CYIENT

AI-ENABLED AUTOMATIC VISUAL INSPECTION SYSTEM

Discover how AI-powered automatic visual inspection systems are revolutionizing the quality assurance process in manufacturing by efficiently identifying product defects

CONTENTS

Abstract

This white paper delves into the implementation of an AI-based Automatic Visual Inspection System for the manufacturing industry, focusing on how Microsoft Azure AI Custom Vision Service can be applied to specific use cases. It provides a detailed overview of the system's architecture, key Azure AI components, configuration, and operational workflow. Additionally, it demonstrates how this innovative approach enhances defect detection accuracy and reliability, ultimately boosting operational efficiency. By examining standards, benefits, limitations, models, and use cases, this paper offers valuable insights into the potential advantages and challenges of adopting AI-driven visual inspection systems in manufacturing.

Introduction

During the verification and validation process on the shop floor in any manufacturing industry, the QA team uses multiple techniques. One common technique is visual inspection where technicians examine the test item, usually with the naked eye and sometimes with simple tools such as magnifying glasses. This non-invasive method does not require measuring equipment and is often used to assess, the general condition of an item under test. Technicians check for missing components, misalignment of installed parts, surface wear, tears, cracks, deformation, corrosion, or other types of damage.

Although simple, visual inspection requires trained technicians to conduct a thorough examination, making it a time-consuming task. This method has been standardized under DIN EN 13018 (General Principles of Visual Inspection).

Since manual visual inspection is time consuming and less accurate, Automatic Visual Inspection System (AVIS) have become increasingly popular. Such systems also align with Smart Factory requirements.

What is an Automatic Visual Inspection System?

An AVIS uses sensors to capture the images of test objects from various angles. These images are then analyzed using image processing and analysis software to detect any defects. The visual inspection software, based on image analysis, provides the test result in the form of either "Pass" or "Reject". Many advanced software can also highlight and provide detailed information about the identified defects. The following figure represents a simple block diagram of an Automated Visual Inspection System.

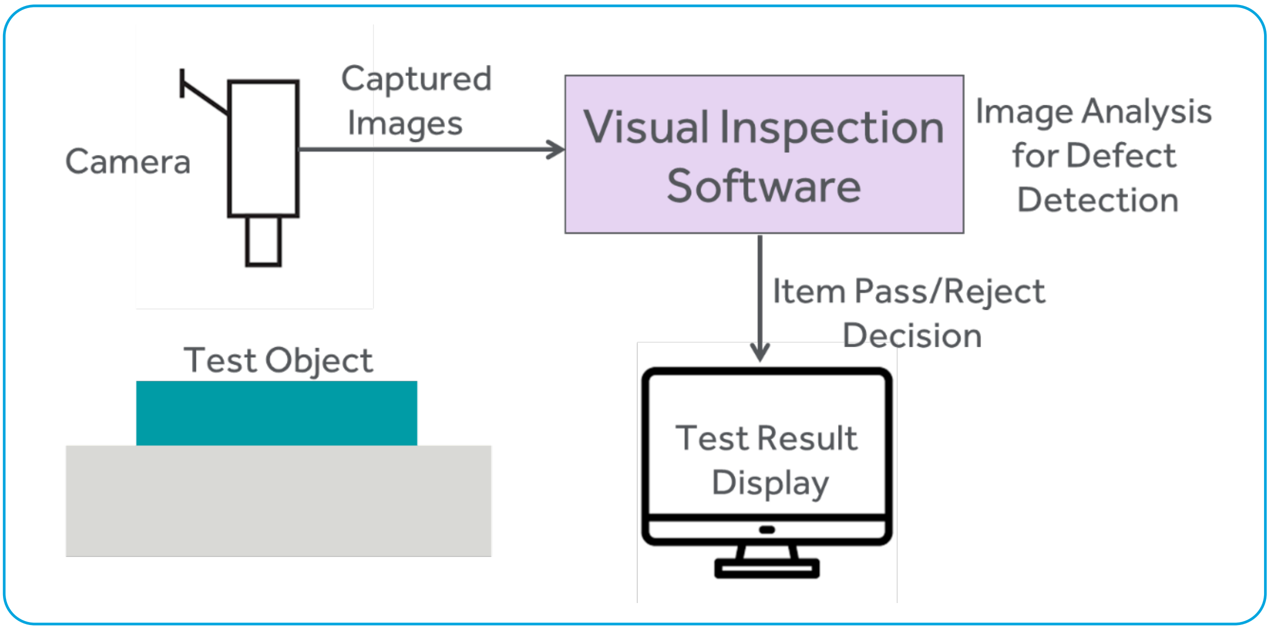
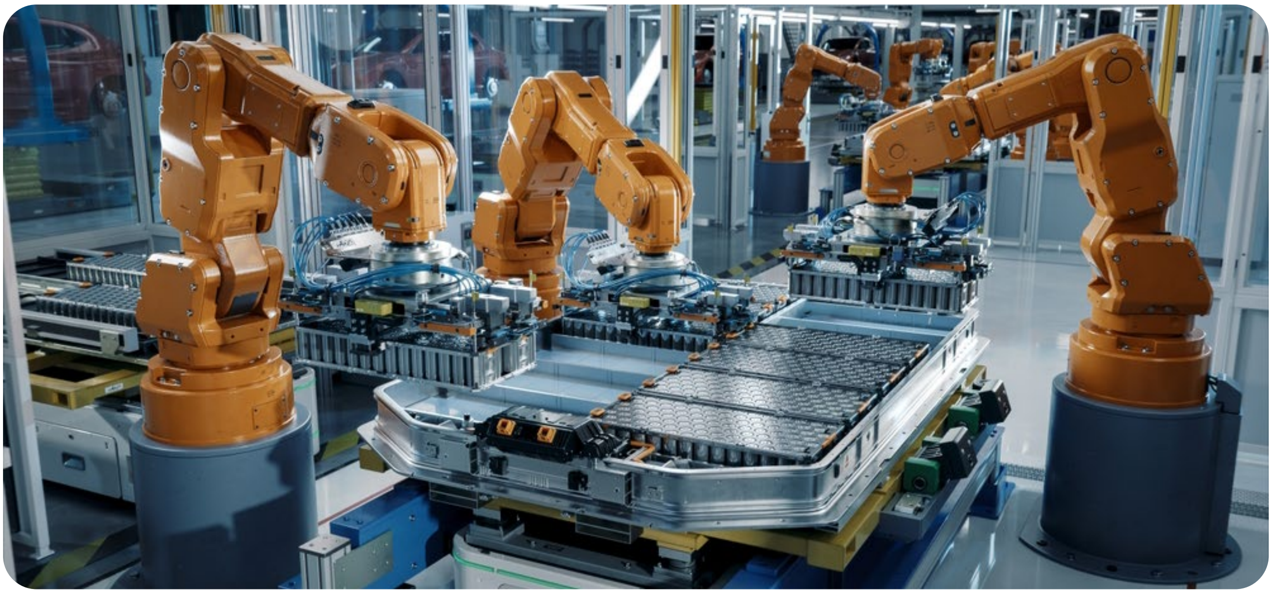


