PSA

NEURAL NETWORKS FOR MACHINE VISION

RELIABLE & AFFORDABLE SOLUTION FOR QC

LEVEL-UP FOR VISUAL INSPECTION: CATCHING UP THE OPPORTUNITIES | 01

Machines have long surpassed the human visual limits of about 300 ppi image resolution. They expanded the concept of "visual" itself by adding infrared, ultraviolet, and X-ray radiation to the scope for visual inspection. They have no peripheral vision, and they don't require a long-time object view to assess its compliance. That's why we have a multitude of immersive developments based on Machine Vision (MV) technology at various applications and costs, and can expect them only to multiply over the upcoming years?

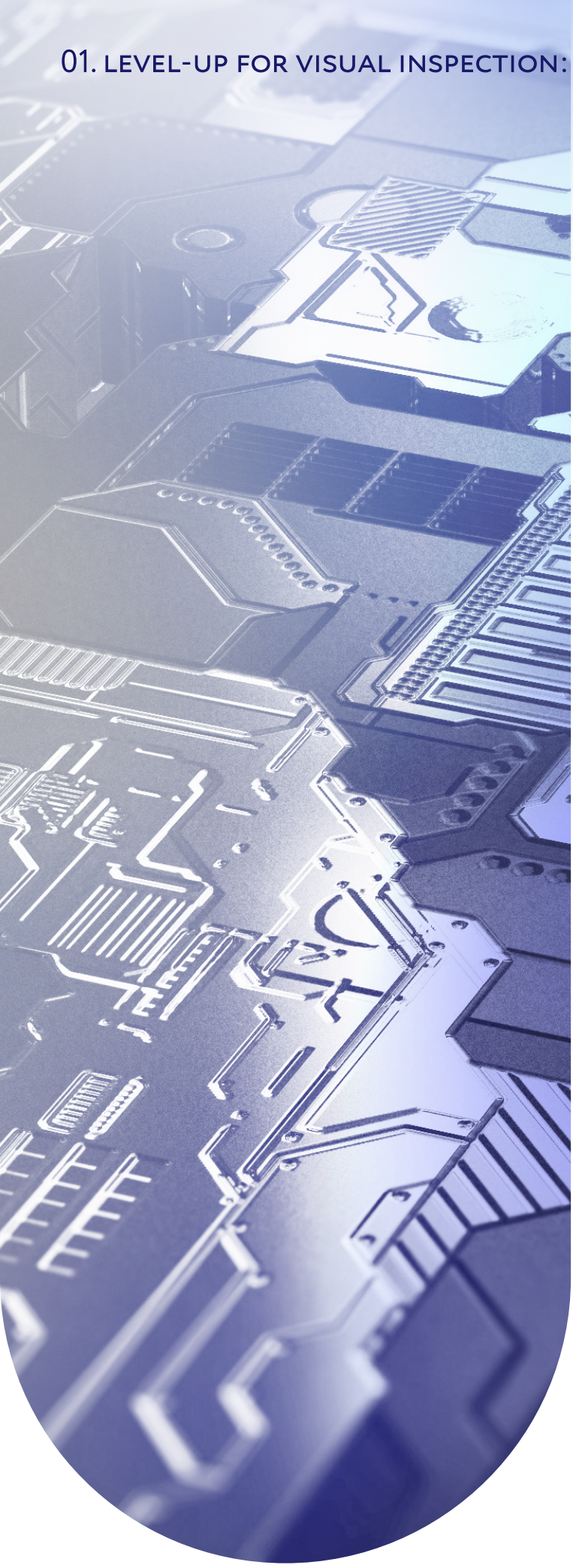
REAL OPPORTUNITIES FOR MACHINE VISION INSPECTION

Today, we can confirm the efficient application of MV tools for quality control (QC) processes in multiple industries, especially for complex and integral equipment and its components, which should be executed at high production speeds. Automotive was among the first to embrace the technology just because of the complexity and specificity of the parts coupled with the enormous scale of production. Also, Machine Vision was rapidly adopted by pharmacy for completeness validation purposes, and by large industries to check surface defects.

