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# VALIDATION STRATEGY FOR INDUSTRIAL 4.0 AI/ML MODEL FOR VISION-BASED QUALITY CONTROL

# Introduction

The Industrial Automation, Manufacturing and Automotive domains are at the edge of Industry 4.0, transitioning into Industry 5.0 by incorporating advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT). This technology shift enables industries to enhance high-end, safety-critical applications including vision-based quality assurance systems. Vision-based quality checks use AI and ML models to ensure compliance with quality standards and improve overall production efficiency. As customer demands evolve, factory floor environments require quality checks at every stage of the manufacturing process. Vision-based AI/ML models utilize advanced image processing techniques, deep learning algorithms, and edge computing to detect defects in real time, reducing manual inspection time and errors. Their scalability and adaptability allow deployment across various manufacturing domains, ensuring performance, predictability and reliability.

## KEY HIGHLIGHTS OF THIS SOLUTION:

### Accuracy

The AI/ML model delivers an accuracy of up to 98% based on the supervised training using product specific historical data.

### Cost Efficiency

Directly contributes to OPEX cost reduction.

### Input-Driven

Models are trained to work with specific product inputs, ensuring high quality output.

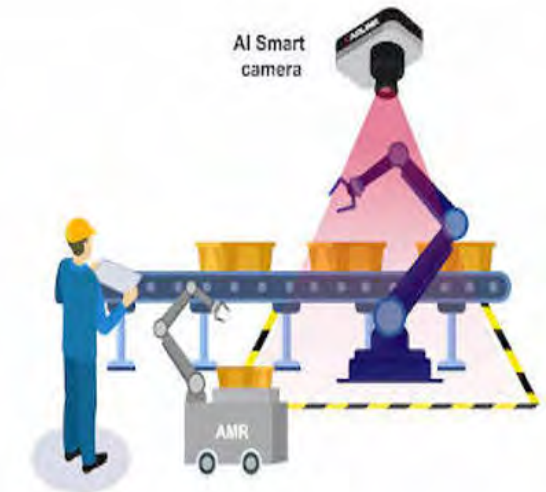
### Scalability

The solution can be deployed on the edge or in the cloud based on customer requirements with scalability designed as a core factor.

# Challenge

Integrating technology from the IT sphere into the OT sphere is one of the toughest challenges due to software and hardware compatibility, cybersecurity concerns, and the need for predictability. The key to overcoming this challenge lies in implementing the right validation strategy for technology.

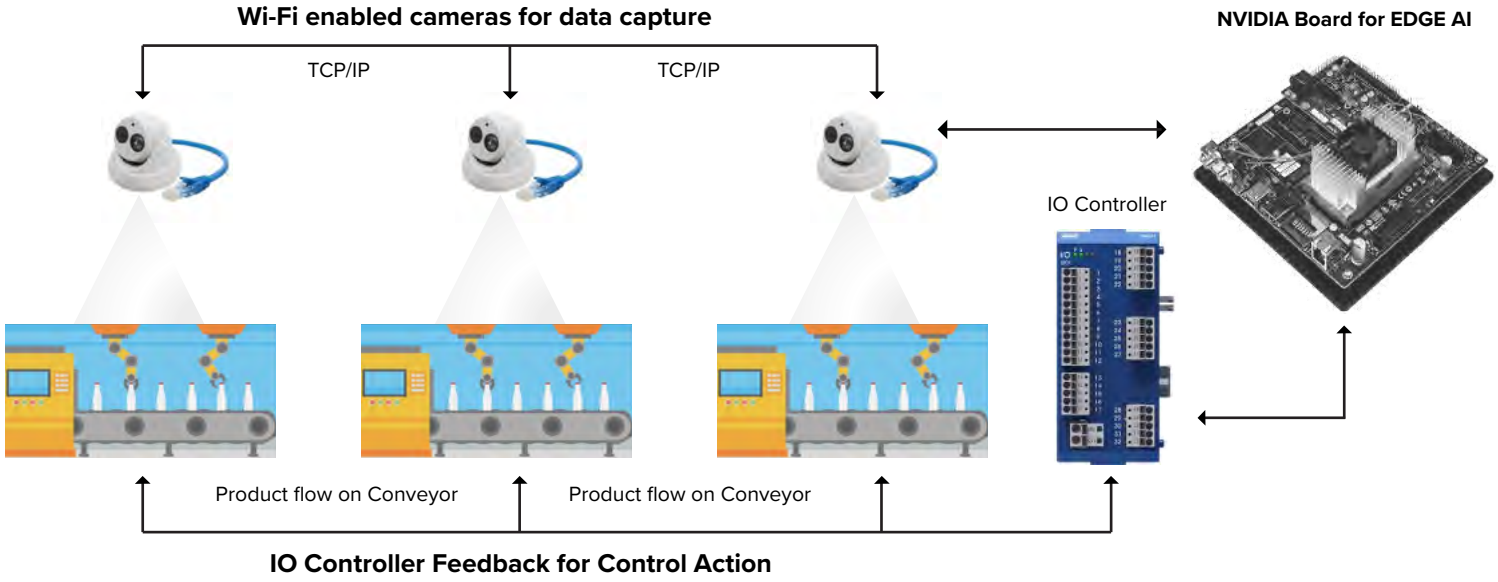
In this whitepaper, we explore the AI-driven validation strategy to address the concerns and ensure the selection of the right AI/ML model.



