

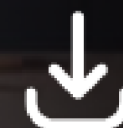
2023 AUTONOMOUS VEHICLE TECHNOLOGY REPORT

Examining the Latest Developments
in Self-Driving Vehicles

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AUTONOMOUS VEHICLE TECHNOLOGY REPORT

The guide to understand
the latest developments
in self-driving vehicles



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State of the Art in Autonomous Vehicles Technologies

The core of this report is to make clear the current status of the technologies that form autonomous vehicles. We have separated the chapters into groups covering Sensing, where we take a closer look at the latest advances in cameras, LiDAR, RADAR, ultrasonic sensors, and emerging imaging radar technologies. The Thinking and Learning and Edge Computing chapters examine the dynamic landscape that encompasses advanced AI algorithms, natural language processing (NLP), machine learning techniques, and the transformative impact of edge computing.

Finally, we explore the technologies that ensure reliable communication, from rapid 5G Connectivity and dynamic Over-the-Air (OTA) Updates, to the use of Blockchain, as well as

Intrusion Detection and Prevention Systems (IDPS) and AI/ML-driven cybersecurity.

Each section highlights recent innovations, outlining why certain technologies have become dominant and gives examples of which companies are prominent in the area.

We provide some high-level definitions and explanations, but the first Wevolver report provides more fundamental knowledge of the technologies.

The report's final chapter looks at four leading autonomous vehicle companies: Waymo, Tesla, Cruise, and Volvo. We compare and contrast their tech stacks presenting a clear overview of the direction of the industry.

Sensing Technologies

At the cutting edge of autonomous vehicle (AV) technology, the confluence of advanced sensing modalities forms the cornerstone of vehicular autonomy. At the forefront of this confluence lies the integration of high-definition cameras with a suite of diverse sensors, including ultrasonic, LiDAR, and RADAR. This amalgamation, known as 'sensor fusion,' represents the zenith of current efforts to endow vehicles with perception capabilities necessary for full autonomous driving.

High-definition cameras, quintessential for their acute visual acuity and color discernment, play an indispensable role in this sensorial symphony. They excel in interpreting complex visual stimuli – from the nuanced hues of traffic lights to the intricate patterns of road signs. Yet, the prowess of cameras is not without its Achilles' heel; their performance can wane under the cloak of night or in the face of inclement weather. It is within these gaps that the orchestration of sensor fusion becomes critically imperative.

At the cutting edge of sensor integration, the marriage of ultrasonic sensors with LiDAR and RADAR is addressing the erstwhile shortcomings of standalone systems. This integration is particularly pivotal in surmounting the challenges of close-range detection – a realm where traditional LiDAR sensors often falter. Such precision in proximal perception is vital for executing complex parking maneuvers and navigating through constricted spaces with unerring accuracy.

The collaborative dynamics between ultrasonic and LiDAR sensors forge a more robust interpretative framework. While LiDAR imparts a detailed topographical map of the vehicle's surroundings, it is occasionally prone to misinterpretations, especially in the presence of reflective surfaces or atypical object contours. Here, ultrasonic sensors contribute a deeper dimension of spatial awareness, validating and refining LiDAR's data, thus mitigating the risks of erroneous object recognition.

Extending this synergy further, the integration of ultrasonic sensors with RADAR technology heralds a new era in perception systems capable of straddling the spectrum of short- and long-range detection. RADAR, with its broader wave patterns, often struggles with pinpoint accuracy in proximate scenarios. Ultrasonic technology deftly fills this void, granting AVs enhanced situational awareness – an attribute of paramount importance in scenarios that demand a harmonious blend of both near and distant perception, such as highway navigation interspersed with intricate parking sequences.

In this avant-garde realm, vehicle manufacturers are not merely choosing between sensor technologies; rather, they are strategically orchestrating an ensemble of LiDAR variants, each contributing its unique strengths to the collective sensory intelligence of AVs. The selection of specific LiDAR models is no longer a mere technical choice but a strategic decision, influenced by a myriad of factors including application-specific requisites, cost-benefit analyses, and the relentless march of technological innovation.