Now, with the increasing availability of MV technology and opportunities to balance development approaches, many more large and small productions can benefit here by experiencing significant cost reduction.

Visual inspection is successfully leveraged to detect defects, misalignments, and surface quality issues in products, defects in printed materials like labels, packaging, and even currency. Thanks to its limitless capabilities of detection of nuanced details, Machine Vision is best assigned to manufacturing and assembly verification tasks for 2D and 3D objects to ensure its full compliance with specification, industry, and safety standards. By leveraging MV capacities, it can verify:

- The presence of all parts and proper placement of all details and objects
- The proper shapes and sizes for details
- Colors and textures for manufactured objects precisely under specification(s)
- Absence of defects, such as scratches, holes, foreign particles, contamination, bent details, etc.
- Product and packaging completeness



Despite the quite impressive cost of the final solution, the Machine Vision system is often chosen for production quality control for the following reasons:

MACHINES ARE MUCH FASTER

They can inspect hundreds or even thousands of parts per minute without sacrificing quality. It is particularly noticeable for tiny and crowded object inspection, such as PCB assembly verification.

MACHINES DO NOT REQUIRE "ASSISTANTS"

They eliminate other, less efficient inspection methods, such as sampling. They are becoming more independent over the years by leveraging AI capabilities.

MACHINES ARE MORE METICULOUS

They simply can't overlook any discrepancy, since a detailed inspection is determined by strict rules within implemented algorithms. As a result, defect detection rates surge while rejection rates fall.

MACHINES PROMOTE PRODUCTION SAFETY

MV devices can be designed resistant to various production environments, which makes it possible to locate them in dangerous zones and enclosed spaces. They also promote safety for the joint work of machines and humans.

It can be said that Machine Vision-based systems are now experiencing their heyday, but it's still quite challenging to enter such an ambiguous market and comply with the feasibility of such products. The capabilities of cameras are now almost unlimited, not to mention the capabilities of analyzing tools. However, standard camera modules of full HD cover most of the production QC needs, but only when combined with neural network capabilities. So, how to balance development approaches to create top-notch NN-based products for inspection purposes? PSA is happy to share our deep-dive expertise of turnkey product development with neural networks involved and tips on how to seamlessly launch it to market.

NEURAL NETWORKS' POTENTIAL FOR PRODUCTION QC | 02

OVERCOMING CHALLENGES OF TRADITIONAL MV

Despite disruptive advantages, traditional Machine Vision will never free the production from human involvement. Moreover, its toughly deterministic nature forces additional human vision inspection to exclude unintentional defects or verify false positives.

Advantages commonly attributed to human vision over traditional Machine Vision are driven by the conscious interpretation of images. That is, human brains make conclusions after combining a range of views into one visual image, applying experience to differentiate the details, and considering multiple external factors for the most relevant decision-making.

Today, by enlisting the power of Artificial Intelligence (AI), Machine Vision systems possess much more extensive capabilities than a simple vision simulation. They simulate the way human brains operate, performing data-driven decision-making and learning from every QC cycle, which allows for the full removal of the human from the inspection processes.

FUNDAMENTALS FOR NEURAL NETWORKS

Neural Network (NN) is a technology of AI implementation, which is a series of algorithms united into a model customly trained to solve specific tasks and continuously adjust to new inputs. Each processing node is called a neuron there, and the strength and efficiency of connections between neurons determine how successfully the task will be completed. To establish and alter these connections, a neural network should be trained using data sets ultra-close to a target real-world application data. After installing onsite, the neural network within the QC device does not stop improving itself using constantly incoming "fair" data from a production line.

MORE SPECIALIZED DETAILS CAPTURING

Neural networks tend to be more accurate when it comes to object detection within complex scenes. They capture low-level features, such as object angles or colors, and high-level features, such as parts' positions or shapes equally effectively. Additionally, neural networks can recognize objects regardless of their location and orientation. Despite limitless training capabilities, neural networks are at risk of being overfitted and performing efficient inspection only for testing data sets.