Figure 1: Block Diagram of an Automated Visual Inspection System



AVIS primarily relies on image analysis techniques and algorithms. The entire operation involves several processes including image acquisition, image enhancement, image segmentation, image feature selection, feature classification, and feature matching. Typically, the following algorithms, transforms, methods, and techniques are used during image analysis and defect detection:

Edge and Line Detection

Sobel, Canny, Prewitt, Roberts Cross, Canny- Denche, Hough and Differential Transform etc.

Corner Detection

Level Curve Curvature, Harris Operator, FAST, SUSAN, Shi, and Tomasi etc.

Blob Detection

PCBR, Laplacian of Gaussian (LoG), Determinant of Hessian (DoH), Difference of Gaussians (DoG), Ridge Detection, and Structure Tensor etc.

Affine Invariant Feature Detection

Affine Shape Adaptation, Harris Affine, Hessian Affine etc.

Scale Space

Scale -Space Axioms, Pyramid etc.

Feature Description

SIFT, HOG, GLOH, LESH, SURF etc.

Based on when the image analysis is performed AVIS can be classified into the following categories:

Online AVIS

Images of test object are captured and analyzed, with the results displayed after a slight lag

Offline AVIS

Images of test object are captured first and then processed offline for defect identification

Real-Time AVIS

Images of test object are captured and analyzed in real-time to display the test results. This system is commonly used in mass manufacturing, where test objects move continuously on a conveyor belt, requiring immediate action.

With the rise of Industry 4.0, there is a growing demand for AVIS systems that leverage cutting-edge tools and technologies such as Artificial Intelligence (AI).

Let's now take a deeper dive to explore the overview and implementation of an Azure AI-based Automatic Visual Inspection System.

AI-based AVIS

We have already seen that image analysis is a critical component in any AVIS to determine the defects. Image analysis involves multiple stages in image processing making it a complex task. Implementing image analysis algorithms through programs can be challenging. However, AI-based image analysis offers numerous advantages including faster processing and higher accuracy. The following AI techniques are typically employed in implementing AVIS.

Artificial Neural Network (ANN)	Fuzzy-Neuro-Wavelet (FNW)
Convolution Neural Network (CNN)	Wavelet based Neural Network (WNN)
Fuzzy Min Max Neural Network (FMMNN)	Neuro- Wavelet (NW)
Fuzzy Logic	Genetics Algorithm (GA)
Neuro-Fuzzy (NF)	Neuro-Genetics Algorithm (NGA)
Neuro-Fuzzy-Wavelet (NFW)	ANFIS
Fuzzy-Wavelet (FW)	CANFIS

For image classification models, a set of training and test images are required. The training image set contains images of test object without any defects, while the testing image set includes images of the test object with various defects. A CNN-based inspection model facilitates advanced learning from defective images, allowing AVIS to detect and classify defects in different environments.

It is important to note that in AI-based AVIS implementations, the accuracy of defect detection and the overall system performance depend heavily on the AI techniques employed. The selection of an AI Technique is determined by the specific use case and defect detection requirements. An AI technique that is effective for detecting a particular type of defect may not be equally effective for other use cases. Choosing the right AI technique depends on:

Type of AVIS
(i.e., Online/
Offline/Real Time)

Test object

Size of test object under inspection

Location of inspection and illumination conditions

Image acquisition rate, image resolution, and image type

Due to its flexibility and ease in implementation and deployment, AI-based AVIS is widely used in manufacturing and production for product quality assurance, inventory management, and automated defect detection. AI systems can be trained to identify a wide variety of defects specific to different applications and use cases. Some of the detectable defects include:

Detection of foreign object

Color discrepancies

Detection of surface defects, such as wear, tear, deformation, cracks, and scratches

Weld joint flaws (porosity, cracks)

Heat treatment inconsistencies

Misalignments, missing components, missing objects

Many cloud platforms, such as Azure, AWS, GCP, offer AI services that can be used to implement visual inspection system with minimal configuration and programming. Using cloud AI services to develop AVIS offers several advantages, as many low-level functions - such as selecting the right AI techniques, building and training models, and designing the user interface—are handled by the cloud platform itself. Let us now delve deeper into implementing AVIS using MS Azure's AI Custom Vision Service.

