Machine Vision Solutions for Today's Automotive Manufacturing Challenges

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Automotive operations must constantly evolve to match today's biggest challenges, which include rising consumer demands, increased custom manufacturing, supply chain volatility, and the rising call for electric vehicles (EVs). Machine vision technologies such as barcode scanners, industrial cameras, 3D sensors, and image processing tools have long served the automotive industry, helping to automate disparate processes, from engine block inspection to tire and wheel identification. New challenges, however, require new solutions.

As automotive manufacturing processes advance, so too must the technologies that help companies increase productivity, enhance efficiency, and ultimately achieve production and revenue goals. Today's automotive companies need real-time visibility over countless moving parts, carefully coordinated production lines, and automation that accomplishes more with fewer workers.

Zebra Technologies™ offers a complete range of machine vision solutions, including fixed industrial scanners, barcode readers, 2D cameras, 3D cameras, smart cameras, image processing and deep learning software, and powerful processing and capture components to address all of today's automotive manufacturing processes and challenges. This comprehensive guide looks at some of the most common automotive manufacturing and assembly applications that rely on machine vision technologies to maintain quality, safety, and production standards.

Automotive Quick Reference Guide

Described within this guide are seven key applications within the automotive manufacturing process in which fixed industrial scanners and machine vision systems typically add value by enhancing efficiency and increasing overall productivity. Within each category, the guide covers common use cases and the different products from Zebra Technologies that deliver the automated imaging capabilities needed for today's manufacturers.

Power Train

Applications: Metal casting inspection; preassembly power train component inspections; engine assembly and part verification

Solutions: Iris GTX or VS smart cameras; AltiZ and AltiZ 4200 3D profilers; 3S series 3D sensors; Aurora Imaging Library™ and Aurora Design Assistant™ software; FS fixed industrial scanners; Zebra Aurora Focus™ software

Highlights: A vast array of proven software tools, from metrology and presence/absence to code reading and deep-learning-based classification

Electronics and Electric Vehicles

Applications: Electric vehicle battery and motor inspection; OCR and barcode reading for track and traceability; wiring harness and electronic control module inspection

Solutions: Iris GTX or VS smart cameras; AltiZ and AltiZ 4200 3D profilers; 3S series 3D sensors; Aurora Imaging Library and Aurora Design Assistant software; FS fixed industrial scanners; Zebra Aurora Focus

Highlights: High-resolution and color smart camera options; dual-camera/single-laser 3D sensors

Final Assembly

Applications: Kitting inspection; assembly verification; glass decking inspection; 3D gap and flush on final assembly; vision inspection/guidance for wheel assembly; badging

Solutions: AltiZ and AltiZ 4200 profilers; 3S series 3D sensors; Iris GTX smart cameras; VS smart cameras and sensors; Aurora Imaging Library and Aurora Design Assistant software; FS fixed industrial scanners; Zebra Aurora Focus

Highlights: High-speed 3D imaging; complementary rules-based/deep learning software tools; color imaging capabilities; a robust toolbox for disparate final assembly tasks

Trim and Interior Components

Applications: Assembly quality; presence/absence of required features; color and stitching verification

Solutions: Iris GTX or VS smart cameras; Zebra Aurora Imaging Library and Aurora Design Assistant software

Highlights: A deep software toolbox for color inspection, presence/absence, pattern and object recognition

Frame and Body

Applications: Body panel stamping inspection and verification; frame and body panel welding inspection; stud and weld nut detection and inspection

Solutions: Iris GTX smart cameras; VS smart cameras and sensors; Aurora Imaging Library and Aurora Design Assistant software

Highlights: Deep learning capabilities; a range of imaging options from 2D to 3D and low to high resolution

Body Assembly

Applications: Body panel adhesive; noise-suppression materials; and sealant inspection; body part joining and gap and flush inspection; etched vehicle identification numbers (VIN) and optical character recognition (OCR) reading

Solutions: Iris GTX or VS smart cameras; AltiZ and AltiZ 4200 profilers; 3S series 3D sensors; Aurora Imaging Library and Aurora Design Assistant software; FS fixed industrial scanners; Zebra Aurora Focus

Highlights: Deep-learning-based OCR tools; high-resolution smart cameras

Tires and Wheels

Applications: Tire identification and verification

Solutions: AltiZ 3D profilers; 3S series 3D sensors; Iris GTX smart cameras; VS smart cameras and sensors; Aurora Imaging Library and Aurora Design Assistant software; FS fixed industrial scanners; Zebra Aurora Focus

Highlights: High-fidelity 3D imaging; powerful software tools; including OCR and photometric stereo capabilities

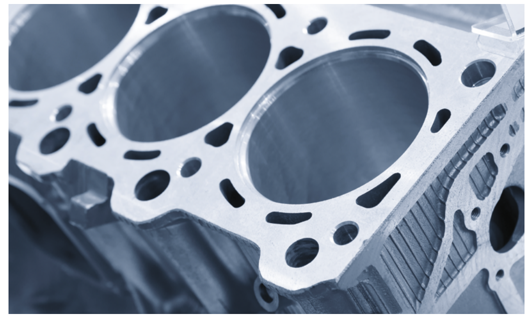
Power Train

Inspections from cast part to engine assembly

Metal Casting

Many automotive parts used in the assembly of components in the vehicle power train are manufactured in a metal casting process that generally involves pouring molten metal—generally zinc, aluminum, or magnesium—into a form or die to create an object. The technique used in automotive casting is typically either green sand or lost foam, the latter of which uses a foam model to hold the place of the metal in a sand form. Lost foam provides more precise and complex forms while green sand is cheaper and easier to accomplish. Regardless of which method is used, 2D or 3D imaging technologies can carry out the inspection, depending on the type of part.