RULES ARE CREATED AND ADJUSTED TO REAL-WORLD

In contrast to sophisticated algorithms underlying the traditional roboto-vision, neural networks allow developers to get away from "what should be" training to "what is" training. Thus, NNs perceive the image details with an allowable deviation. In the training process, neuron layers make up a pyramid, which allows for the establishment of more tailored image features, while 3+layered neural networks provide Deep Learning. Thus, by training to recognize the patterns from production-line images, they start to absorb increasingly nuanced details analyzing real-world video streams. Training data can be augmented to continue NN enhancements while operating.

IDENTIFICATION OF UNPREDICTABLE DEFECTS

Traditional Machine Vision apps are built to recognize specific image patterns, which brings a risk of unintentional defects to be missed. Thus, we can't speak about a 100% defect detection rate here. It also brings an opposite issue by increasing the risk of false positive results. The modern Convolutional neural Networks (CNN) are constantly learning models to properly identify new types of defects. Moreover, they are much more sensitive and can distinguish acceptable anomalies instead of rejecting everything that does not exactly repeat the sample.

RUGGEDNESS & RELIABILITY

For the traditional MV application, you often encounter a choice between camera sensitivity and resolution, since these parameters are mutually exclusive. Neural networks "support" both of these features, which allows for replenishing the lack of them with NN capacities. Additionally, they soften some of the hardware requirements and pay less attention to object orientation. They perform their functions well in poor lighting conditions, which makes them more reliable than traditional MV algorithms.

THE SURGE OF NN-BASED DEVELOPMENTS: WHAT'S THE REASON AND WHAT TO EXPECT NEXT?

For a long time, the fact that Neural Networks can generalize the result to other data sets, provided that they do not differ much from the original ones, was the stumbling block of NN wide adoption. Neural Networks that can produce one highly specialized use case bring a significant risk both for productions forced to develop this resource-intensive solution and product companies through specialized and narrow audiences for such products. But now, when 35% of businesses have already mastered AI, and 45% voiced intention for this shortly, the challenge of who to sell gradually reduced to how to balance budget and development efforts to create the product of the highest efficiency considering all possible features of the production environment.

Today, businesses require competent guides to affordably advance their quality control processes. Highly specialized QC products based on Neural Networks are gathering pace for two main reasons:

- End customers are ready to pay a high price for the immense value the solution brings
- Remarkable capabilities of well-trained NN allow for high product development flexibility

Thus, we are now at the dawn of the wide NN adoption for production inspection and can expect a new business struggle on whose rules are the most relevant for a particular industry, and whose app is most convenient.

DO YOU WANT TO CARVE OUT A NICHE IN THIS YET-VACANT MARKET?

EFFICIENCY INDICATORS

A synergy of Neural Networks with Computing Vision promotes unconditionally valuable product development even when focused on budget-saving. According to PSA statistics collected from relevant clients, ROI for NN-based inspection devices for one production point is in a year on average.

As reported, customers were able to reduce delivery of defective items by about 90% just within 6 months when Neural Network had been training on the custom data sets. Having shifted from human inspection, they managed to increase throughput for the items inspected performing quality control for the film tape at speeds up to 1000 meters per minute. However, there are only instant visible effects on production QC, whereas long-term use will allow for the definition of the most common production issues that lead to product defects. It unlocks data-driven strategy creation with the most accurate risk assessment.

