



Edge AI Empowers Robot Arm :

The "Intelligent Hands" in Smart
Automotive Manufacturing

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Edge AI Empowers Robot Arm

1. Global Industrial Robot Arm Development Trends and Overview

The global industrial robot arm market is undergoing significant growth and transformation. According to multiple market research reports, the market size is approximately 17 billion USD in 2024 and is projected to reach 60 billion USD by 2034, showing a strong growth trend. The main reasons are rising labor costs, expanding demand for industrial automation, and the promotion of Industry 4.0 through the combination of Smart Manufacturing and artificial intelligence with automation. Many national governments are also actively encouraging manufacturing industries to adopt automation equipment through tax incentives and subsidies, thereby driving the penetration rate of robot arms across various major industries worldwide year by year. With technological advancements and market changes facing various risks in the global supply chain, rising labor costs and the need for supply chain flexibility are also factors contributing to the increased adoption of industrial robots.

In terms of geographical distribution, the Asia-Pacific region is currently the largest application market for global industrial robot arms and is also the fastest-growing market in the future. This is mainly due to the region's rapid industrialization process, vast manufacturing base (especially in the electronics and automotive industries), strong government support for automation and industrial upgrading, and continuously rising labor costs that drive companies to adopt automation solutions. Among them, China is the world's largest single market, accounting for approximately 51% of global installations in 2023. Europe is the second largest market, and the North American market, although smaller in scale, also shows steady growth due to the continuous development of the manufacturing industry and the demand for advanced automation solutions.

In terms of application industries, the automotive industry has long utilized robot arms to enhance welding, painting, and assembly accuracy to meet the demand for high customization and quality consistency. With the accelerated development of the electric vehicle (EV) trend, the demand for robot arms in this industry is also expected to continue to grow. As global demand for consumer electronics, 5G equipment, and smart home appliances continues to rise, and investment in the semiconductor manufacturing sector increases, the electronics and electrical machinery industry is another important growth driver.

2. Major Growth Sector for Industrial Robot Arms - Automotive Industry

The automotive industry has historically been a pioneer in the adoption of industrial robot arms. Due to their wide range of uses, covering high-precision and high-risk operations such as welding, painting, assembly, and material handling, their role will become even more critical in the future, especially as the manufacturing process for electric vehicles is more complex,

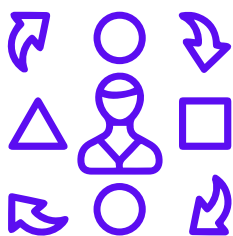


including new components such as battery modules that require robot handling for heavy loads and precision assembly; coupled with increasing product diversification and personalization, requiring extremely high demands on production line flexibility and responsiveness; these factors make industrial robot arm an indispensable core power in automotive manufacturing.

Under the highly automated nature of the automotive industry and its stringent requirements for safety, stability, and production efficiency, the successful deployment of industrial robot arms relies on adherence to a series of important technical standards and specifications: The ISO 10218 series is an international standard for the safety design and application of industrial robot arms to ensure the highest safety in industrial environment production processes and maintain consistent quality. The IEC 61508 standard emphasizes the functional safety of control systems, ensuring that

controllers can reliably perform safety functions such as emergency stops and speed limitations. In addition, to achieve seamless operation in automated automotive manufacturing production lines, effective communication between robot arm controllers and other equipment is crucial. Common communication protocols in automotive robot arm technology include EtherNet/IP, PROFINET, Modbus TCP, EtherCAT, and CC-Link. Each protocol offers different characteristics in terms of speed, real-time capabilities, and network topology. The Controller Area Network (CANbus) is also a widely used communication protocol in robot arm systems, facilitating communication between internal components of the robot arm (such as sensors and actuators). Furthermore, industrial robot arm controllers used in this field are often exposed to harsh environmental conditions, including dust, coolant, welding fumes, and other contaminants. Therefore, the IP rating specification for robot arm controllers is extremely important, and the required protection level must be defined based on different deployment scenarios to ensure the equipment operates stably and reliably under various industrial environment conditions.