After casting, most parts are precision machined to create joining or sealing surfaces or to add mounting features such as threaded holes or other characteristics unique to each part. Throughout this process, manufacturers must ensure that parts are correctly assembled and within tolerance and that no defects are present. Machine vision systems can help automate these inspections and improve their results.



The power train stage of automotive manufacturing requires several critical machine vision inspections, including a close examination of the engine block.

Machine vision systems can help in the tracking and tracing of machined parts such as gears.

When cast parts are ground or machined to create a smooth or precise surface, small voids or foreign materials can create pits or defects in the machined surface. Additional defects may include cracks—particularly at sharp edges—and grinding or machining marks on the part surface. In some cases, the surface quality must be inspected on interior features, such as the inside of a cylindrical bore on an engine block, which can be accomplished with either 2D cameras and specialized optics or even a 3D borescope. Surface defect size metrics can be very small, however, so machine vision systems deploying high-resolution cameras may be required for the application. 3D solutions like Zebra's AltiZ, AltiZ 4200, or 3S series 3D sensors—or even 2D cameras with structured light or photometric stereo capabilities—can accomplish many surface quality-inspection tasks.

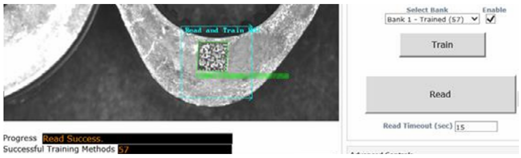
Another common visual inspection required after the machining process is precision measurement of the machined features of the cast part. This is done to ensure the parts are within tolerance, as out-of-tolerance (OOT) parts will not mate upon assembly or may not perform as required, which could lead to issues including recalls or worse. High-resolution cameras paired with powerful machine vision software can adeptly tackle such tasks.

Track and Trace for Production Flow and Quality

Modern automobiles are incredibly sophisticated systems comprised of assemblies, subassemblies and components. A modern automobile might incorporate 30,000 parts. Track and trace technology based on 1D and 2D barcodes is essential to control the flow of many parts through production, track component history and ensure consistent quality.

Fixed industrial scanners are designed to read barcodes quickly and reliably to create a digital record of inventory that can be used for shipping manifests and locating goods. Mountable on forklifts, on conveyors or overhead for faster manual loading, these scanners can help streamline workflows, increase quality and save time in every area of your plant.

Zebra smart cameras further enhance track and trace operations. Able to read 1D and 2D barcodes, they can also provide a visual record of parts and perform complex quality inspection checks.



A smart camera reads a barcode on a machined gear for track-and-trace purposes.

Problems such as defective die molds can produce cast parts with excess material (e.g., "flash") or voids in the casting due to too little material. Machined parts that go into brake control or power steering systems (see right), for example, must be inspected for such defects. Parts that come out of the casting process incomplete or with these defective conditions must be detected prior to any machining of the part. A smart camera carried by a robot is a good candidate for such an inspection. Cast components that must be inspected with machine vision systems after the machining process include:

Engine Blocks

Engine block inspections check for roughness/smoothness, quality of joining surfaces, and the presence of defects such as voids, cracks, or pits in the machined surfaces, particularly on critical sealing surfaces and in the cylinder bore. A machine vision system must also verify the presence of numerous other machined features such as through holes and threaded holes. The location and size of these features will often be measured along with the quality of the machined surfaces surrounding the features.

Cylinder heads

As with engine blocks, cylinder heads must be inspected for surface quality, for defects, and to verify machined features.

Transmission/gearbox housings and valve bodies

Complex machining of these components often requires 100% inspection for casting or machining defects. Inspecting locations and measurements of machined features is also common.

Brake rotors

Surfaces of brake rotors are critical to performance and must be inspected for surface machining quality and defects such as pits, voids, and cracks.

Preassembly Power Train Component Inspections

Prior to engine, transmission, steering, braking, and exhaust system final assembly, a wide range of components used in automotive power train assemblies must be inspected. Examples include ensuring the correct position of gear and shaft assemblies in the transmission body, verifying the clutch/torque converter, and examining transmission gear teeth for defects that could cause premature failure of the assembly. Additional tasks include verifying that the correct component—such as a clutch plate gear/gasket—has been installed and measuring subcomponents such as the catalytic combustor in a catalytic converter. Aside from catalytic converter inspection, which is done with 3D imaging, most of these tasks are performed by 2D machine vision systems.

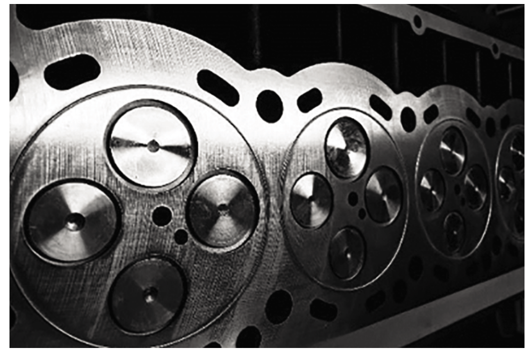
Many power train components have sealant or gasket beads on the joining surfaces prior to assembly. These components include engine or transmission oil pans, drivetrain and differential assemblies, and transmission and brake valve bodies. The sealant/gasket bead must also be inspected for skips, width, and in some cases to verify height and profile; this inspection could also extend to sealing O-rings and gaskets, which are often inspected at the time of manufacture with 2D imaging. Bead inspection can be accomplished using Zebra smart cameras or 3D sensors mounted on a robot.

Engine Assembly and Part Verification

The final assembly of an engine incorporates many components and several different possible inspection points throughout the process. Machine vision can detect defects in the cylinder head valve assembly—and sometimes even the valve lifter, valve springs, and retainer—and help correct improper valve spring retainer keeper insertion. Manufacturers typically use 2D imaging devices to inspect valve retainers and keepers, though 3D sensors can prove useful when the inspection involves verifying the planarity or height of the retainers, which confirms proper assembly and that the right components have been used.