Azure AI enabled AVIS

AI Custom Vision is a part of MS Azure AI Services. The cloud-based Azure AI Vision service provides developers with access to advanced algorithms for processing images and extracting information. Custom Vision enables users to define their own labels and train custom models to detect them. It can be accessed through a client library SDK, REST API, or through the Custom Vision web portal. By uploading an image or specifying an image URL, Azure AI Vision algorithms can analyze visual content in diverse ways, based on inputs and user configurations.

Please refer to the following figure, which presents a high-level block diagram of an Azure AI-based AVIS. While we have considered an Azure cloud-deployed AVIS, containerization allows for, the creation of portable models that can also be deployed on edge devices. Vision inference models can be trained in the cloud, containerized, and used to build custom modules for Azure IoT Edge runtime-enabled devices. Deploying vision AI solutions at the edge yields significant cost and performance benefits.

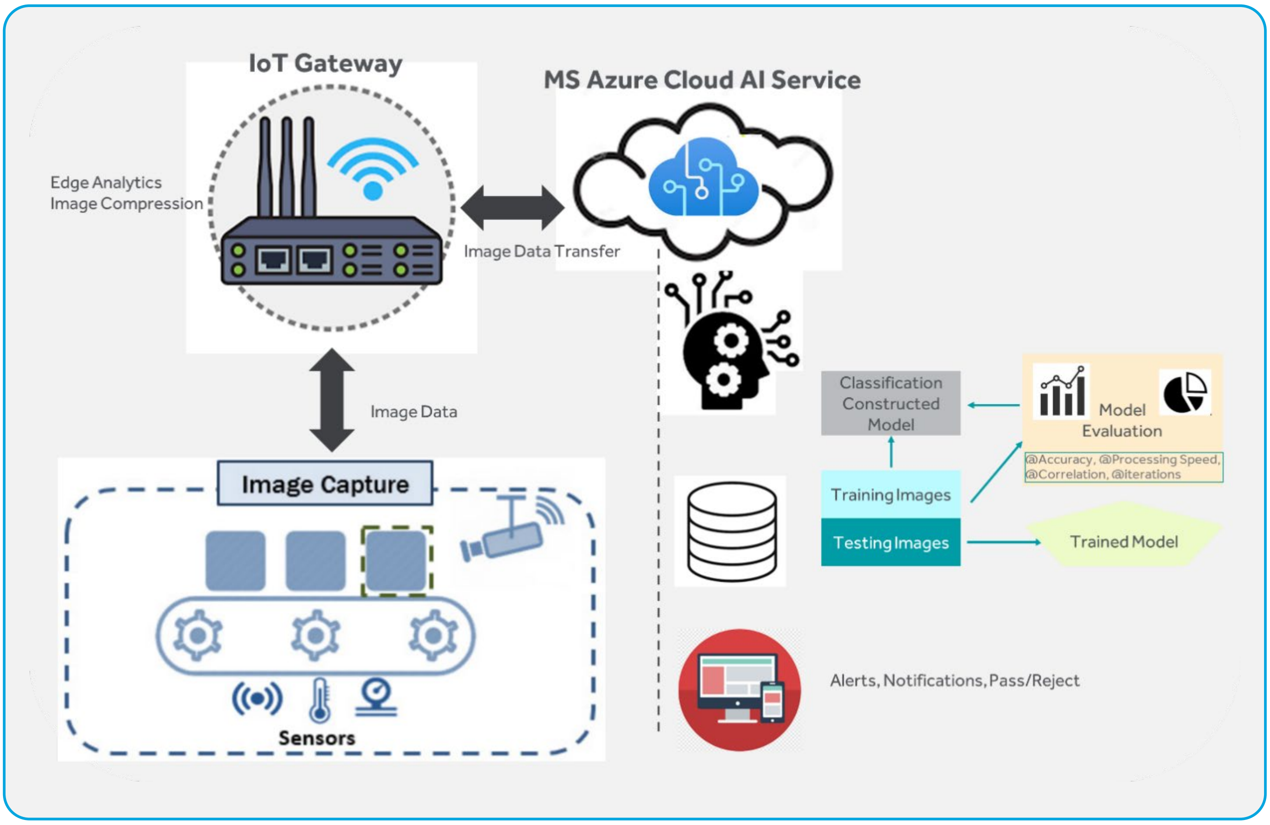


Figure 2: High Level Block Diagram of MS Azure AI-based AVIS

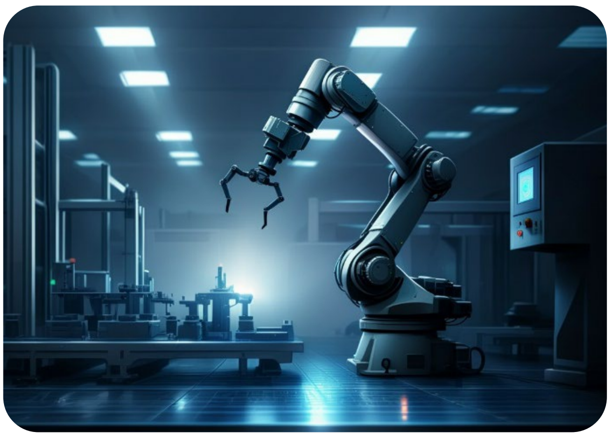
Before starting with any AI-based AVIS implementation, it is necessary to identify the end purpose and the application areas where the system will be deployed. For this basic implementation we have considered a simple problem statement: Inspecting the outer enclosure (10CM x 8 CM x 6 CM) of a finished product, which has 8 screws, to automatically detect whether all screws are properly fixed on the enclosure cover. Please refer to Figure 3.