This chapter aims to delve into the intricate and sophisticated world of sensing and vision technologies in autonomous vehicles. We will explore how the nuanced integration of cameras with ultrasonic, LiDAR, and RADAR sensors is sculpting the frontier of autonomous navigation, steering us towards an era of unprecedented vehicular intelligence and autonomy.

Cameras and Vision systems

Cameras have a foundational and technically intricate position within autonomous vehicles, functioning as primary sensors to provide vital visual data for perception and navigation systems. Their role extends beyond mere image capture, encompassing intricate computer vision processes to interpret the surroundings with pixel-level precision. Cameras are instrumental in critical tasks, including real-time lane detection, object recognition, and complex depth perception, making them indispensable for AV safety and operational efficiency.

In the last three years, there have been significant advancements in high-resolution cameras, which have shown a remarkable increase in their ability to capture fine details. This, in turn, has enabled autonomous vehicles to accurately identify objects in their surroundings, making them more reliable and safe. Therefore, in this section, we explore developments in vision technology that have impacted AV development over the last three years.

3D Stereo Vision

3D stereo vision technology utilizes two cameras to determine the depth and precise positioning of objects in the environment. This is similar to how humans use binocular vision for depth perception. They are an integral part of the future of autonomous vehicles by enabling them to navigate roads more safely than single cameras.

The technology has seen rapid growth over the past decade, with significant strides being made by companies that are enabling automakers to quickly and inexpensively add 3D Stereo Vision to existing Advanced driver assistance systems (ADAS) with software solutions.

The positioning of cameras in vehicles is an ongoing topic within the industry. Wider-placed cameras have the potential to fall out of alignment when impacted by temperature shifts in the chassis or road vibrations - an issue when the cameras need to maintain an alignment within one-100th of a degree.

Major players, such as Subaru’s EyeSight and the Drive pilot system in Mercedes’ EQS, use stereo vision systems deployed in tighter formations to negate that - those systems are working in – tandem with RADAR. Stereo vision is an ever-growing technology, with researchers and developers exploring new ways to improve its accuracy, efficiency, and field of view.

The biggest impacts will likely come from deep learning and neural networks being used to handle occlusion and calibration issues. Other interesting areas of research include active stereo vision, which is being employed to project patterns or signals onto the scene, creating artificial texture and contrast.

Some of this cutting-edge research is being tested by university teams on the race track. For example, the Formula Student racing team of the University of Bayreuth is using Nerian’s SceneScan Pro and the Karmin3 stereo camera to create a 3D stereo vision system for their autonomous racing car.^{2,3}



The 3D stereo vision deployed on the autonomous race cars. Image credit: Nerian.



A pedestrian crossing a dark suburban street. Visible light camera vs. FLIR® thermal camera captured by Foresight’s test vehicle. Image credit: Foresight.

Thermal cameras

In the early 2000s, several notable car manufacturers, including General Motors, BMW, and Honda, blazed the trail by introducing passive thermal cameras to enhance safety during nighttime driving. These innovative thermal cameras were designed to address the dangers posed by animal collisions and the risk of pedestrian accidents in poorly lit or foggy areas. Their primary purpose was to provide invaluable assistance to human drivers.

However, the landscape of autonomous driving began to evolve significantly with the advent of the DARPA Grand Challenge. This competition sparked a surge of interest and substantial investment in various sensing technologies. Among them, LiDAR (Light Detection and Ranging) emerged as the frontrunner, capturing the lion’s share of attention and financial support. Together with radar and visible cameras, this sensor suite gained widespread recognition as the optimal perception stack for achieving higher levels of autonomy.

In an effort to bolster their sensor

capabilities, certain companies are incorporating thermal cameras into their sensor suites, recognizing the unique advantages they offer in complementing LiDAR, radar, and visible cameras. This additional sensor modality proves invaluable in addressing specific challenges, such as identifying animals and humans in environments characterized by low light or heavy obscuration like fog, smoke, or steam.