Fixed industrial scanners, barcode reading and OCR tools can help verify the correct component is being used for an assembly process. Such components might include piston rings, camshafts and lifters, and spark plugs. When paired with proper illumination and deep learning–based machine vision software, 2D cameras also make good candidates for inspecting engine components and assemblies. Such inspections might involve the use of industrial cameras to ensure wiring components are correct and have good connection integrity; to verify hose and clamp assemblies are complete and correct; or to confirm presence/absence and proper location of components—for example, when verifying the proper routing of cables.

Zebra offers multiple cameras and 3D sensors for inspecting engine components and assemblies, as well as fixed industrial scanners and cameras for reading 1D and 2D barcodes respectively. It further offers a range of software tools for machine vision or scanning tasks, as well as deep learning software to further aid assembly inspections. Again, deep learning represents a suitable technology for such an inspection, while 1D or 2D code reading technologies are often deployed as well. Zebra software offers multiple deep learning tools as well as barcode-reading sensors and cameras.



Deep learning software can recognize and classify different automotive parts, including valve heads.

The power train phase of manufacturing comprises several steps, most of which benefit from the use of machine vision technologies, such as Iris GTX or VS smart cameras, FS fixed industrial scanners, AltiZ 3D profile sensors, and Zebra Aurora, Aurora Imaging Library, and Aurora Design Assistant software.

Electronics and Electric Vehicles

From EV battery to ECM inspections

Wiring Harness and Electronic Control Module Inspection

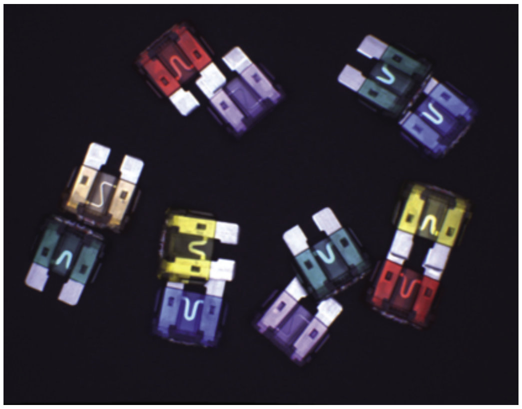
Many electrical components comprise an automobile, and in most cases, these components are inspected for assembly and quality at the supplier level. Wiring harnesses, for instance, undergo 2D color inspections, often using many cameras and recipes for different harness configurations. The machine vision system must ensure that the correct connectors and wirings are present at the connection point and that the harness components are the proper length.

Engine electronic control modules (ECMs) represent another set of components that must be inspected. In these applications, machine vision systems can verify components, perform presence/absence checks for solders for both surface mount and through holes, and verify board seating, potting, and insulation, as well as connections. Typical machine vision applications involving ECM inspections deploy 2D and 3D imaging components, such as those offered by Zebra.

Ensuring Quality of Cathode and Anode Coatings

EV battery manufacture involves a progression of assemblies, from cells to modules to packs. The progression begins with the manufacture of thin-film cathodes, anodes and separators. Ensuring the quality of these is critical to avoiding downstream waste. It is also essential to the efficiency, safety and performance of finished batteries.

Anodes and cathodes are made in a high-speed calendaring process that involves multiple rounds of web inspection as coating layers are progressively applied to each electrode component. High-speed machine vision cameras offer the only practical solution for inspecting these webs for defects. High-resolution smart cameras can later inspect finished battery components for flaws and ensure proper alignment as cathodes, anodes and separators are stacked to form battery cells.

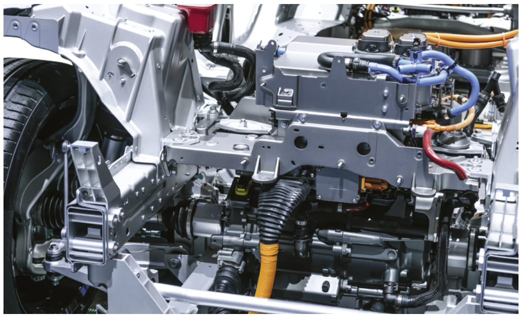


Machine vision systems leveraging color cameras can identify electronic components such as fuses by color.

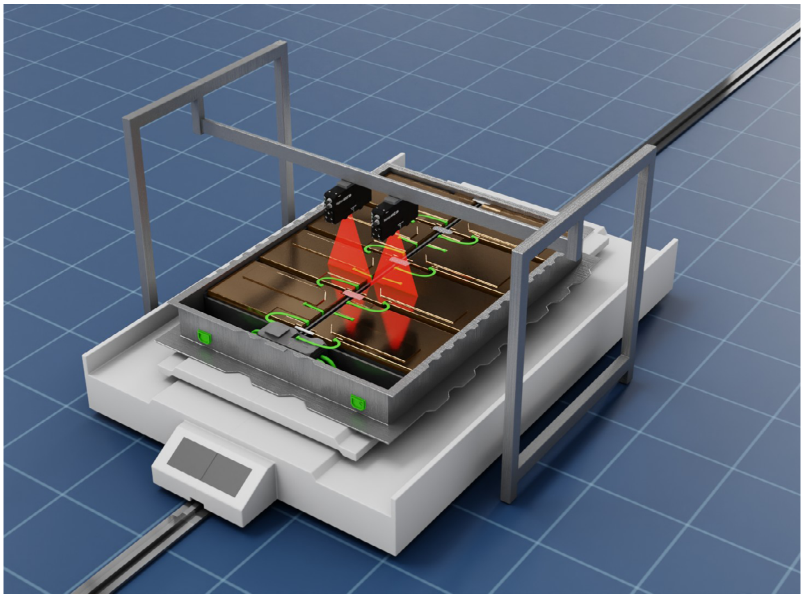
Electric Vehicle Battery and Motor Inspection

As EV usage continues to scale, so too must the manufacturing processes and the technologies behind them. EV battery inspection represents an emerging inspection use case. In EV battery inspection, machine vision systems can help verify the assembly of battery packs, detect foreign objects, and perform dimensional checks. In addition, machine vision systems—typically 2D but sometimes 3D for metrology—can verify components and connectors and look for defects while also performing coating quality inspection and stacking alignment.