Despite the increasing widespread application of industrial robot arms in the automotive industry, there are still some pain points and challenges in practical applications as follows:



1. Insufficient Flexibility and Adaptability

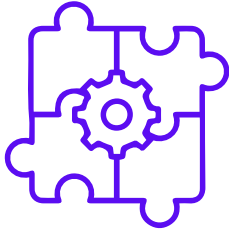
Production demands in the automotive industry change rapidly, with new car models and increased customization options leading to frequent production line adjustments. Traditional industrial robot arm are good at performing fixed, repetitive tasks. When faced with diverse product portfolios, subtle differences in part positions, or unexpected situations, they often require time-consuming and expensive reprogramming and calibration, lacking real-time flexibility and adaptability.

2. Safety Challenges of Human-Robot Collaboration:



With the rise of humans and robots working in shared spaces, collaboration (Cobots) has become an important issue. Ensuring human safety in dynamic environments is crucial, which requires robot arm to accurately and instantly perceive the surrounding environment and human movements and react immediately (e.g., decelerate or stop). Existing safety systems sometimes struggle to achieve the required reaction speed and precision.

3. Integration and Utilization Efficiency of Diverse Sensor Data :



Robot arm operations increasingly rely on various sensors (such as vision, force, etc.) to perceive the environment and workpiece status. Traditional processing methods have higher latency. How to effectively integrate the massive sensor data from different sources and formats and quickly infer and convert the information into a basis for real-time decisions by the robot arm remains a complex challenge.

By pushing computing to the edge, flexibility and adaptability can be improved, allowing for dynamic adjustment of operations to cope with changes. Low-latency edge analysis enhances human-robot collaboration safety and efficiently integrates and processes multimodal sensor data for real-time decision-making and precise control by the robot arm. Local data analysis enables predictive maintenance, reducing unplanned downtime. In addition, the edge computing platform serves as a heterogeneous data processing hub, helping to simplify the integration of AI applications for field equipment. Through edge computing, robot arms in the automotive industry are becoming smarter, safer, more flexible, and more reliable.

2.1 Application and Benefits of Industrial Robot Arms in Automotive Production Line Processes



In the modern wave of automation, especially in the automotive manufacturing industry which has an extreme pursuit of precision and quality, Robot Vision Systems have become a core technology for enhancing the intelligence, precision, and efficiency of industrial manufacturing. This system gives robot arm perception capabilities beyond traditional preset paths,

mainly reflected in two key applications. First, precise positioning and guidance: capturing the real-time position and posture of automotive components, such as chassis or car body panels, through 2D or 3D vision sensors and transmitting precise coordinate data to the robot arm controller, enabling it to dynamically adapt to variations in workpiece incoming material (e.g., different batches of stamped parts), position deviations, or complex car body assembly environments to complete challenging tasks such as high-difficulty gripping, headlamp

assembly, or precise alignment of engine components, significantly improving production flexibility and accuracy. Second, automated defect detection: utilizing high-resolution imaging and advanced image processing and artificial intelligence algorithms to quickly, objectively, and consistently identify and judge defects on the product surface, such as paint scratches, weld quality, dirt, defects, or incorrect or missing parts, etc. This not only replaces a large amount of tedious and error-prone manual visual inspection work but also identifies problems early in the production process, effectively controlling quality costs. The powerful image data processing and real-time decision-making capabilities behind this often rely on a high-performance industrial computing platform as support.

2.2 Key Applications of Robot Arm Vision in Positioning and Guidance :

The application of robot arm vision systems in "Positioning and Guidance" is extremely extensive and has profoundly changed traditional production models, especially common in the automotive industry:

1. High-Precision Pick and Place:



For randomly arranged automotive components (such as gears, bearings) on a conveyor belt or small stamped parts scattered in a bin, the vision system can quickly identify the position and orientation of the target object, guiding the robot arm to accurately grasp and place it in the designated position, widely used in logistics sorting, production line loading and unloading of automotive components.

2. Precision Assembly:



On automotive final assembly lines, the vision system guides the robot arm to perform tasks such as applying sealant and installing windshields, precise alignment of dashboard modules, screwing seats to the car body, and precision assembly of powertrains such as engines and transmissions. It can instantly compensate for minor shifts and angle deviations of workpieces, ensuring assembly precision and success rate.

3. Path Guidance and Tracking:



In continuous processing processes such as laser welding, sealant application, and chassis anti-rust coating spraying on automotive car bodies, the vision system can identify the edges, welds, or characteristic lines of the car body panels, guiding the robot arm to accurately work along complex 3D curved surfaces, ensuring the accuracy of the processing trajectory and the uniformity of the coating even if there are variations in workpiece shape or position.