The finished products will be placed on a moving conveyor, and a suitable resolution camera will be needed to capture images of the products. Please note that for detecting fine defects in complex assemblies, high-resolution, high-quality images are necessary, which requires a good camera. However, considering the current problem and the dimensions of the test object, a low-cost USB camera with a resolution of around 2 MP will be sufficient. The camera communication interface should be selected based on the IoT gateway and budget. Since USB cameras are low cost and widely supported by many IoT Gateways, we recommend using a USB interface camera for this application.

Figure 3: Test Object

To transfer the captured images of the test object to the cloud-based AVIS, a suitable gateway is required. The selection of the gateway will be based on following key parameters.

- **Supported communication interface for communication to the camera and the cloud**
- **Number of communication ports to support multiple cameras/sensors**
- **Edge analytics capabilities**
- **Local storage capacity**
- **Cost**



Considering the camera's communication interface, the connection to the Azure Cloud instance, and the image storage and compression requirements, any low-cost enterprise gateway would be suitable for this purpose. We have selected Cyient IoT Gateway 5400 for this implementation as it offers a USB 2.0 communication interface, ample local storage, 2 GB of RAM, and a comprehensive communication stack (Ethernet, Wi-Fi, 5G, LTE, LORA) for secure cloud connectivity. It also runs on a Linux operating system, supporting advanced processing and edge analytics. Furthermore, Cyient IoT Gateway 5400 is Azure Certified, making it an ideal choice for this application.

As shown in Figure 2, the USB camera will be positioned on a pole that it is perpendicular to the conveyor belt, providing a clear view of the test object. The camera is connected to a nearby IoT Gateway via a USB Cable. The camera captures live images of the test object, and the application running on the IoT Gateway collects the image data, performs image compression and sends the time stamped, compressed images along with an image ID to the Azure Cloud Platform over an HTTPS Connection.