Another common machine vision application in EV manufacturing is motor inspection. Manufacturers can deploy vision systems to inspect motor components for defects, ensure weld quality, or verify correct wiring and assembly. Additionally, fixed industrial scanners can perform code reading and OCR for track and trace operations.



With electric vehicle manufacturing on the rise, EV battery and motor inspection has emerged as a popular machine vision application.

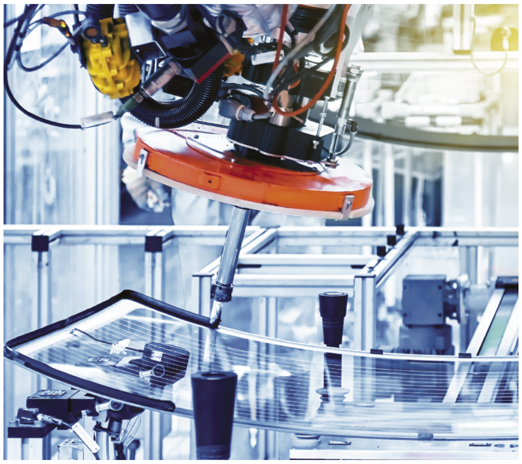


3D inspection of assembled battery packs

Zebra solutions aid electric vehicle production from end to end. FS fixed industrial scanners and Aurora Focus software enable traceability of battery components. Later, Iris GTX or VS smart cameras ensure cell stacks are properly aligned and free of defects or contaminants. AltiZ 4200 3D profilers further enable fast, accurate inline inspection of adhesive beads during cell stack assembly.

Final Assembly

Ensure quality from windshield to wheel mounting



During the final assembly stage of automotive manufacturing, several machine vision inspections must occur. At this stage of production, the process is a mix of automated and manual inspections, both of which can benefit from machine vision technology. Components that are manually installed onto the automobile are typically "kitted" and delivered to the operator to match the vehicle in production. These parts—which include headlights/taillights, grilles, door handles, and similar features—must be inspected prior to assembly or immediately following assembly. Machine vision systems leveraging 2D cameras, smart cameras, and sometimes deep learning technology can be reliably deployed for such inspections.

Vision-guided robots are also used throughout several parts of the automotive production process, verifying assemblies that require inspection both before and after installation. Glass decking is a common example, since windshields and backlights are almost always robotically applied (left). During this process, the robot requires guidance in the pick of the glass. Once an adhesive bead is applied to the glass or body, this too is typically inspected. In many cases, the opening on the car body is inspected and located for the best fit of the glass, and after insertion, the final position of the glass must be inspected. These operations typically involve the use of smart cameras or 3D profile sensors such as those offered by Zebra.

Upon final assembly, manufacturers must perform another set of 3D gap-and-flush inspections. These will include not only body panel inspection but many other assemblies, including front/back lights, windshields/rear windows/sunroofs, or even interior assemblies, such as correct placement of an arm rest within a plastic/fabric inner door panel. For inspections like these, a vision-guided robot carrying a Zebra AltiZ 3D profile sensor is an ideal solution.

Wheel mounting is another assembly process that often leverages machine vision technology. Wheels or tires often carry barcodes, for example, to help ensure the proper part is being installed per the bill of materials. Verifying the correct part may involve the use of fixed industrial scanners or smart cameras, respectively, to read 1D or 2D barcodes. Such codes also support track and traceability of parts.

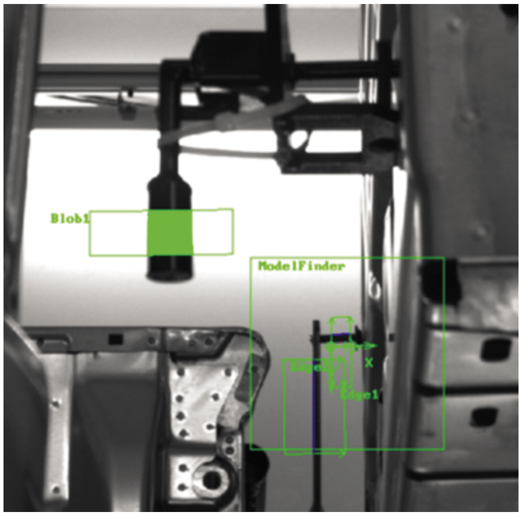
Vision-guided robots leveraging 2D cameras or 3D sensors can mount the wheel during assembly and tighten lug nuts. Other automated processes also require the use of machine vision during this stage of production. One such example is ensuring that a trunk lid is open prior to a robot inserting a spare tire.

Near the end of the final assembly process, all manufacturer logos and individual model IDs on the front, sides, and back of the vehicle must match the manufacturing order against that vehicle. In addition, badge location must be verified, as logos and IDs can be located in different locations from vehicle to vehicle. This might mean deploying a multi-camera inspection system comprising Zebra 2D cameras and an industrial controller, or even Zebra smart cameras.