# Definition of the Project

In the Industry 4.0 era, vision-based quality checks powered by NVIDIA's AI ecosystem offer a ground-breaking approach to automating defect detection on the factory floor. With NVIDIA Jetson edge devices, DeepStream SDK, and optimized AI models, manufacturers can achieve real-time, high-precision inspections directly on the production line. This solution leverages advanced computer vision and GPU-accelerated processing to ensure constant quality, lower operational costs, and increased productivity. Whether detecting scratches, misalignments, or other anomalies, NVIDIA's scalable platform sets a new benchmark for smart manufacturing.

NVIDIA provides both hardware and software for vision-based quality checks on the factory floor. The Jetson Xavier Orion Nano, integrated with a high-resolution camera, can be connected to a secure industrial Wi-fi network for seamless server communication.




## Use Cases

- Industrial + Manufacturing
- AI vision-based quality check
- Industrial AI-based predictive analysis

## Hardware & Software Needs

- NVIDIA Jetson Dev Kit with accessories
- IP-based cameras
- IO Controller

## Dev Activities

- Environment setup using NVIDIA Board
- Algorithm identification for image analysis
- Integration of the camera module to Jetson
- Image processing – as needed by the algo
- Feedback on the quality check back

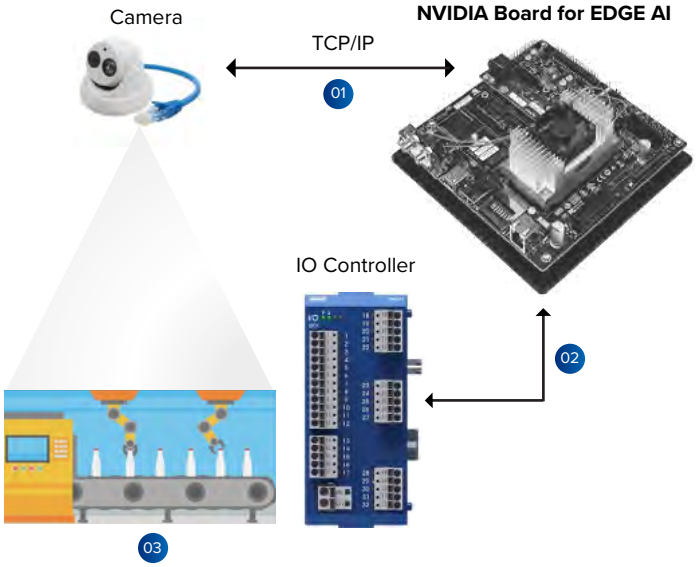
## Testing & Test Automation

- Test plan definition
- Augmentation model for test data generation
- AI model testing & automation
- Application validation

# Validation Strategy

Identifying the right strategy for quality control is essential for factory floor quality checks. A hybrid validation model, combining real and simulated environments ensures comprehensive testing. The following validation strategy outlines the in-lab test bench approach for validating the AI/ML software model used in quality checks leveraging the test automation using the open-source library. This test strategy does not cover the hardware, camera or security aspects of the use case.