4. Machine Tending:



The vision system can locate raw parts such as automotive engine blocks and crankshafts on pallets or conveyor belts, guiding the robot arm to accurately feed them into equipment such as CNC machining centers and die-casting machines, and then take out the finished products after processing, realizing the automated cycle of automotive component processing units.

2.3 Key Applications of Robot Arm Vision in Defect Detection :

In the pursuit of "zero defect" production in automobiles, robot arm vision systems play an indispensable role in the field of "Defect Detection," with applications covering all stages from components to the final vehicle off the assembly line:

1. Surface Defect Detection:



Detecting common defects on automotive car body paint surfaces such as orange peel, sagging, color difference, scratches, particles; indentations, dirt on plastic or leather surfaces of interior parts such as dashboards and door panels; and screening for defects on exterior parts such as wheel hubs and lamps.

2. Dimensional Gauging and Geometric Verification:



Commonly used in automotive manufacturing for online inspection of key dimensions of the "Body-in-White," measurement of gaps and flatness between doors and hoods, ensuring the accuracy of the car body structure.



3. Assembly Integrity and Correctness Check:

Verifying whether automotive products are assembled correctly, such as checking whether various pipe joints and buckles in the engine compartment are installed in place, and whether critical safety components such as airbags and sensors are missing or installed incorrectly.



4. Component Identification and Traceability Inspection:

Checking whether barcodes, QR codes, Data Matrix codes, or laser-etched Vehicle Identification Number (VIN) on components are clear and readable, ensuring traceability of the production process.



5. Electronic Module Precision Inspection:

With the increasing number of electronic control units (ECU), in-vehicle infotainment systems (IVI), and advanced driver-assistance systems (ADAS) camera and sensor modules in automobiles, the quality of PCB solder joints, connector pins, and the precision of component placement all require strict control by the vision system.



6. Weld and Sealant Inspection:

Inspecting the appearance and size of welds (spot welds, laser welds) on the car body structure to determine whether there are defects such as missed welds, cold welds, or burn-through; inspecting whether the sealant application is continuous, uniform, and meets the width standard.

The introduction of robot arm vision systems brings revolutionary comprehensive benefits to automated applications. In terms of precise positioning and guidance, it gives robots arms "smart eyes," enabling them to flexibly adapt to changing workpieces and complex operating environments, greatly improving operating accuracy, production flexibility, and overall operating efficiency, immediately ensuring product quality from the source, significantly reducing defect rates, rework costs, and customer complaints, ensuring the excellent quality and brand reputation of precision manufactured products such as automobiles. Overall, the deep integration of machine vision technology and robot arm not only optimizes the efficiency of individual operations but also realizes the intelligent upgrade of the production process, which is a key driver for enterprises to move towards high-efficiency, high-quality smart manufacturing and enhance overall market competitiveness.

Application Cases of Industrial Robot Arms in the Automotive Industry

3.1 Edge AI Computing Empowers Automotive Defect Detection and Polishing

In the fast-paced world of automotive manufacturing, the polishing and grinding of vehicle body panels is critical to final appearance quality. Picture robot arms in action, sparks flying as they strive to create flawless, streamlined surfaces. Yet, this high-speed, high-pressure environment makes defect detection extremely challenging. Traditional visual inspection methods, dependent on human eyes, often struggle to keep up with production speed, leading to fatigue, inconsistent standards, and missed fine flaws like micro scratches, shallow dents, or orange peel textures.

These challenges create pain points for manufacturers: low detection efficiency, inconsistent quality, high costs from rework or customer complaints, and the risk of undetected flaws damaging brand reputation. With advancements in Edge AI, intelligent robot solutions for defect detection and surface finishing are becoming the go-to choice for manufacturers. By combining machine vision with intelligent robots, edge-based defect detection enables real-time analysis of visual data during production. The system automatically detects flaws and adjusts polishing force and paths, dramatically improving efficiency and consistency.