Verifying Correct Gap and Flush

Gap and flush inspections are so critical to ensuring the quality, functionality and aesthetics of fully assembled automobiles that they are often mandatory. Traditionally, manually operated feeler gauges verified the correct spacing between automotive parts, such as doors and body panels. Machine vision cameras have more recently offered a contactless—and automated—alternative to such tools. But while 2D cameras can detect whether a gap between two panels is consistent and to spec, determining whether the panels are flush—that is, flat along the same plane—is more challenging.

Another solution is to deploy 3D profilers or sensors, which can reliably verify that the gap between door panels is correct and that the panels are flush. The demand for accuracy in these inspections calls for 3D profiler designs able to minimize the impact of optical occlusions that some 3D sensor technologies perceive at surface junctions.



Software tools include pattern and object recognition and presence/absence inspection.

Several automated imaging tasks take place during final assembly. Iris GTX or VS smart cameras, FS fixed industrial scanners, AltiZ 3D profile sensors, and Zebra Aurora, Aurora Imaging Library, and Aurora Design Assistant software can be confidently implemented during this phase to ensure a high-quality, accurate final assembly.

Trim and Interior Components

Common, cost-effective inspections and verifications

Moving toward the end of the manufacturing process and inside the vehicle, trim and interior components are part of another set of necessary inspections. Interior trim, seating, and other components must be inspected for assembly quality and presence/absence of required features. These inspections often rely on machine vision systems that perform color inspection because interior trim color—both plastic and fabric—must be verified for consistency and the trim must be checked to ensure it corresponds with the interior bill of materials.

During the trim preassembly process, robots are often deployed to attach plastic or fabric trim to external panels using clips, making it necessary to verify clip presence and proper seating as part of the final assembly process. Machine vision cameras, controls, and software can help here, as well as with seat and seatbelt inspection, other necessary elements of the verification process.

Fabric, leather, or plastic seat coverings are often inspected for color and proper assembly. One common inspection demand is verifying the color and accuracy of stitching, particularly in the case of expensive seat coverings such as leather, and especially when the stitching is part of the design, or trim, of the seat cover. Inspecting seatbelt brackets and connectors is a critical seat assembly task. Machine vision technologies commonly handle inspection for both presence/absence and quality of the attachment of the bracket and connector. Zebra machine vision software offers several tools for such inspections.

Interior trim—especially high-end fabrics and leathers—must be inspected for color and proper assembly during the trim and interior components stage of manufacturing.

Ensuring that "Christmas tree" clips are on the right parts ranks among the most popular automotive interior inspection applications.

Iris GTX or VS smart cameras and Zebra Aurora Imaging Library or Aurora Design Assistant software are useful to address key applications in trim and interior component inspection.

Frame and Body

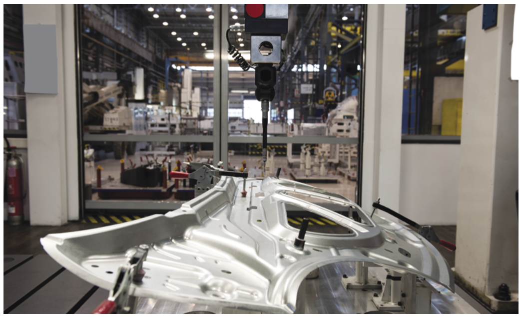
From car frame to weld nut inspection

Body Panel Stamping Inspection and Verification

In automotive manufacturing, stamping involves bending sheet metal into steel body panel shapes while also cutting large openings into the panels for features such as windows and making smaller holes required for panel mounting and assembly. During the stamping process, it's critical to check for splits in the panel, which can occur anywhere but typically emerge at the edges of a die cut or at points of extreme bending.

Machine vision systems can find these splits, but the process proves challenging because of the size of the panel and the need to inspect nearly its entire surface area. Panels vary in size and presentation; accurate inspection can be done, however, by restricting the inspection to specific key areas or by deploying a robot to move a camera or part. A smart camera and capable machine vision software from Zebra can carry out these tasks.

Immediately after stamping, a panel may also be inspected to verify the presence and location of stamped or die-cut features. During multiple press stages, it is possible for a blank to be mispositioned and/or shift, resulting in out-of-position features even if the panel itself is in the correct geometric position. Assessment of feature presence/absence and location can be accomplished for many panels with 2D imaging and minimal manipulation of the camera(s) or panel.



Most automotive manufacturing stages, including body panel stamping inspection and verification, benefit from machine vision and automation.

Machine vision technologies automate the quality assurance process by inspecting car body panels.

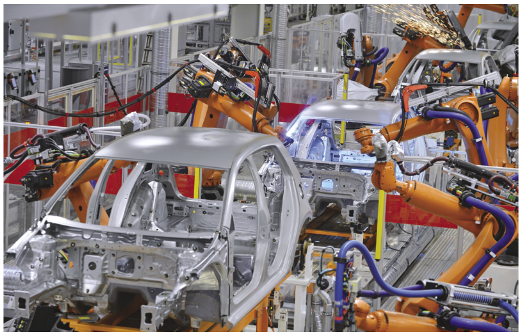
Frame and Body Panel Welding Inspection

Finished automobile frame sections are assembled into a complete frame using either one or a combination of these welding techniques: spot, tungsten inert gas (TIG), metal inert gas (MIG). Typically made of steel or aluminum, the I, C, U, or square tubes must be properly welded for stability and rigidity. Manufacturers commonly deploy machine vision cameras or 3D sensors for nondestructive inspection. Oftentimes, a structured light implementation will examine the weld for size, shape, continuity, and voids.