BALANCED DEVELOPMENT FOR FASTER PROFITABILITY

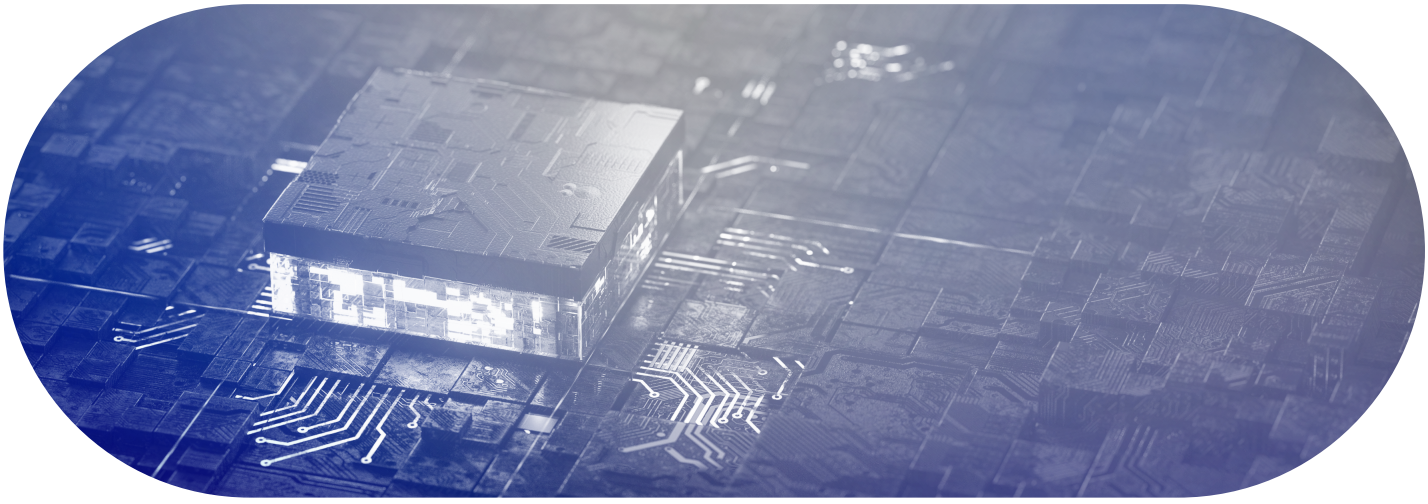
Despite NN being a heavy technology, it does not invalidate sufficient flexibility with product design, which allows for the creation of low-risk products with reasonable cost of ownership. For instance, NN-based product for inspection purposes promotes the following maneuvers:

- Reduction of the camera, backlight, and sensor requirements by filling them through NN computing capabilities
- Wide components' variation for optimal industry deliverables
- Utilization of embedded interfaces to minimize development efforts
- Utilization of standard hardware architecture with off-the-shelf components, such as enclosure, SSD, and SoM to save on

Besides, when developing a commercial offer, the following opportunities are unlocked:

- To develop an extended product offer by distinguished AI intervention
- Opportunity for "razor blade" business model by providing constant updates
- Continuous client support allows for getting instant feedback to enhance the product

Neural Network takes over the core computing operations to bring the accuracy of defect detection to absolute value. This allows for more affordable development for other components, but only if you consider a range of aspects of Neural Networks operation.



IMPLEMENTATION OF NN-BASED PRODUCT INTO PRODUCTION QC | 03

Speaking of AI introduction into quality control processes, we speak of the incorporation of an integrated IoT-based system into a specific production environment. A Neural Network is a core of such a system, a high-value driver that is responsible for real-time data processing from a production line, generation, and communication of the output on the target object quality. The development in general is built around NN, but competently implemented architecture, software, hardware, UI, and other design solutions can significantly amplify its basic value.

For the NN-enabled product to be ultimately efficient within a production environment, you should comply with the following basic aspects:

- Top-notch detectability provided by relevant NN training
- Hard real-time operability supported by the relevant operating system of the device
- Seamless UX and prompt notifications of defects detected
- Resistance to environmental factors
- Scalability potential