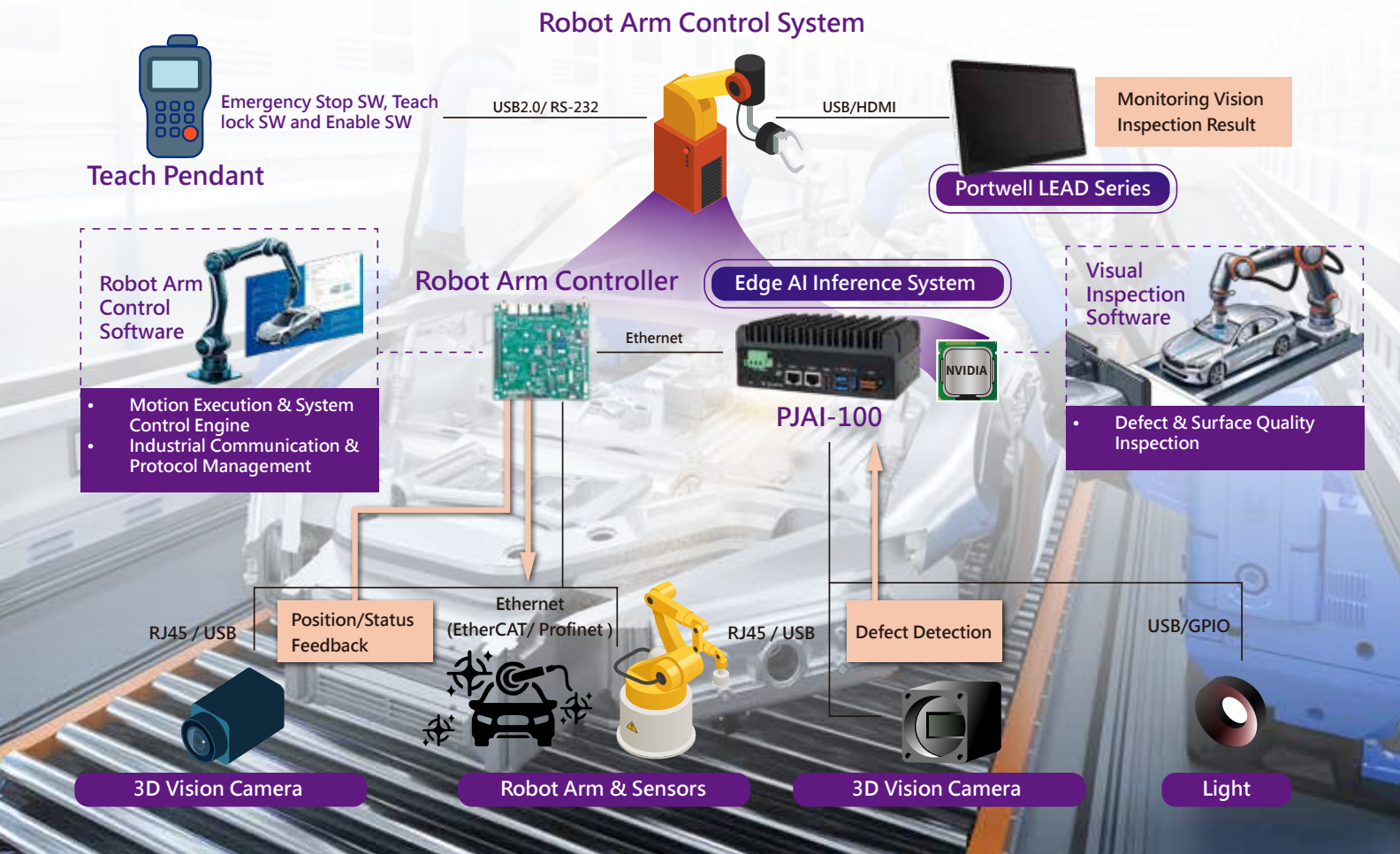
Portwell's PJAI-100 Embedded System Empowering Smart Automotive Inspection

At the heart of this smart solution is Portwell's PJAI-100 series embedded industrial computer, integrated with robot arm controllers and machine vision components. High-resolution cameras, mounted on robot arm, capture real-time surface images via RJ45 and USB interfaces. These images are transmitted to the PJAI-100 system, which is equipped with the NVIDIA® Jetson Orin™ module, delivering 100 TOPS of AI performance for real-time complex image recognition. The system identifies defects with precision beyond the human eye and sends control commands over EtherCAT/ PROFINET to the robot controller. Motors and servo drivers execute exact polishing motions, guided by 3D vision and force sensors to ensure even force and perfect contours.