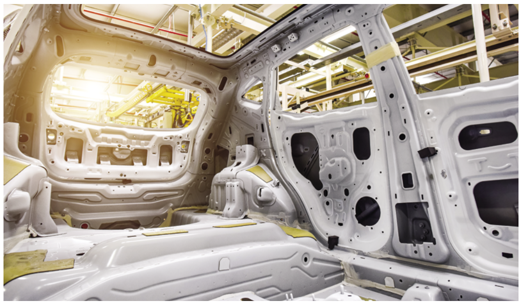
One of the key challenges in frame welding inspection is the position of the welds and the large number of welds that may be present. As a result, manufacturers may inspect only key welds or perform the inspection with a flexible robotic imaging system. Deep learning software such as Zebra Aurora or Aurora Imaging Library, paired with 2D cameras or Zebra smart cameras, may also be able to address the variability involved in frame-welding inspections.

Frames contain many components, including brackets and weld nuts, most of which are welded to the frame. These welded frame components must also be inspected. Machine vision systems using Zebra smart cameras or 3D profile sensors can inspect not only the weld itself but the position of the component relative to other frame features such as machined features.

Challenges may emerge when components are attached after a frame has been coated or plated, or if the frame is inspected after coating or plating. Vision system integrators must therefore choose the right components to accomplish the inspection without overchallenging the vision system. Inner and outer sections of stamped body panels are joined using spot welding, and machine vision cameras can help verify the presence of a weld and, to a certain extent, the weld quality. Other body panel inspections examine joining components such as brackets and weld nuts; 2D cameras or smart cameras can also inspect the weld and position of these components using a presence/absence tool. Body panel inspection can prove challenging when the semi-reflective surface of the unfinished metal grain creates glare, but the right combination of 2D cameras and illumination can address this issue. Alternatively, 3D profilers and sensors can also detect many surface defects, even on highly reflective surfaces.



After vision-guided robots perform welds on the car frame, machine vision systems must inspect the welds.



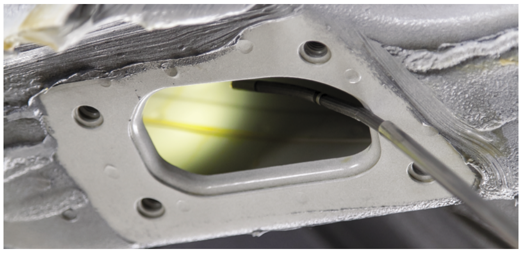
During the assembly process, finished automobile frame and body sections are welded. Machine vision can inspect and verify these welds.

Iris GTX smart cameras, VS smart cameras and sensors, and Zebra Aurora Imaging Library and Aurora Design Assistant software can be reliably deployed for common machine vision tasks during the frame and body phase.

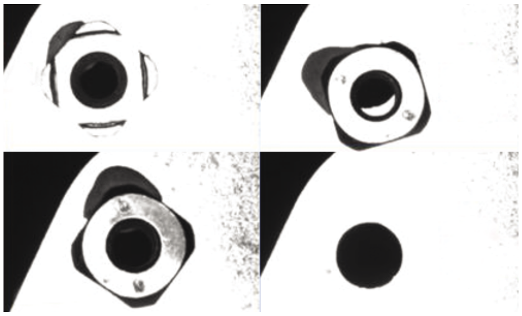
Stud and Weld Nut Detection and Inspection

Studs—which are threaded bolts without bolt heads—are welded onto surfaces such as frames, body panels, hinges, or brackets to join components. Studs are more secure and robust than through-bolts, and welding technology has made it easier to weld the frames, oftentimes with vision-guided robots. Studs themselves are welded, so manufacturers must ensure a proper weld, verify the correct position of the stud relative to other features on the object, confirm the correct stud was used, and perform quality inspection.

On the other end of the stud is the weld nut, which is welded to a substrate such as a frame, bracket, hinge, body panel, or other joining panel. As with studs, manufacturers must ensure the presence of weld nuts, verify weld continuity on all sides, and verify the position of the weld nut for joining relative to other features. A straightforward machine vision application, weld nut inspection is very cost-effective and useful. For both stud and weld nut detection and inspection, Zebra's Iris GTX or VS smart cameras can be reliably deployed.



Weld quality can be inspected using machine vision systems.



Weld nut inspection. Alias: orientation, wink, presence/absence of weld nuts.

Spotlight on Deep Learning

Rule-based machine vision algorithms are suitable for detecting visually consistent and clearly detectable defects. But they struggle when flaws vary in appearance or location, or when the difference between acceptable and flawed components is subtle.

Deep learning algorithms, in contrast, mimic how the human brain processes visual input, allowing the automation of significantly more complex vision tasks. The technology has enabled several new capabilities for automotive manufacturing, such as:

- Optical character recognition: Deep learning–enabled vision systems can quickly perform optical character recognition on direct part marking codes, even in low-contrast conditions or when a code is slightly damaged.
- Ensuring weld quality: Deep learning tools can more easily distinguish between acceptable variations in weld seams and actual defects.
- Inspecting textured metal sheet: Deep learning algorithms can more easily detect and classify imperfections, such as stains and scratches, on textured metal sheet and can differentiate between flaws and acceptable anomalies.

Body Assembly

Automating quality assurance and traceability

Body Panel Adhesive, Noise Suppression Materials, Sealant

During an automobile's body-in-white stage—which occurs after the metal frame has been assembled—several different types of inspections must take place, including examination of adhesive materials applied to body panels for various purposes. Adhesive beads used in addition to or in place of welding to join inner and outer panels, as well as noise suppression or sealant materials applied to body panels must all be inspected at this stage.

Typical inspection requirements include measuring bead width and detecting skips, voids, or bubbles. In some cases, it is critical to inspect the height or "volume" of the bead width, provided there is consistent and predictable viscosity. Oftentimes, the position of the bead must be verified relative to features on the panel or the edge panel. Zebra smart cameras or 3D profile sensors can reliably perform these inspections, but certain challenges do exist.