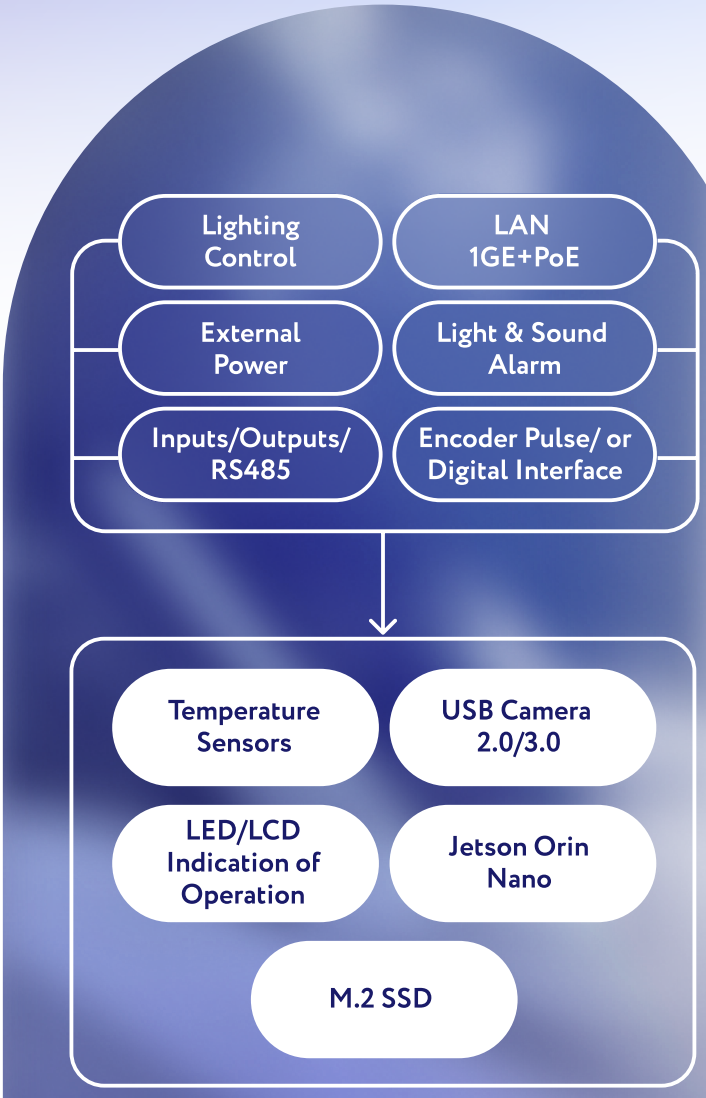
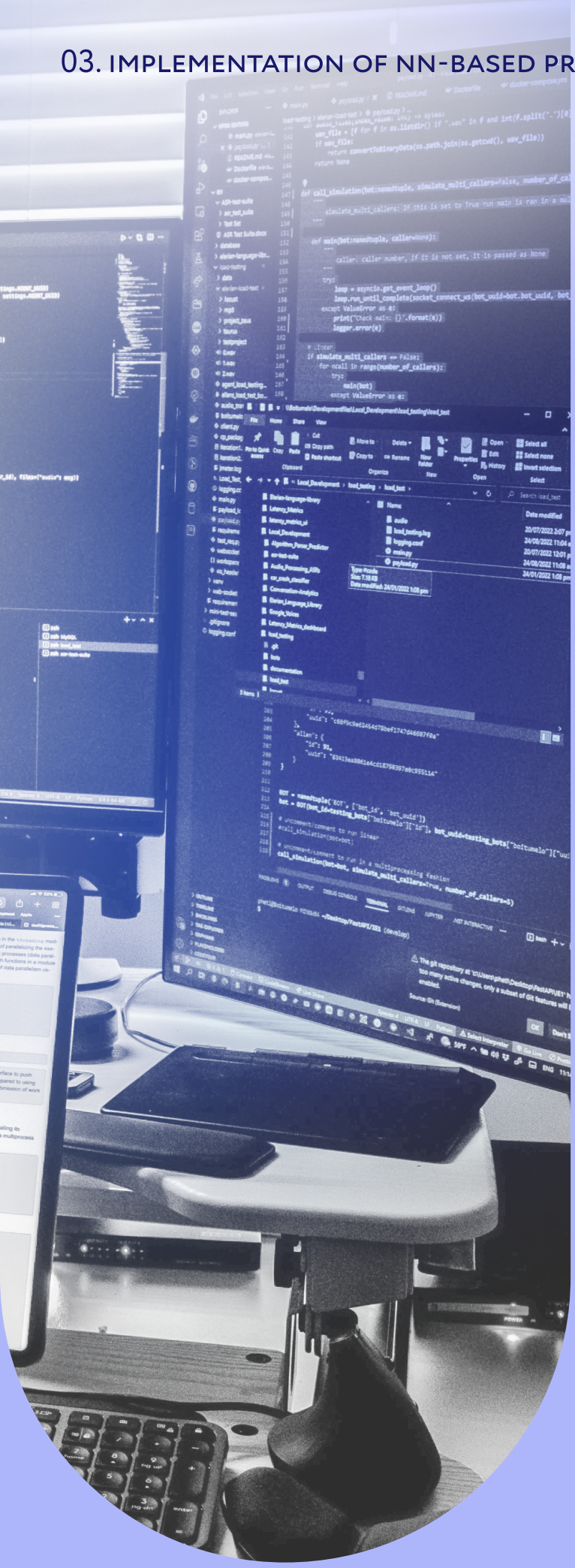