Built for industrial environments, the PJAI-100 features fanless operation, wide temperature tolerance (-20°C to 60°C), and a full range of I/Os (USB 3.2, COM, CANbus), making it easy to integrate with other devices on the floor. The system supports real-time monitoring via teach

pendants and HMIs, ensuring safe and accurate operation. Its edge AI capability reduces latency and stabilizes data processing, enabling a fully coordinated and automated production line.

AI Vision Defect Detection for Robot Arm Polishing and Grinding: Automotive Industry



3.2 Edge AI Computing Drives Intelligence in Automotive Assembly and Appearance Quality Verification

In automotive manufacturing, assembly verification has always been the core of quality assurance. Previously, many car manufacturers without robot arm and AOI (Automated Optical Inspection) real-time inference systems commonly faced the following challenges: as car models diversified and assembly parts became more complex, it became difficult to distinguish between good and defective products. Furthermore, fragmented verification data collection couldn't provide strong support for subsequent quality analysis and process optimization. However, with the advancement of edge AI computing and machine vision technologies, the

integration of high-resolution industrial cameras and embedded AI real-time inference systems can now perform hundreds of inspection tasks within minutes. This not only improves the yield rate of inspections but also transforms production lines from traditional "experience-based inspection" to "data-driven intelligent verification," significantly enhancing overall quality management and production efficiency.

Portwell's PJAI-100 and PSYS-508 Embedded System Series: Building Intelligent Defect Detection Solutions for Automotive Production Lines

To meet the high precision, real-time performance, and traceability requirements of automotive assembly verification, a dual-vision inspection architecture incorporating the PSYS-508 and PJAI-100 is introduced to create a complete intelligent quality inspection environment. The PSYS-508 training server, equipped with 14th/13th/12th Gen Intel® Core™ processors, supports 128GB DDR5 memory and 7 SATA 6.0Gb/s storage interfaces. It can rapidly process vast image data from the production line and accelerate the deep training of AI models for appearance inspection and assembly verification using GPU acceleration. The trained models are then securely deployed to the edge-based PJAI-100 inference system via HTTPS/SFTP secure protocols. The PJAI-100 serves as the intelligent inference core. This system, powered by the NVIDIA® Jetson Orin™ NX SOM, boasts 100 TOPS of inference performance, enabling complex image analysis to be completed within milliseconds. Its configuration includes 2 Gigabit LAN ports, 3 USB 3.2 Gen1 interfaces, and multiple M.2 expansion options (E-Key for WiFi/BT, M-Key for NVMe storage), ensuring high-speed connection and stable communication with industrial cameras, robot arm control boards, and other equipment.