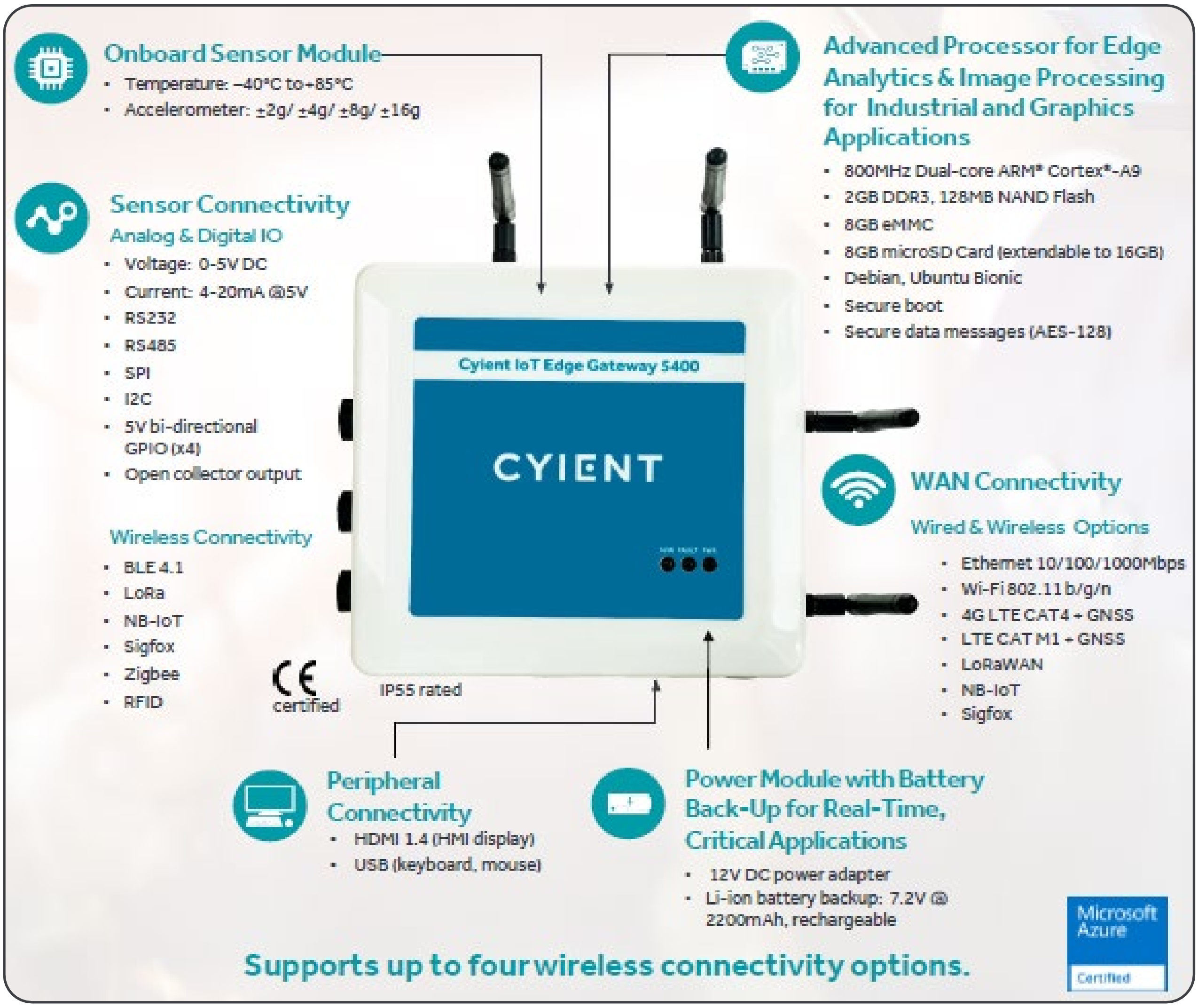


Figure 4: Cyient IoT Gateway 5400 – Azure Certified Gateway

The Azure Cloud Platform facilitates the Azure AI Service. To use this service, we will need to configure them. The Azure AI Custom Vision Service, a part of Azure AI Service, hosts the Custom Vision Service Models.

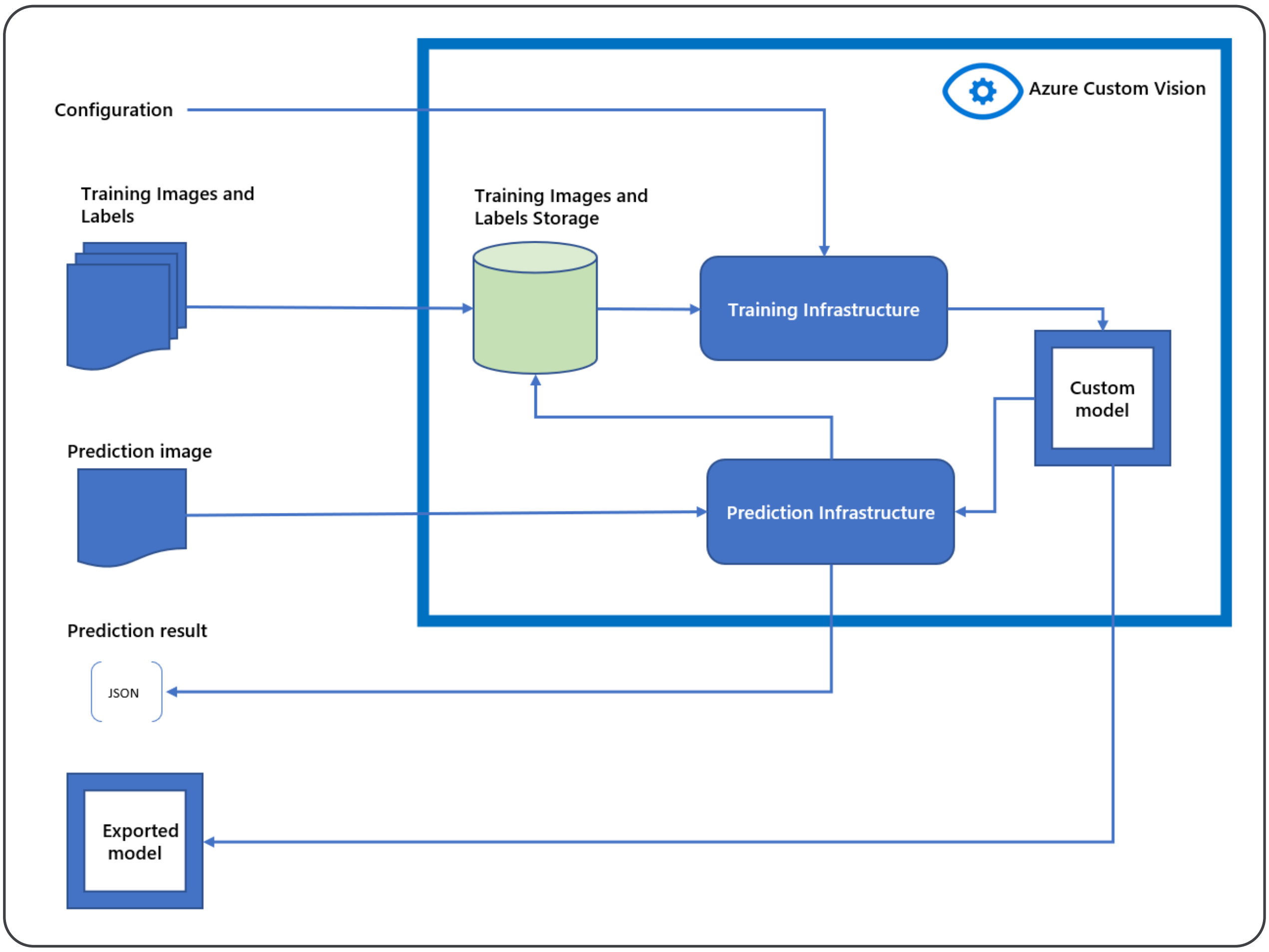


Figure 5: Azure AI Custom Vision Data Process Model (Source Microsoft Learn)

The data sets used by Custom Vision AI model are as follows.

Training Images: These are the customer-supplied images that cover various categories of defects, as well as images without defects. The images are labeled and used for training base models. Once the project is created, these images are uploaded and stored in Custom Vision Service. For the present implementation, we have included images showing the enclosure with all 8 screws intact, as well as images with some screws missing. Refer to Figure 6.

Training Labels: These are metadata generated from the data labeling, which annotates the training images. Examples include “Perfect Board”, “Defective Board”, “A Screw Missing”, “B Screw Missing”, “C Screw Missing”, “D Screw Missing” etc. Refer to Figure 10.