## REAL WORLD

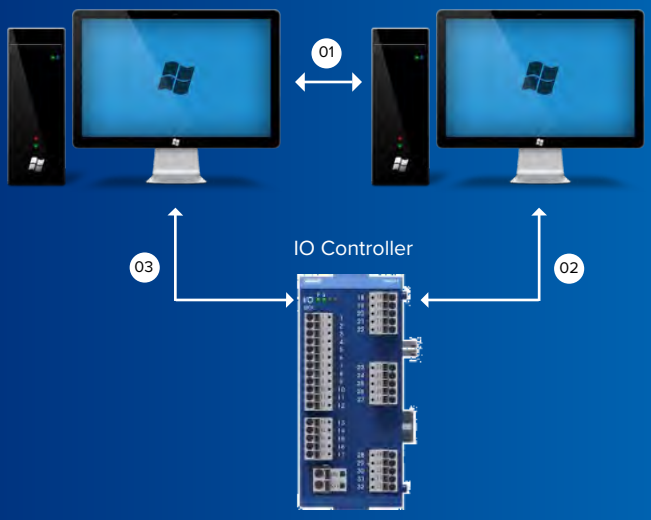



01 Step one camera capture the image of the bottle & send the image to EDGE AI

02 EDGE AI checks the quality & sends a signal to the IO Controller to move on

03 IO Controller gives a command to the motor to move on

## IN LAB




01 The image generator AI tool creates a good quality image of the bottle & sends it to the Edge AI.

02 The Edge AI checks the quality & sends a signal to the IO Controller.

03 The IO Controller gives a command to the motor.

04 The image generator AI tool creates an image of the bottle with defect.

# Test Validation & Automation Strategy

The test automation solution for the hybrid in-lab test bench approach for AI/ML quality validation follows the steps below. The focus is on monitoring the factory's soap production line. Elements to monitor during the production include:

- **The shape of the soap/bottle (shape of the object in terms of AI)**
- **The colour of the soap/bottle (colour of the object in terms of AI)**
- **The size of the object (length-x-width of the object in terms of AI)**

The goal is to develop an AI application that monitors the above-mentioned parameters during production using existing models.

**The primary objective of this application is to test the AI models used within it. Below are the key parameters for validating an AI model:**

**Data Quality:**
Ensure that the data used for training and testing is of high quality, free from errors, biases, and inconsistencies.

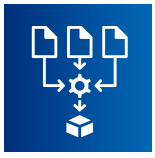
**Model Fairness:**
Test the model for fairness to ensure it does not discriminate against certain groups. Use appropriate fairness metrics to evaluate this.

**Model Accuracy:**
Evaluate the model's accuracy by comparing predicted results with the actual outcomes. Use appropriate metrics such as precision, recall, F1 score and ROC AUC.

**Model Generalizability:**
Test the model's ability to generalize from training data to unseen data, which can be evaluated by using techniques such as cross-validation.

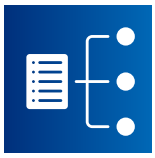
**Model Performance:**
Evaluate the model's performance in terms of speed and resource usage. It should be capable of processing data and making predictions within acceptable time frames.

**Model Validation:**
Validate the model using a separate validation set to ensure it has neither overfit nor underfit the training data.



**Model Robustness:**
Test the model's ability to handle variations in the input data. It should be able to make accurate predictions even when the input data changes.

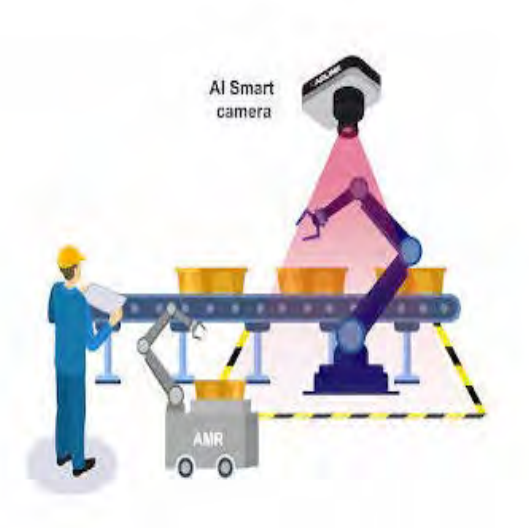
**Hyperparameter Tuning:**
Test different hyperparameters to find the ones that yields the best results.