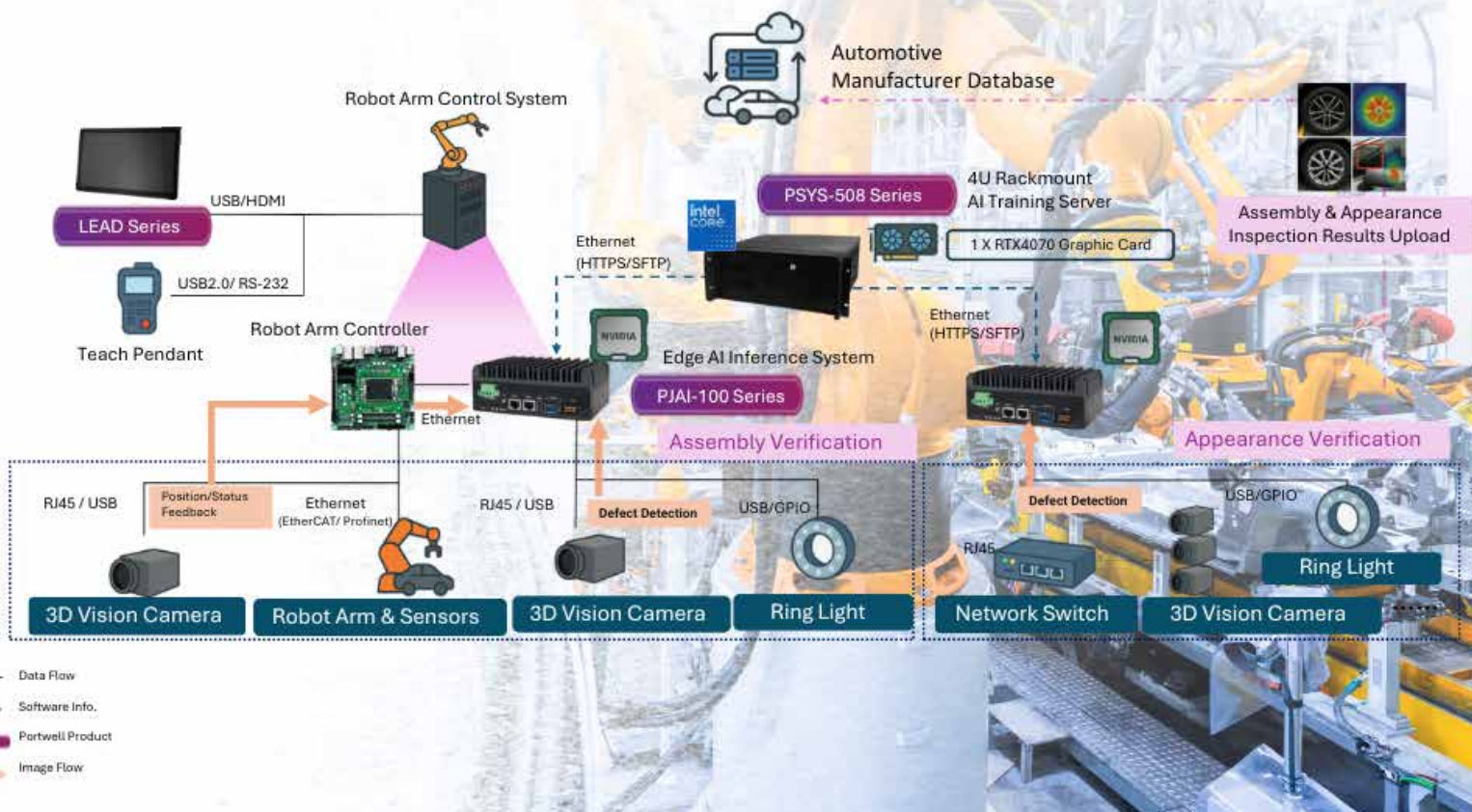
In practical applications, the entire image data flow begins at the sensing layer. During the assembly verification confirmation process, 3D vision inspection cameras capture subtle differences on surfaces such as car door trim parts and headlamp covers, and instantly infer whether their flushness and gap meet design specifications. These inspections not only ensure aesthetic quality but also directly impact airtightness and safety. Through AI inference, the system real-time analyzes images of the car body surface, gaps, logos, lamps, and other features. It automatically classifies good and defective products, and continuously learning abnormal patterns to reduce batch defects.

When the system infers an anomaly (e.g., out-of-tolerance flushness, incomplete adhesion), the PJAI-100 can send the abnormal image and structured data back to the PSYS-508, initiating AI model fine-tuning and retraining to continuously optimize inference accuracy. Furthermore, the overall architecture supports EtherCAT and PROFINET industrial communication protocols, ensuring data synchronization and real-time interoperability between cameras, robot arms,

lighting systems, HMI, and other equipment, forming a highly collaborative and intelligently aware manufacturing environment. Through the perfect pairing of the PSYS-508 and PJA1-100, these two systems work in concert to create a cycle of model training → model deployment → real-time inference → anomaly feedback → retraining, fully meeting the stringent requirements of "high-accuracy defect identification" and "high-reliability operational stability" in automotive manufacturing production lines. This solution, by instantly establishing a complete data traceability mechanism, automatically records and feeds back every inspection image and judgment result to the car manufacturer's traceable quality database, supporting subsequent analysis and process optimization, and significantly enhancing the basis for future assembly technology or work decisions.

Automotive Industry

AI Vision Defect Detection for Assembly Verification



3.3 Edge AI Computing Enhances Automotive Powertrain Component Inspection

Automotive powertrain component inspection, especially engine blocks, transmissions, and crankshafts, critically impacts vehicle performance, lifespan, and safety. These parts require

exceptional structural strength and manufacturing precision, ensuring correct positioning, defect absence, and complete sub-component presence (e.g., screw holes, oil/cooling channels, mounts). Minute flaws like sand holes, cracks, machining errors, or missing assemblies can cause catastrophic failures (power loss, leaks, safety incidents).