Prediction Images: These are the images of the test object captured by the camera, that require defect identification. These images are received at the cloud platform and sent to the Custom Vision service for prediction. After processing, the images can be stored and associated with the project for further labeling and training. Refer to Figure 7.

Prediction Results: These are the results produced by Custom Vision after running inference on prediction images using the trained model. These results are then linked to the corresponding prediction image to identify the defect. Refer to Figure 11.

Custom Model: This is the model trained on the labeled training images and tested with the prediction images. The model can be hosted within Custom Vision and used with new prediction images. Additionally, this model can be exported for embedding into AI Application.

Figure 6: Training Images

Note: Each Enclosure image is a separate Image.

Figure 7: Prediction Images

As shown in Figure 5, the Custom Vision Service requires training images and labels for training through transfer Learning, to generate a custom model tailored to the specific use case. Refer to Figure 8, which presents the model training interface. The custom model can be used for inference with prediction images, and these images can be stored for future training iterations to further improve the custom model.

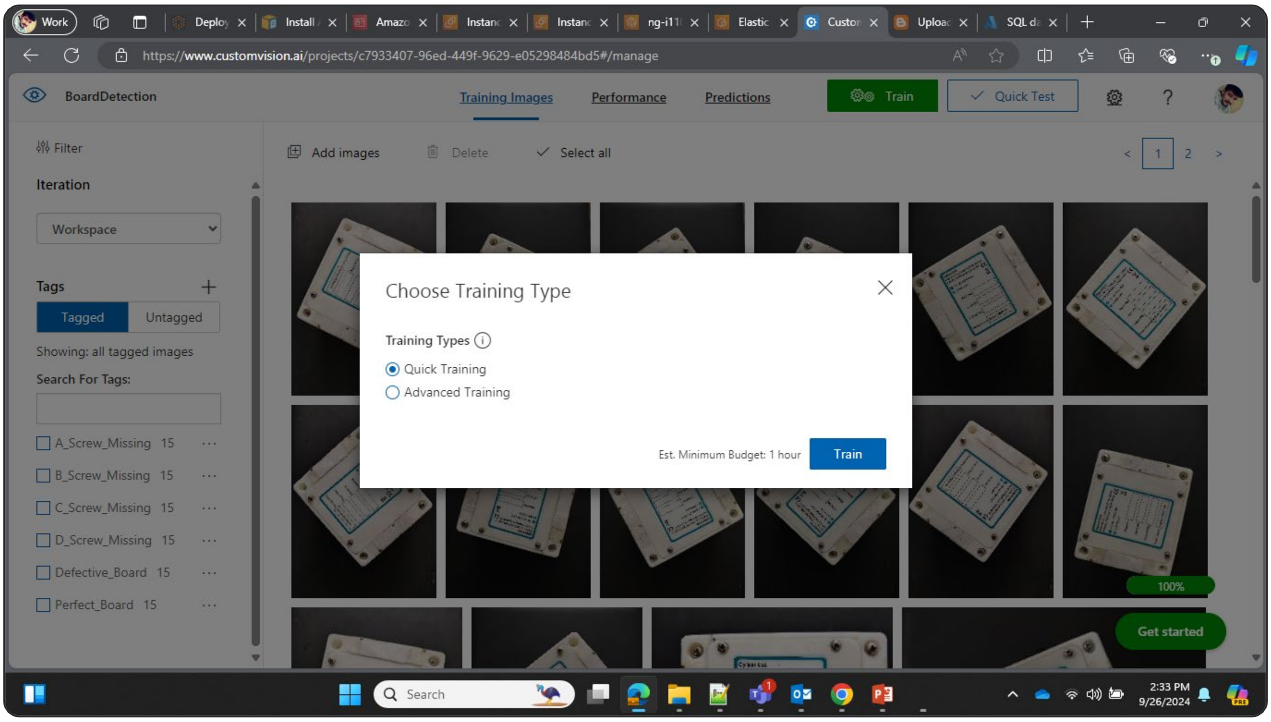


Figure 8: Model Training

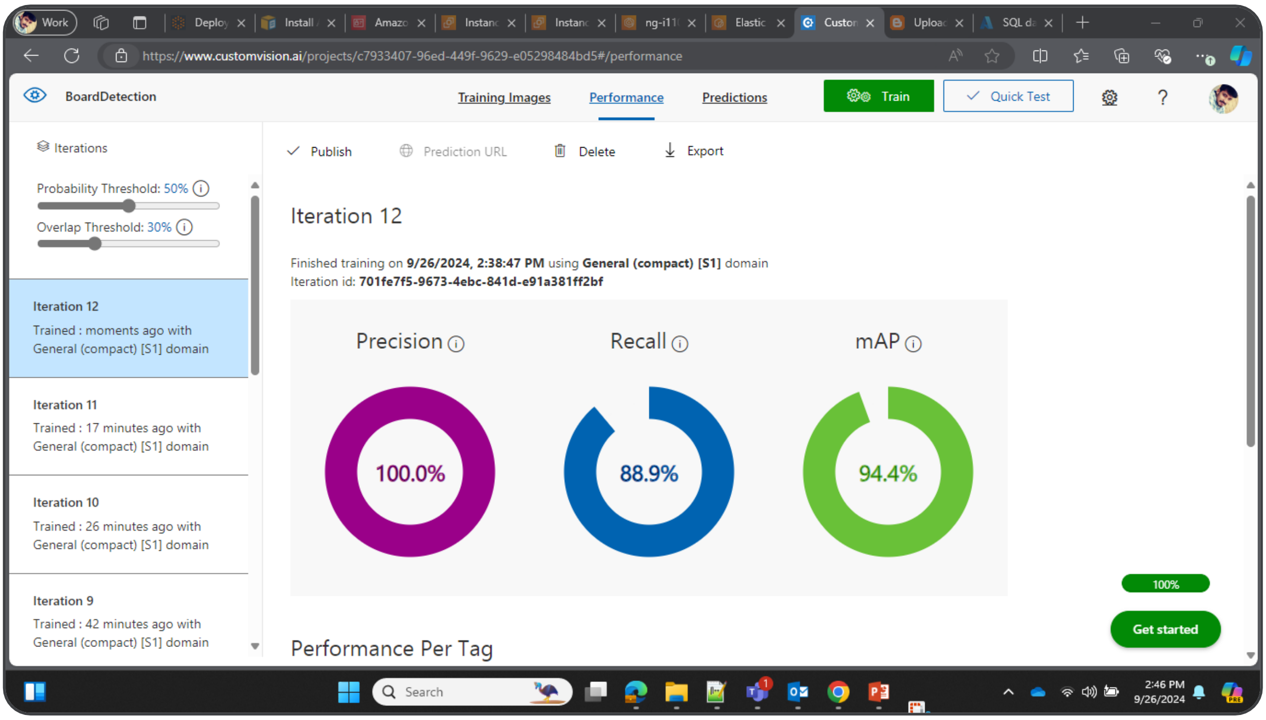


Figure 9: Model Training Iterations Result

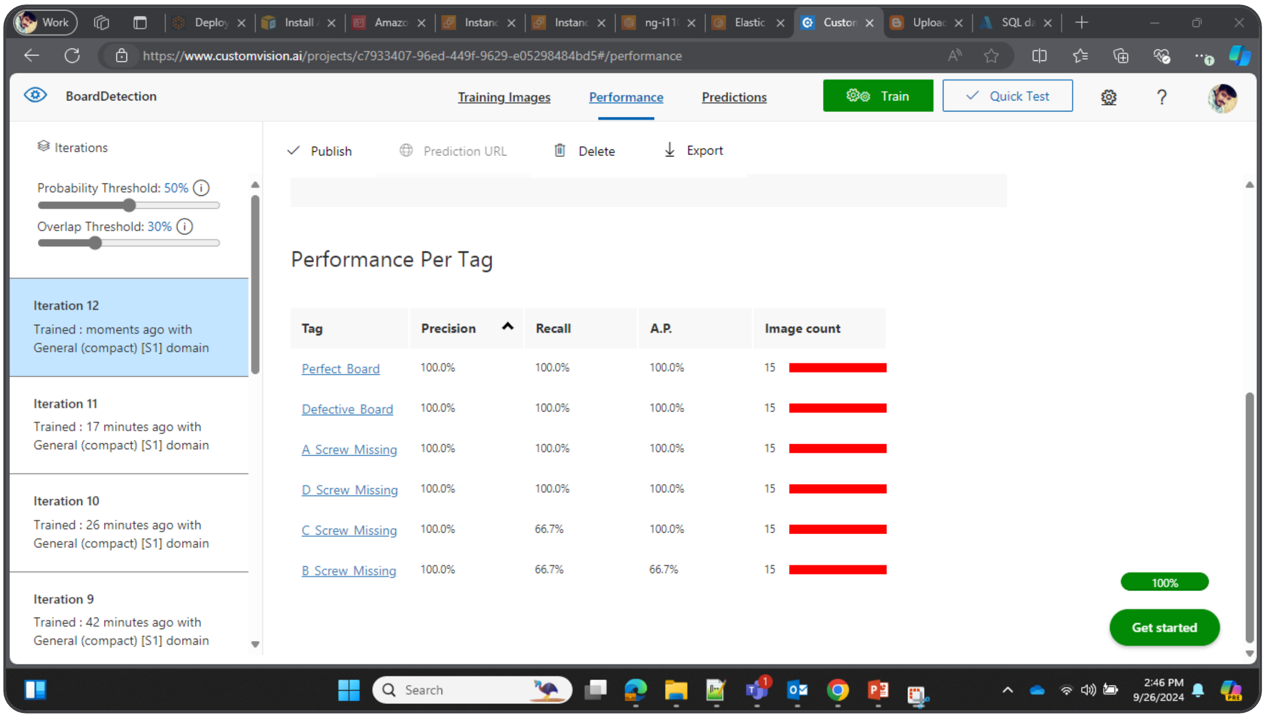


Figure 10: Model Training Iterations Result with Training Labels

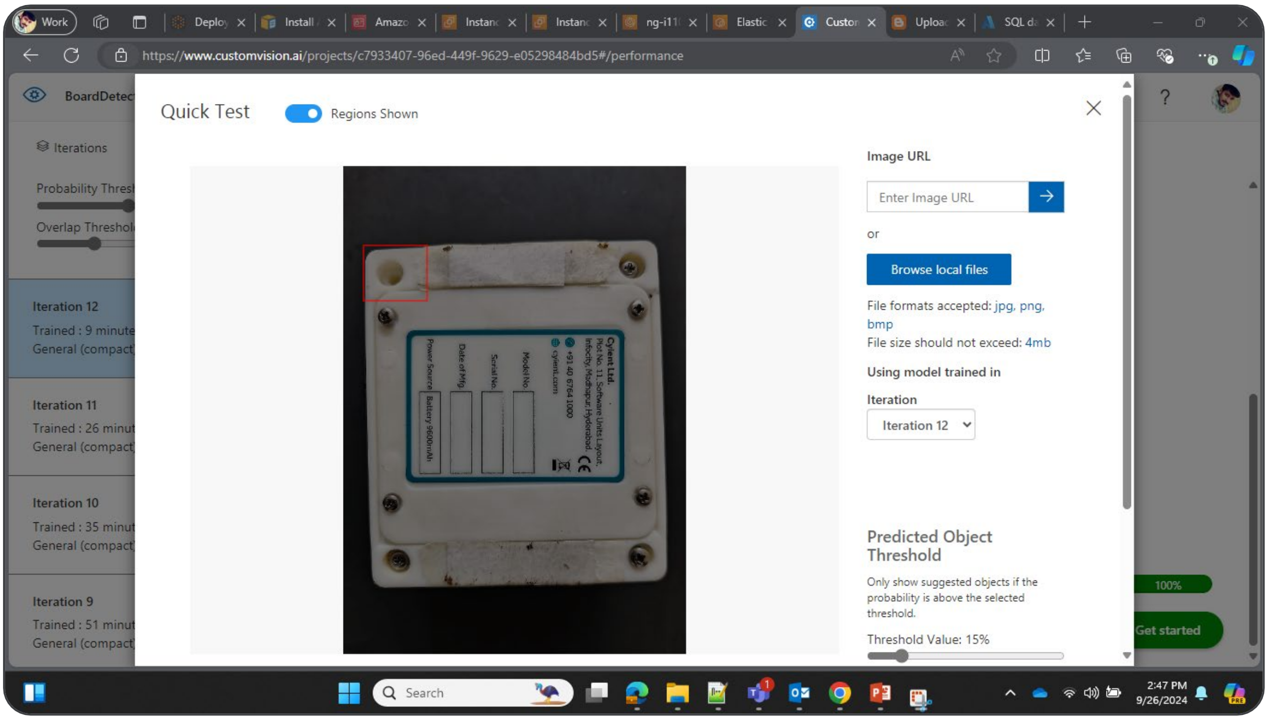


Figure 11: Prediction Result with Prediction Image

Once the Custom Vision model is trained and evaluated, it is essential to further improve it by deploying the model and testing it regularly with various prediction images to verify its accuracy. Only when the model consistently meets the required standards should it be integrated into the full system.

