with the car. For example, in response to a phone call, the driver could make a simple swipe gesture to decline the call or make a tapping motion with one finger to accept it. Spinning a finger clockwise could indicate a request to turn the volume up or zoom in on a map displayed on the console. Making a circle with a thumb and index finger and moving them to the right could signal "next song" or "next menu item."

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

Eye Gaze With Voice and Gesture Recognition

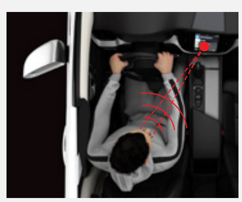
1

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



2

The center console could brighten when a driver looks at it.



3

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

HOW IT WORKS

❶ **Gesture control** uses downward-facing infrared lights, a camera and 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.

APPLICATIONS ACROSS INDUSTRIES

Interior sensing technologies have significant potential beyond passenger vehicles. For example, train operators and pilots face complex safety-critical responsibilities that require continuous monitoring of multiple displays, controls and external conditions. Advanced interior sensing capabilities, such as gaze tracking, driver state monitoring and gesture recognition, can help ensure situational awareness, identify distraction or fatigue and support safer interactions with sophisticated digital displays.

Similar benefits apply to operators of heavy construction, agricultural and industrial equipment, where monitoring attention, cognitive workload and operator readiness could help reduce accidents and improve productivity.

In manufacturing facilities, interior sensing could extend beyond safety into workflow optimization, enabling the monitoring of operator engagement, compliance with procedures, ergonomic behavior and human-machine collaboration.

As sensing platforms become more capable and cost-effective, they have the potential to transform a wide range of transportation and industrial environments by improving safety, operational efficiency and workforce wellbeing.

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.

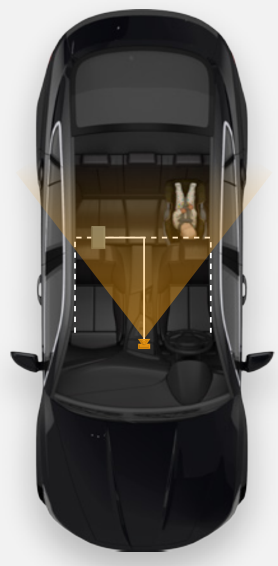
SCALABLE INTERIOR SENSING PLATFORMS

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 Detec-tion
- Gesture Recognition
- Point to Search

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 integrate its own features with 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 has been a leader in interior sensing for more than a decade, with features that extend well beyond regulatory compliance. In 2015, the company launched the automotive industry's first production-integrated 3D gesture-recognition system with BMW, enabling intuitive touchless vehicle interaction. Today, Aptiv's interior sensing technologies are deployed across leading automotive and commercial vehicle manufacturers, including General Motors, Audi, Volvo Cars, Volvo Trucks and Daimler Truck. At GM, Aptiv's full-stack driver-monitoring system supports the Super Cruise hands-free driving system by continuously monitoring driver attention, distraction and readiness to take control. Aptiv technology provides the foundation for next-generation smart cabins that enhance safety, enable automated driving, personalize the user experience and create new opportunities for software-defined vehicle features.

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 yet been imagined. Given the pace of innovation, it is critical to partner with a technology provider that can continually unlock new capabilities throughout the life of a vehicle.

ABOUT THE AUTHOR

Doug Welk
Director, Digital Cockpit and Interior Sensing

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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