Traditional manual inspection of powertrain parts is inefficient and error-prone due to human factors and limited coverage of complex structures. Delayed defect detection from lacking real-time feedback increases rework costs and brand risk. Consequently, robot arm and machine vision Edge AI automated inspection systems are trending. These systems flexibly cover inspection points, enabling flaw detection, precision comparison, position verification, and sub-component completeness. Real-time inference and data feedback allow manufacturers to proactively control process quality, improving yield, enhancing production

Portwell's PSYS-508 Industrial Embedded System: Driving High-Precision Inspection of Automotive Powertrain Components

Within the intricate inspection of engine and powertrain components, the computing system serves as the core of the intelligent edge computing architecture, comprehensively driving the digitalization of quality management from sensing and inference to data feedback. The system is equipped with 14th/13th/12th generation Intel® Core™ i9/i7/i5 processors, supports 128GB of DDR5 memory, and offers up to seven SATA 6.0Gb/s high-speed storage interfaces. It can be paired with a discrete graphics card (such as the RTX4070) to effortlessly process high-resolution image streams from multiple 3D vision inspection cameras.

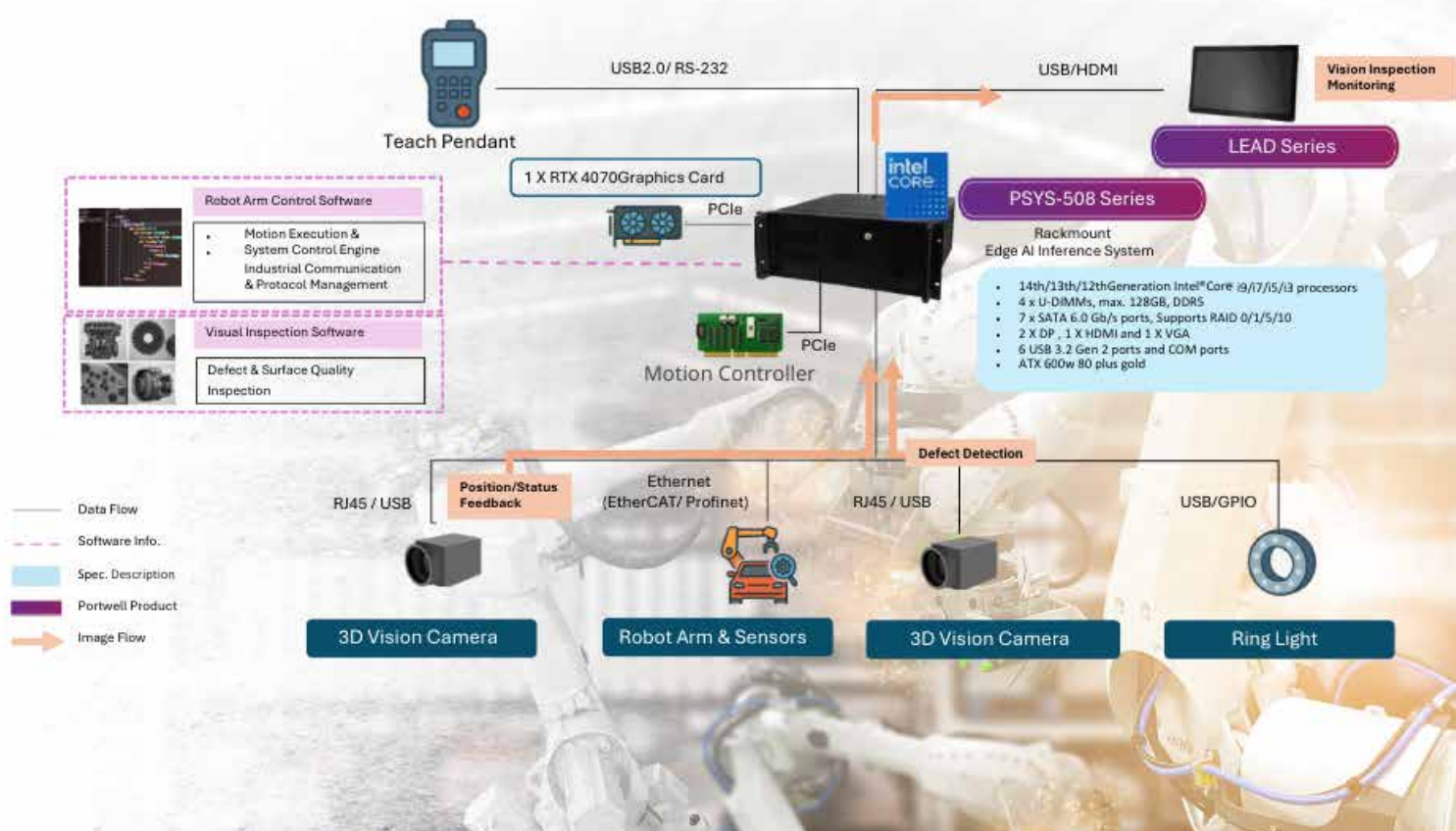
The entire inspection process begins with the 3D vision inspection cameras, while the robot arm agilely guides the cameras to critical areas within the complex cylinder block cavity, crankshaft surface, and transmission housing. Once the images are transmitted back to the edge inference system, it immediately performs defect classification, surface finish measurement, and screw hole position angle verification. Through the PCIe expansion motion control card interface within the edge inference system, the arm's micrometer-level movements are precisely driven, ensuring accurate alignment of each inspection point.