The AI Custom Vision model we developed to detect missing screws in the enclosure required a few hundred training images, including images under both ideal and harsh conditions, as well as those showing missing screws. We ensured that the images captured the enclosure from various angles to reflect practical conditions for training the model. The model was then further refined by running multiple iterations with additional prediction images. After thorough testing, we observed that the model's predictions - identifying missing screws and classifying perfect boards – were nearly 100% accurate. Additionally, the results were fast, comparable to the performance of real-time AVIS. Refer to Figure 11.

Advantages of MS Azure AI Custom Vision Service

Vision Customization

The model can be customized to recognize specific objects tailored to the use case under consideration.

Intuitive Model Creation

The image identifier can be easily built using a simple and user-friendly interface

Flexible Deployment

AI Custom Vision can be deployed either in the cloud or on edge devices using containerization.

Advantages of AI-based AVIS

- Non-destructive inspection
- Faster prediction with real-time decision-making capability
- Detail reporting and analysis
- Accurate and reliable
- Cost-effective
- Highly efficient
- Secure
- Independent of environment

Limitations of AI-based AVIS

While AI-based AVIS does not have any major limitations, the accuracy of defect identification depends heavily on the quality of the training images and the AI algorithm used to train the model. If the model is not professionally trained and thoroughly evaluated, it may produce incorrect predictions leading to inaccurate results. Deploying such an AVIS in a real production environment could result in poor product quality and deficiencies in the final products.

Conclusion

AI is a rapidly advancing field with diverse applications and exciting prospects. AI-based AVIS are more intelligent, versatile, and be can easily integrated into various industries, leading to increased automation, efficiency, and productivity. These systems ensure that defects are detected early in the production process, reducing waste, rework costs, and saving time and resources. Additionally, they provide valuable data analytics to further enhance operations.