Pedestrians are most at risk of an accident with a road vehicle after dark. More pedestrian fatalities occurred in the dark (75%) than in daylight (21%), dusk (2%), and dawn (2%).⁴

Notably, pioneers like Waymo Via and Plus.ai have harnessed the power of thermal cameras to advance autonomy in the realm of trucking, particularly on highways. By doing so, they are enhancing safety and efficiency in long-haul transportation.

Companies like Nuro, Cruise, and Zoox have adopted thermal cameras as part of their sensor repertoire for purpose-built vehicles designed to navigate the intricate landscapes of

densely populated urban areas. These vehicles are not only revolutionizing last-mile food and grocery delivery but also providing innovative solutions in the realm of ride-hailing services. Through the strategic deployment of thermal cameras, these companies are significantly elevating the safety and effectiveness of their operations within urban environments.

Harnessing AI-Enhanced Vision

Traditional cameras capture raw visual data, which requires subsequent processing and interpretation to derive meaningful information about the surroundings. AI algorithms, especially deep learning models, have revolutionized this process by enabling cameras to interpret visual information from their surroundings, enhancing their ability to comprehend images.

The integration of AI-enhanced vision represents a groundbreaking development that significantly improves the capabilities of camera systems in AVs. For example, HADAR, an AI-powered

thermal imaging system created by Purdue and Michigan State University researchers, provides clear thermal images by interpreting heat signatures. It significantly improves AVs and robots by resolving the blurring ,ghosting' effect seen in traditional thermal imaging.

Moreover, Omniq has recently launched a face detection feature for AVs, improving safety by recognizing faces to prevent crimes. Their AI uses neural network algorithms for smart decision-making and has already seen over 20,000 global installations. In a collaborative effort, SemiDrive and Kankan Tech are improving in-car imaging systems, where SemiDrive's X9 chip powers the systems and Kankan Tech provides comprehensive development services.

Kankan Tech has expertise in high-resolution cabin cameras and has developed a camera-based alternative to traditional rearview mirrors. They've

also introduced palm vein biometric recognition for AV access. The system, unaffected by lighting changes due to IR cameras, uses YOLO v7 algorithms for real-time face detection, analyzing facial expressions and head orientation for safety, with plans for commercial market integration after thorough testing.

Cameras, empowered by convolutional neural networks (CNNs) and appropriate classification ML techniques, enable AVs' vision systems to accurately identify and categorize objects, pedestrians, road signs, and lane markings. This level of understanding improves the vehicle's ability to make informed decisions in complex and dynamic traffic scenarios.

AI-enhanced vision is crucial in autonomous vehicles, encompassing tasks like object identification, motion tracking, and classification. This technology significantly augments AVs' understanding of their surroundings,

resulting in more informed and secure decision-making processes.⁵

An illustrative example of the potential of AI-enhanced vision comes from the research conducted at RIKEN in 2023. Their innovative approach, inspired by human brain memory formation techniques, involves degrading the quality of high-resolution images for training algorithms in self-supervised learning. This method enhances the algorithms' ability to identify objects in low-resolution images, addressing a notable challenge in the field of computer vision.⁶

Furthermore, researchers at Purdue University and Michigan State University have introduced a groundbreaking AI-enhanced camera imaging system known as HADAR (heat-assisted detection and ranging). HADAR utilizes AI to interpret heat signatures, effectively resolving issues such as ,ghosting' that are commonly associated with thermal imaging. Its applications span a wide