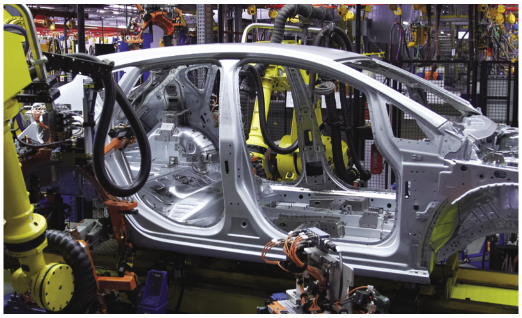
Obtaining suitable image contrast between the bead and the unfinished body surface, for example, is a key challenge. Pairing creative illumination or even nonvisible illumination with cameras can help solve this issue when the bead does not contrast well with the metal. Inspecting an entire panel is often necessary but can also be challenging due to the panel's size. Oftentimes, integrators will deploy a robot carrying a camera or a camera that follows the bead application as it occurs. In addition, deploying high-resolution smart cameras such as those offered by Zebra can be viable options, but illumination must be carefully integrated for large fields of view.

Inspecting Automotive Paint and Finishes

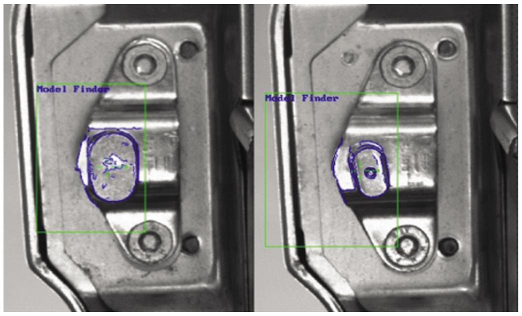
Ensuring that automotive coatings and paint are defect-free presents unique challenges for machine vision systems, due in part to the reflective, glossy surfaces of painted car bodies, which can create glare or reduce contrast in captured images.

To counter this, machine vision systems often pair high-resolution 2D cameras with patterned light projectors. By analyzing the reflected patterns, such systems can identify imperfections such as scratches, inclusions and other anomalies with micrometer-level precision. Mounting cameras at multiple angles further ensures full-surface coverage, including hard-to-view contours or angled surfaces. Use of polarized filters and lighting can reduce glare from glossy finishes.

Combining Zebra's smart cameras with machine vision tools provided by Aurora Design Assistant or Aurora Imaging Library software offers a cost-effective yet versatile solution for inspecting automotive finishes.



The stage after a vehicle's body frame components have been joined together, prior to painting, is called body-in-white. Machine vision systems perform several tasks during this stage.



Additional body inspection applications include using machine vision to verify the correct trunnion using a model-finding software tool.

Body Part Joining, Gap and Flush Inspection

Depending on an automobile's design, chassis body panel components may be joined together via welding by fully automated welding robots using a variety of different weld types, including spot, TIG, MIG, or a combination of techniques. It is critical for automobile manufacturers to ensure these components are properly welded together. This could mean deploying machine vision systems equipped with Zebra 2D/smart cameras and 3D cameras—sometimes mounted on the end of a robot arm—to reliably inspect the weld seam for presence/absence and thickness to ensure there are no voids or skips in the weld. Gap and flush measurement—checking the alignment of body components at the time of joining—is another critical part of the manufacturing process. Manufacturers want to catch errors to avoid painting an out-of-spec automobile body.

Gap measurement helps verify the consistency of gaps between components such as the body frame and door panel, which must be uniform and of a specific size. Flush measurement ensures that the surface of one body component is on the same plane as (e.g., "flush with") the surface of the adjoining body component near the mating point where the gap is measured. Gap and flush measurements can be of medium to high precision, and the length of the gap to inspect can be long, such as the perimeter of a door, roof, or hood. In many cases, the inspection system—oftentimes a laser-based 3D sensor like Zebra's AltiZ 3D profiler—is mounted on a robot.

Machine vision technologies automate the quality assurance process by inspecting car body panels.

Automated inspections during body assembly can leverage Zebra's GTX or VS smart cameras for 2D imaging tasks, or 3D solutions, such as our AltiZ or AltiZ 4200 3D profilers or 3S series 3D sensors. FS fixed industrial scanners or smart cameras offer solutions for reading 2D or 3D codes and OCR.

Etched VIN and OCR Reading

A laser-etched VIN is a unique 17-character identifying code for a specific automobile that essentially acts as the car's fingerprint. Checking VIN numbers during the final assembly stage lets the manufacturer ensure the automobile currently being worked on is using the correct bill of materials and even allows the company to verify that the automobile going out during delivery matches the order.

Similarly, nearly all parts and components within a vehicle will have codes dot- or laser-etched onto them for unique identification purposes. Identifying these unique codes lets manufacturers verify the right part is being used during assembly while also letting aftermarket maintenance and repair businesses verify part numbers as needed. Industrial scanners or smart cameras—either mounted on a robot arm or in a fixed location—can reliably read these codes.

In addition, Zebra's software tools are needed for such applications. This includes dot-reading and OCR algorithms, along with several other options in the OCR toolbox, from font-specific dot-etched reading to the latest update, a tool for OCR. The deep learning OCR tool delivers reliable, accurate reads without the need to train numerous different texts or fonts, which simplifies setup and deployment for automotive manufacturers looking to solve VIN and OCR reading tasks.

Tires and Wheels

Solve unique tire imaging challenges

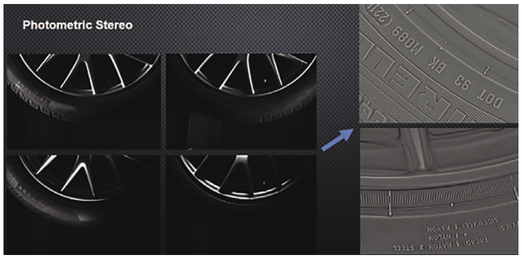
In today's build-to-order environment, each automobile on an assembly line may have different options, including for tires and wheels. Marriage of the tire and wheel is based on a specific assembly schedule, and each set of tires must match the order for a given vehicle. During final assembly, it is critical to verify that the correct tires are put on each vehicle.