Figure 1. Instance of the Product Hardware Architecture



A WORD ABOUT NN TRAINING

For the complex product implementation, the neural network should be trained first. It learns from a large amount of data, and the closer this data is to a real-world application, the more efficiently it detects anomalies. The training process identifies the most efficient neural connections to maximize the accuracy of the delivered network. The main thing here is to provide the neural network with a sufficient amount of data, dividing it into training, validation, and test sets while monitoring the accuracy of the model for each option.

Thus, when implemented at the client's site, the neural network-based product will be adapted for production to a sufficient extent to bring them the expected output. However, during use, as real data is mastered, the neural network should be regularly updated to maximize its value. This once again confirms that it is better to choose a highly specialized, but in-demand use case for mass production development.

Note that NN training is time-consuming, so if your project includes these activities as well, we recommend performing them in parallel to development activities.

IMPLEMENTATION OF THE TRAINED NN INTO AN IOT-ENABLED SYSTEM

A comprehensive product for advanced defect tracking should be seamlessly incorporated into the production environment considering its specific nature. As a rule, a defect detection device involves a high-speed camera, sensors, backlight, and a range of connectivity slots for issue-free data transmission on multiple devices (the architecture instance is provided above). Cloud-based and cloud-free architectures can be equally considered here when it comes to NN deployment. By the way, training is performed in the cloud only through sufficient computing capabilities required.

To develop requirements that perfectly meet the target demand, the product architecture should be designed considering the share of human involvement, their distance from the inspection area, the number of stakeholders, the character of the objects under inspection, and the environmental conditions of the inspection area. After meticulous analysis, you are likely to define multiple precise factors to affect the architecture, while the most common requirements are the following:

- Capturing and processing video information from a control object moving at extremely high production speeds
- Speed tracking and control for a production line
- Camera angle covering entire objects
- Processor units with at least 800 MHz clock speed
- Light and sound alarms
- Robust video transmission and processing when server deployment
- Multi-issue delivery service & notification
- Reliable powering and issue-free licensing implementation

The major challenge of efficient co-existence of the Neural Network with other system components of the integrated product is addressed at the architecture level and with the proper components selection. The delivered solution should manage the heaviness of the neural network while the risk of system freeze, and data transfer delays should be eliminated. First, consider a powerful board for design activities with 4 cores and 4GB+ of RAM to avoid hardware glitches. To prevent downtime through network failure, it's better to provide multiple channels for different operations, such as USB, Ethernet, and MQTT.

The development of the integrated QC product with NN capabilities usually involves:

- Hardware design given optimized performance and robust connectivity
- Embedded software with RTOS implementation considering diverse communication capabilities
- Mechanical design for the product to be seamlessly mounted directly behind the QC zone
- Server software for NN deployment (if required)
- Web app to control the state of the device, and analyze notifications

PECULIARITIES FOR CLOUD NN DEPLOYMENT

Within a distributed system, all the hardware including devices with sensors and camera are located at the edge while the Neural Network should be deployed in the Cloud. To complete the inspection operation, the data should be transferred to the cloud first where analysis is performed, and then back into the device to perform relevant activity based on the output from the NN. This architecture can be used with quite a limited hardware module that can't perform the computing required for Neural Network operation.