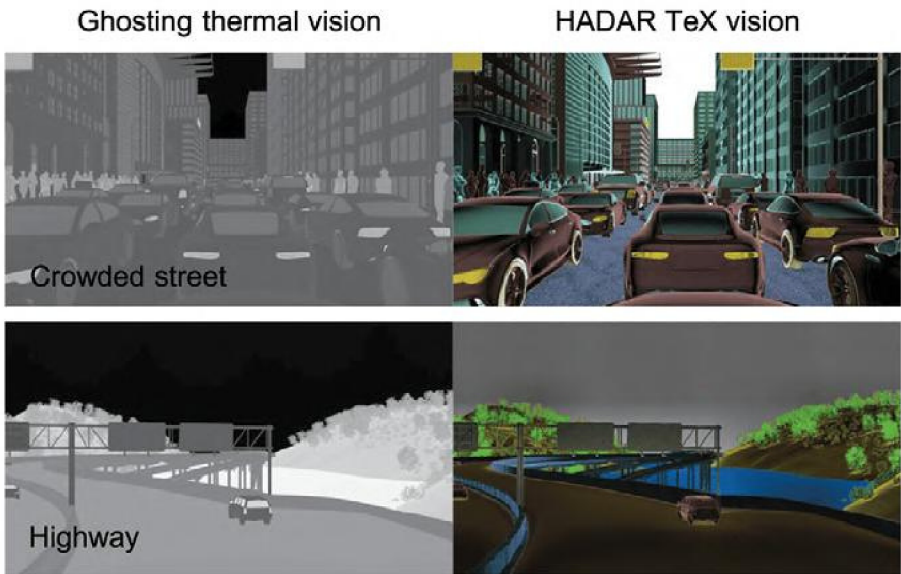
spectrum, from enhancing the perception of AVs and robots to enabling touchless security screenings at public events.⁷

Another example comes from NVIDIA, which has developed a pixel-level segmentation approach using a single deep neural network (DNN) to achieve comprehensive scene understanding. This technology can divide a scene into various object categories and identify distinct instances of these categories, as reflected in the lower panel's colors and numbers.

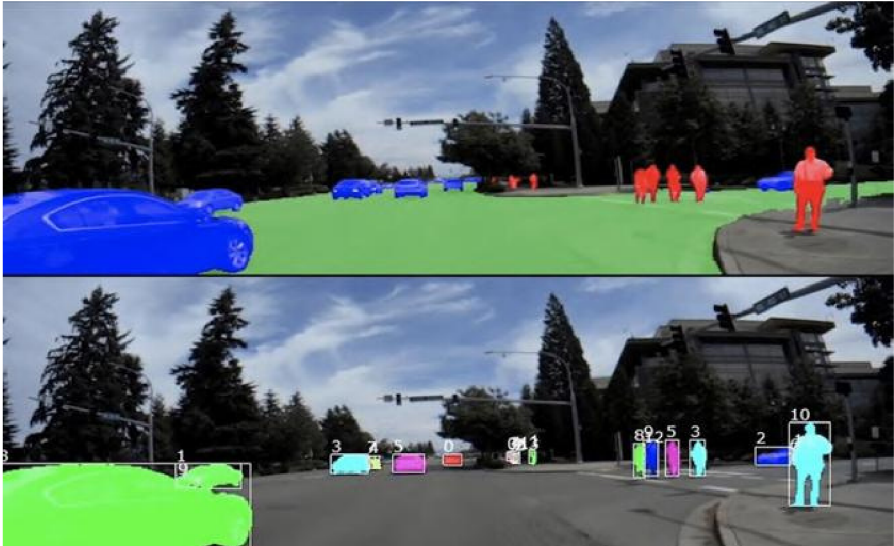
The benefits of this technology are far-reaching, including reductions in training data, improved perception, and support for the safe operation of autonomous vehicles. These innovations collectively underscore the transformative potential of AI-enhanced vision in shaping the future of autonomous vehicles and related technologies.⁹

“We have algorithms that are reading for lanes, but there’s also an object detection, but then there’s also a DNN we call free space. Which is looking for the absence of objects.”