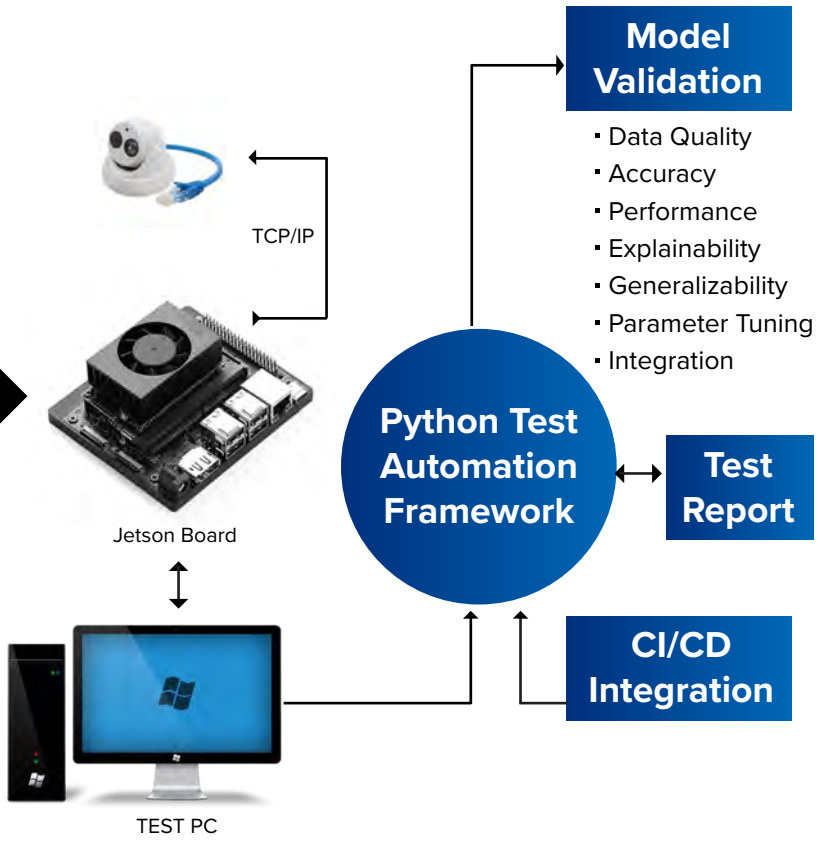
**Model Explainability:**
The model should be able to provide explanations for its predictions, which is crucial for understanding how it makes decisions.

**Integration Testing:**
Test the integration of the AI model with other components, including data pipelines, model serving infrastructure, and user interface.

**Factory Floor Production Line**
**AI Vision-Based Quality Check**




- AI vision-based quality check
- AI-based predictive analysis
- AI-based batch processing downtime




# Conclusion

To address the industry's growing concerns and challenges, particularly in terms of reliability and safety, selecting the right validation approach for any safety-critical application is crucial. This whitepaper provides insight into choosing the appropriate validation strategy for an Industry 5.0 vision-based application. This strategy will reduce the failures during development and ensure that CapEx and OpEx yield the right ROI for the project. Using the open-source tools for validation provides flexibility and reduces the cost, with Python-based frameworks being an industry standard for AI/ML-based project development and testing.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He has 16+ years of experience in Industrial & Manufacturing Product Validation. His expertise lies in testing multiple products used across Level 0 to Level 4 in the Industrial 4.0 Space. In his role at Happiest Minds, Vishnu handles multiple industrial automation and manufacturing turnkey projects.

# For more information, write to us at business@happiestminds.com

## About Happiest Minds

Happiest Minds Technologies Limited (NSE: HAPPSTMNDS), a Mindful IT Company, enables digital transformation for enterprises and technology providers by delivering seamless customer experiences, business efficiency and actionable insights. We do this by leveraging a spectrum of disruptive technologies such as: artificial intelligence, blockchain, cloud, digital process automation, internet of things, robotics/drones, security, virtual/ augmented reality, etc. Positioned as 'Born Digital. Born Agile', our capabilities span Product & Digital Engineering Services (PDES), Generative AI Business Services (GBS) and Infrastructure Management & Security Services (IMSS). We deliver these services across industry groups: Banking, Financial Services & Insurance (BFSI), EdTech, Healthcare & Life Sciences, Hi-Tech and Media & Entertainment, Industrial, Manufacturing, Energy & Utilities, and Retail, CPG & Logistics. The company has been recognized for its excellence in Corporate Governance practices by Golden Peacock and ICSI. A Great Place to Work Certified™ company, Happiest Minds is headquartered in Bengaluru, India with operations in the U.S., UK, Canada, Australia, and the Middle East.