Azure AI-based AVIS implemented for detecting missing screws and identifying good and defective enclosures, was highly effective in serving its intended use case. The application demonstrated perfect accuracy, and the results were produced quickly enough to make it suitable for quality assurance in a continuously operating plant. the system also proved flexible, allowing for the detection of multiple types of defects by providing appropriate training images and labels, making it easy to train and evaluate the custom model.

AI-based AVIS aligns with the Smart Factory framework and will play a critical role in modern manufacturing industries, operating in accordance with Industry 5.0 practices and guidelines.

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Dr. Dipak Gade, is the Global Head of IoT and Manufacturing Operations Management Practice at Cyient. He has around 24 Years of experience in software design, development, testing, review, delivery, systems engineering, and program management. Dr. Gade has led various projects in IT, embedded software, industrial automation, mining, M2M, digital manufacturing, IoT and cloud computing. He assists global customers with the successful implementation of Smart Factories, digital transformation and Industry 4.0 initiatives, leveraging his expertise in industry and process automation. He holds a Post Doctorate in Computer Science and Engineering and an alumnus of IIM Calcutta.

About Cyient

Cyient (Estd: 1991, NSE: CYIENT) partners with over 300 customers, including 40% of the top 100 global innovators of 2023, to deliver intelligent engineering and technology solutions for creating a digital, autonomous, and sustainable future. As a company, Cyient is committed to designing a culturally inclusive, socially responsible, and environmentally sustainable Tomorrow Together with our stakeholders.

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