Danny Shapiro, VP of Automotive at NVIDIA



Comparison between ghosting thermal vision and HADAR TeX vision. Image credit: NVIDIA



Panoptic segmentation DNN output from in-car inference on embedded AGX platform. Top: predicted objects and object classes (blue = cars; green = drivable space; red = pedestrians). Bottom: predicted object-class instances along with computed bounding boxes (shown in different colors and instance IDs). Image credit: NVIDIA

Prominent Companies
Developing AV Vision
Systems

This section highlights some of the cutting-edge vision systems currently enabling the development of AVs.

Mobileye
Mobileye uses a variety of cameras within its vision-based driver assistance systems, including fisheye cameras, wide-angle cameras, and thermal cameras.¹⁰ In 2023, Mobileye launched the first camera-based Intelligent speed assist that complies with the new EU standards. Their technology, which only uses cameras, has received official approval throughout Europe, making it the first of its kind. Mobil-

eye's technology can recognize various traffic signs, aiding Intelligent Speed Assist systems by using cameras alone. It relies on Mobileye's 400-petabyte database of global driving footage to swiftly meet increasing automotive safety standards.

Continental
Continental develops various cameras, including fisheye, wide-angle, and thermal cameras. These cameras are designed to meet the specific requirements of different AV applications. More specifically, the surround-view camera features fisheye optics for a short-range view, and it supports Ethernet or LVDS communication.

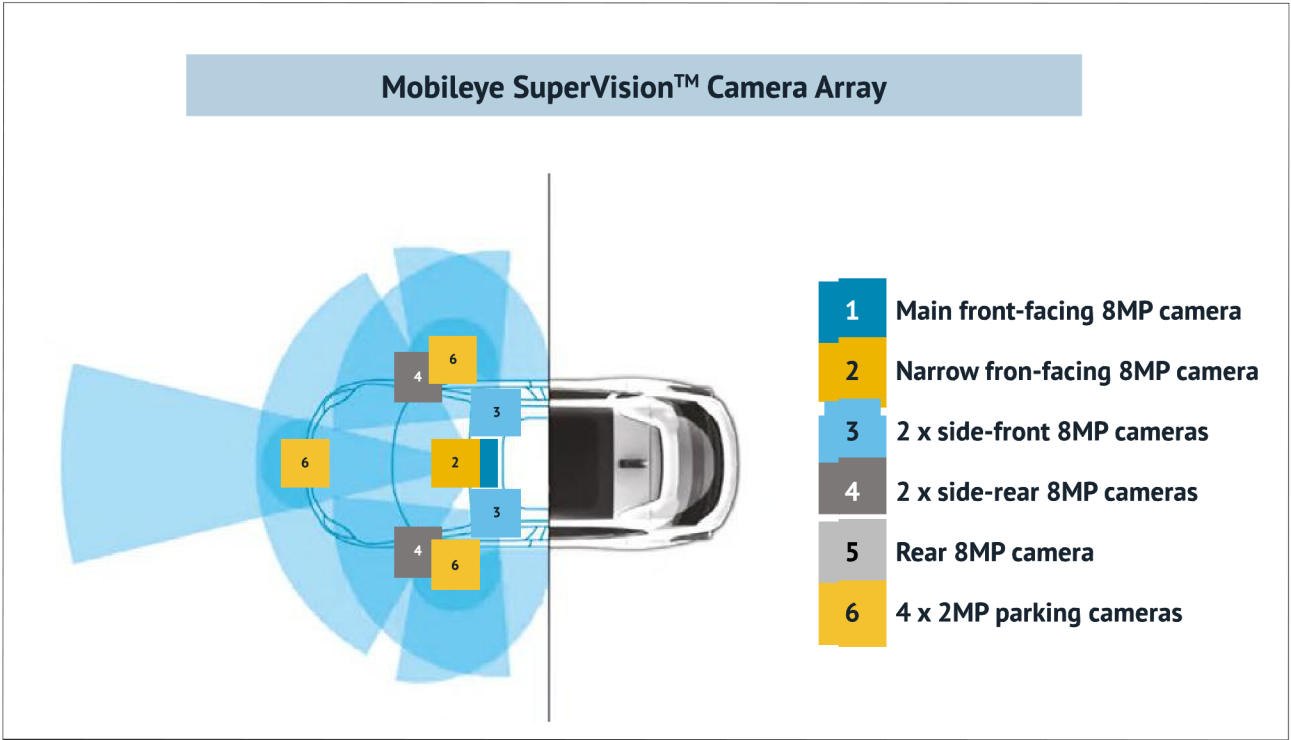
In November 2022, Continental and Ambarella entered a collaboration to