When the system detects an anomaly (such as a sand hole, misaligned weld, or surface crack), it instantly marks the defect type and location and displays the inspection results on a LEAD Series HMI via a visual dashboard. This includes defective product classification statistics, real-time yield rate curves, and defect distribution heatmaps. Operators can make quick judgments based on system prompts, and the system can be configured to automatically feed abnormal data back to the edge inference system for continuous optimization of inference accuracy.

Furthermore, the industrial inspection lighting module is uniformly controlled via USB/GPIO,

ensuring the switching of appropriate light intensity and angle at different inspection stages to enhance surface detail recognition. The overall communication architecture of the robot arm utilizes EtherCAT/ PROFINET high-speed synchronous signal transmission, closely with the inference system, HMI, and sensing equipment to create a real-time responsive, high-precision intelligent quality inspection platform. This not only improves production yield and uptime but also accelerates the automotive parts manufacturing industry's progress towards the smart factory goal.

Automotive Industry Robot Arm AI Vision Inspection of Automotive Powertrain



4. Conclusion

In modern automotive manufacturing processes, empowering robot arm with "intelligence" to achieve real-time object recognition, precise positioning, or automated defect detection is at the core of elevating automation levels. All of this relies on powerful and reliable AI computing platforms. The PJA1-100 and PSYS-508 series products each have distinct characteristics and can flexibly address the diverse AI application needs in automotive manufacturing, making them suitable for deployment near robot arms or within controller systems in automotive factories.

The PJA1-100 series performs edge AI inference tasks. It can be used for applications such as real-time object recognition, defect detection, predictive maintenance, or guiding robot arm positioning. Equipped with the NVIDIA Jetson Orin NX, its 100 TOPS of AI performance enables it to execute complex inference tasks at the edge, making it suitable for real-time processing of data from robot arm 2D or 3D vision systems. The compact fanless design enhances reliability and reduces maintenance requirements, which is crucial for long-term deployment in factory environments. The PSYS-508 supports high-performance Intel® Core™ processors, capable of handling the intensive computing tasks required for AI model inference. Its 128GB DDR5 memory capacity can accommodate large datasets. Its rackmount form factor and multiple PCIe slots allow it to support high-performance GPUs, further accelerating AI inference. It can be used to develop and deploy AI models for robot arm control and simultaneously process defect detection inference. The rich I/O ports and network interfaces also facilitate integration with various sensors, robot arm controllers, and other factory equipment, further optimizing performance for specific AI workloads. The wide operating temperature range and resistance to shock and vibration (compliant with IEC 60068-2-6 and IEC 60068-2-27 standards) ensure its reliable operation in harsh automotive manufacturing environments.

Portwell's Design and Manufacturing Services (DMS) provide end-to-end comprehensive customization support for industrial applications, covering everything from product design to production and global logistics. These services enable customers to quickly transform innovative concepts into reality while ensuring a long-term stable product supply, which is crucial in a rapidly evolving market. The products are widely used in mission-critical industrial environments, including automation, medical equipment, and railway systems. The company's solutions demonstrate exceptional stability, precision, and reliability, making them particularly suitable for automotive industry applications requiring uncompromising performance and reliability. As a leading provider of edge computing and industrial computer solutions, Portwell is not only at the forefront of technological trends but also leverages its extensive DMS expertise to be a trusted partner. Looking ahead, Portwell will continue to place innovation at the core of its strategy, providing cutting-edge, high-performance solutions to help customers overcome technical challenges and achieve sustainable growth.





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