Tires are positively identified by verifying the Department of Transportation (DOT) tire identification number (TIN) and the brand or model name, tire size, and other readable data on the tire's sidewall. Static sidewall information is molded into the tire and makes up part of the overall mold/die for that specific tire model. Dynamic information in the DOT TIN (such as manufacture date) is changed during the tire manufacturing process by manually placing different inserts into the mold cavity.

The main imaging challenge when using machine vision for tire identification is the challenge of imaging low contrast black-on-black graphics and print on the tire sidewall as well as variations in the graphics due to mold wear. The imaging is made more difficult by content that contains both debossed and embossed features. In typical applications, the tire also may be presented at any rotation and with some positional variation. To solve these challenges and successfully highlight the sidewall features, multi-image photometric stereo systems or 3D laser profile scanners solutions—such as Zebra's AltiZ or AltiZ 4200 3D profilers, or Zebra's 3S series 3D sensors—are often deployed.

A vision-guided robot carries a tire and wheel during the assembly process.

A photometric stereo implementation typically uses a single high-resolution camera to capture illumination of the tire surface from different angles in multiple images. Machine vision software combines these images to create a profile or "surface curvature" image of the sidewall. Alternately, a 3D laser profile scanner can acquire a full-depth image of the sidewall.



A photometric stereo imaging system captures four different images with light coming from different angles to produce an image that allows the software to read and verify codes on the tire.

Verifying tire type by tread profile may also be done during the assembly process. The tread profile or pattern can be used to uniquely identify a tire or to ensure that the same tire tread appears on the group of tires used on a specific vehicle. Tire treads can be imaged using 3D imaging systems such as laser profilers or structured light imaging sensors leveraging parallel structured light technology. The 3D tread profile image is analyzed and matched by pattern to an expected tire tread for identification or simply verified with the other tires in the group to ensure the vehicle's tires match.

Zebra GTX or VS smart cameras, as well as 3D imaging tools such as AltiZ or AltiZ 4200 profilers and 3S series 3D sensors all tackle challenging verification and inspection tasks involving automotive tires and wheels.

Machine Vision and Fixed Industrial Scanner Solutions

Iris GTX Smart Cameras

Iris GTX smart cameras feature CMOS sensors ranging from 2 to 16 MP and substantial processing power in a compact all-in-one vision system. These model edge IoT devices are capable of handling traditional machine vision workloads as well as deep learning inference.

Learn more

VS Smart Cameras and Sensors

Zebra's machine vision solutions feature a family of smart cameras available with 1.2 to 5.1 MP image sensors. From simple track-and-trace to complex quality inspection checks, you always know what's happening and can anticipate issues before they impact operations.

Learn more

AltiZ 3D Sensors

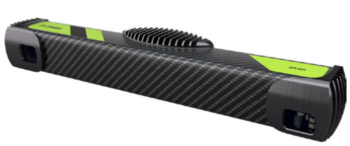
AltiZ high-fidelity, high-speed 3D profile sensors feature a dual-camera single-laser design that minimizes scanning gaps at critical surface junctures. Get 3D vision applications up and running quickly on your AltiZ by pairing with Aurora Imaging Library or third-party vision software.

Learn more

AltiZ 4200 3D Profile Sensors

Zebra's AltiZ 4200 3D profilers are distinguished by a compact single-camera design and tighter fields of view compared to legacy AltiZ sensors, allowing AltiZ 4200 models to deliver higher resolution, faster capture and richer 3D data. These sensors are well-suited for close inspection of fine details and inline inspection of adhesive beads.

Learn more



3S Series 3D Sensors

Zebra's 3S series uses Structured Light technology to deliver best-in class 3D scanning for broad range of machine vision applications. The 3S series can scan both static scenes and items in motion with sub-millimeter resolution and accuracy.

Learn more

Machine Vision and Fixed Industrial Scanner Solutions

Zebra **Aurora** Imaging Library™

Aurora Imaging Library Software

Aurora Imaging Library is a machine vision software development kit (SDK) offering an extensive collection of tools—including a new deep learning inference engine—for developing and refining vision applications. This robust toolkit helps address the severe time constraints encountered in demanding vision applications.

Learn more

Zebra **Aurora** Design Assistant™

Aurora Design Assistant Software

Aurora Design Assistant is an integrated development environment (IDE) for Microsoft Windows. Users build machine vision applications by constructing a flowchart instead of writing traditional program code. The software includes project templates to help new developers get up and running quickly as well as deep learning tools for image classification and segmentation.

Learn more

Zebra **Aurora Vision** Studio™

Aurora Vision Studio Software

Zebra's Aurora Vision Studio is a dataflow-based software that empowers machine vision engineers without programming expertise to quickly create, integrate and monitor powerful vision applications with straightforward drag-and-drop functionality.

Learn more

Machine Vision and Fixed Industrial Scanner Solutions

FS Fixed Industrial Scanners

Zebra's family of fixed industrial scanners are available with 1.2 to 5.1 MP sensors and are designed to enable automatic track and trace of every part and package. Rely on trusted decode performance as items move through your production, storage, and fulfillment operations.

Learn more

Zebra **Aurora** Focus™

Aurora Focus Software

One powerful tool controls all enterprise-wide manufacturing and logistics automation solutions, so your team requires less training and benefits from an unrivaled level of asset-management simplicity. Exclusive features such as ImagePerfect+, Golden Image Compare, Object Locate, and more put Aurora Focus in a class of its own.

Learn more

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