co-develop hardware and software solutions based on AI for assisted and automated driving. The partnership aims to produce products for global series production by 2026, addressing the increasing demand for assisted and automated driving technologies. The collaboration focuses on camera-based perception solutions for advanced driver assistance systems and scalable full-stack systems for vehicles with Level 2+ and higher autonomy.

TIER IV
TIER IV, is an open-source autonomous driving technology company who are their expanding production based on the huge interest in Automotive HDR Camera C1 which launched in 2022.



Continental's AV advanced camera solutions.
Image credit: Continental



Mobileye SuperVision diagram presenting the components and coverage of the camera array. Image credit: MobileEye

The camera is designed for autonomous mobility applications and has gained widespread adoption in various fields, including autonomous driving, driver assistance, autonomous mobile robots, security, and surveillance. These applications are possible thanks to its impressive 120dB high dynamic range and high-quality automotive-grade hardware.

Over 100 companies worldwide have implemented the C1 Camera. Building on the success of the C1, in June 2023 TIER IV introduces the C2 Camera, a superior model with double the resolution at 5.4 megapixels, improving its capabilities in distant objects and signal recognition. Finally, TIER IV is developing the C3 Camera featuring an 8-megapixel image sensor to meet

the demands of high-speed applications such as highway driving. The goal is to complete its development within the year and start providing it in early 2024.

SPONSOR INTERVIEW



Mark Patrick
Director Technical Content, EMEA at Mouser Electronics

Accelerating AV Development Through Customer Collaboration

Mark, could you please describe your role at Mouser and the company’s activities?

Mark Patrick: I oversee technical content for Mouser in EMEA. This role encompasses not just written content but also involves projects and event booth development aimed at engaging our primarily technical audience with relevant content and activities. Our goal is to both inspire and inform our audience, providing ideas and guidance on various projects, offering detailed instructions, code, hardware, and related materials. Ultimately, we are a technical distributor, supplying highly technical products to design engineers and component buyers. The technical marketing aspect is inherent in what we do, as authenticity is crucial when addressing our audience. This requires the collaboration of engineering and content teams. My background lies in semiconductors, technical sales, and application support. My engineering team consists of master’s-level electrical engineering students from the Technical University of Munich. They are a young, dynamic team capable of diverse tasks.

Thank you for the introduction. Can you elaborate on Mouser’s activities?

Mark Patrick: Certainly. In simple terms, Mouser is a global distributor with full authorization from all our manufacturers. We stock products from around 1,200 manufacturers, including well-known brands and specialized niche players. Our commerce platform allows anyone to purchase products needed for their development, design, or production processes.

You serve a wide range of customers, from OEMs to startups, correct?

Mark Patrick: Our customer base is diverse, ranging from individuals, including DIY enthusiasts often referred to as ‘Fred in the shed,’ to small consultancies, and up to large corporations and OEMs. This includes well-known companies like Google and Apple who seek the convenience of our services.

Could you tell us about Mouser’s unique selling proposition (USP)?

Mark Patrick: There are other organizations similar to Mouser, but our USP lies in our focus on new product introduction. We lead our marketing efforts with the latest products and designs. We maintain over a million individual part numbers in stock at one location, ensuring a high-quality customer experience. This means that what you see on our website is readily available. We offer authentic and traceable components, a critical factor in light of recent supply chain concerns. Our vast inventory and commitment to offering new and innovative products set us apart.

How do you stay updated on the latest products and technologies?

Mark Patrick: We collaborate closely with our suppliers, maintaining a relationship that provides insights into their upcoming products and release schedules. We are prepared to create content, including technical details, for these products, ensuring we can go live as soon as the product hits the market. Additionally, we create content that becomes highly visible on search engines, helping customers find these new products quickly. This way, we facilitate access to technology and introduce it to new customers.

What are the benefits of Mouser’s services for your customers?

Mark Patrick: Our customers, often engineers working on designs, require rapid access to products, particularly during testing, proof of concept, and prototyping phases. They need assurance that the products are readily available. We offer this level of trust through our website, in-stock inventory, and our ability to deliver products within two to three days worldwide from a single location in the US. This high-quality service hinges on the convenience and ease of finding products, combined with our informative and inspirational content.

With the increasing complexity of vehicles, particularly in the context of autonomous cars, how important is Mouser’s service in providing the necessary technology and components?

Mark Patrick: Autonomous vehicles rely on various technologies, many of which require semiconductors for their functionality. The increasing capabilities and functionalities in modern vehicles are directly enabled by semiconductors. These components are now essential for even basic features like reversing cameras, navigation systems, audio systems, and safety features. Semiconductors play a critical role in processing the data generated by sensors and providing a seamless user experience. As the automotive industry continues to innovate, the role of semiconductors will only grow.

If an OEM needs a specific part that doesn’t exist, can Mouser assist in facilitating the creation of such parts?

Mark Patrick: While we primarily stock standard products, we do collaborate with customers and tech support to address inquiries about specific components. However, for OEMs developing entirely new components, it is more common to work directly with manufacturers to create bespoke components, particularly given the scale of production in the automotive industry.

Regarding autonomous vehicles, do you think many of the underlying technologies and components are shared across different manufacturers?

Mark Patrick: Yes, there are common components and technologies that serve specific functions in autonomous vehicles, such as connectors, semiconductors, and sensors. Many of these components are not exclusive to a single manufacturer. However, there can be custom parts created for specific OEMs. In general, a wide range of standard components can be used to build various aspects of autonomous vehicle systems, with the focus shifting more toward software and user experience differentiation.

When do you anticipate mass rollout of fully autonomous vehicles, and what are the main challenges to overcome?

Mark Patrick: The rollout of fully autonomous vehicles is already happening to some extent, particularly at level two, where we see vehicles with various assistance features. To achieve higher levels of autonomy, there are technical, ethical, and social challenges to address. Technically, the necessary processing power and machine learning algorithms are increasingly available. Social acceptance of driverless cars and ethical considerations, such as decision-making in complex situations, remain areas of concern. While trials of fully autonomous vehicles are ongoing, predicting when they will become mainstream is challenging. However, we may see more of these services in cities across the world in the next five years.

Before fully autonomous vehicles become commonplace on the road, do you expect them to be used in controlled environments, like ports, airports, or factories?

Mark Patrick: Yes, we are already witnessing the use of autonomous technology in controlled environments, such as autonomous ground vehicles and robots. In these settings, the technology is more readily accepted and deployed. The same principles can be applied to larger-scale deployments in defined geographical areas with established infrastructure. Controlled environments with specific infrastructure and limited interaction with the general public are more suitable for early adoption. Industrial facilities and warehouses are already leveraging autonomous technology for efficiency.

Is there anything else about Mouser or your role that you would like to mention for the report?

Mark Patrick: Our primary role at Mouser is to enable access to technology. We work

closely with our suppliers to ensure that those working on advanced systems have access to the technology they need, whether it is high-end processing power, sensing technologies, or a wide range of components. We offer a comprehensive range of products that can be used to build end-to-end systems. Essentially, we aim to provide everything customers need to develop their projects, from individual components to complete kits, making the process of accessing technology as straightforward as possible.