HARDWARE FOCUS

In our project, we've chosen an easy-to-program Toradex's Colibri module capable of efficient handling of HD video streams over Ethernet. This hardware was a core for efficient component placement, such as a full HD camera, DIMM, USB, and Ethernet slots, and alarm lamp. By implementing the STM8 microcontroller using C++ and SPI, PSA addressed several issues at a time, such as speed measurement and crypto protection.

SERVER COMMUNICATION SERVICE

The first critical task for the system is to verify that the operability of the equipment is under control and the device's capability to alarm defect production is operational. Thus, we provided a feedback delivery form device to the server on the state of the machine, as well as the ability to control light and sound signals in different modes from semi-finished products to defect detection.

VIDEO STREAMING TRANSMISSION

For the Neural Network analysis to be performed, the video stream should be flawlessly delivered from the device to the server. Here we relied on the resource-efficient use of mjpeg-streamer for efficient video streaming through built-in Yocto support for the Colibri module.

PECULIARITIES FOR EDGE NN DEPLOYMENT

The impressive progress of edge computing has made over the past decade allows us to talk about intelligent Machine Vision devices that can be installed as a plug-and-play solution at the customer's site. Such an architecture does not affect the size of the final device and allows it to be compactly placed in the target premises or mounted to the necessary equipment. Full edge deployment is frequently chosen through:

- The opportunity to free-loaded industrial networks by eliminating device-cloud transfer delays
- Independence from network outages
- Simplified deployment through a component exclusion
- Enhanced security management by getting rid of the 3rd-party cloud storage

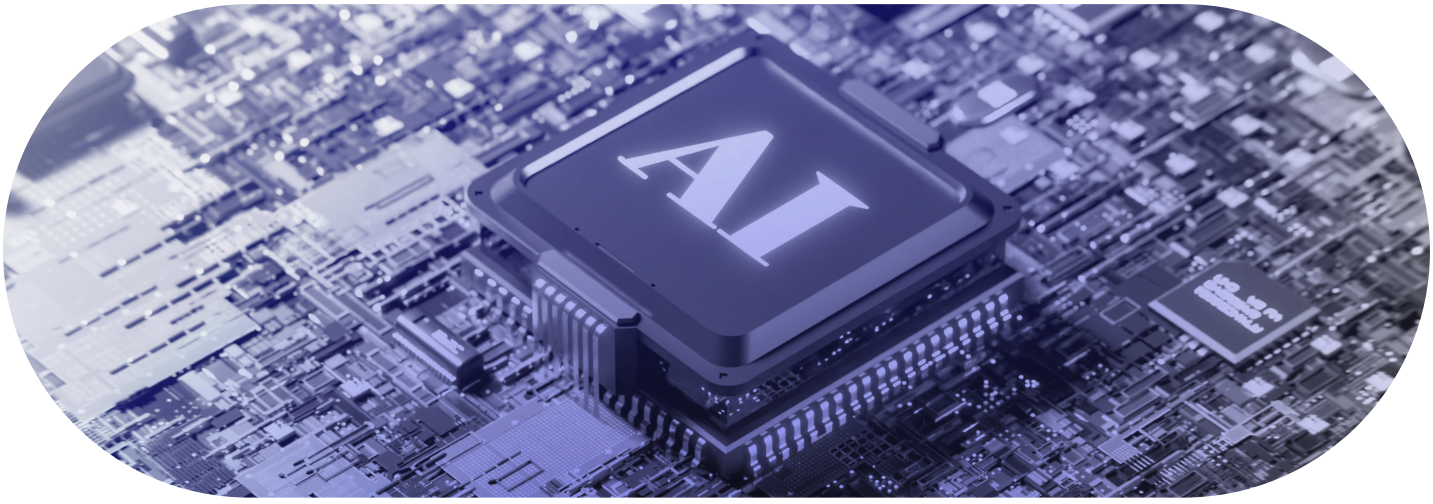
For this capacious solution to be successfully implemented, consider the following:

- More powerful processor to comply with a heavy Neural Network
- Light and sound signaling incorporated into the device
- Advance strategy to comply with more sophisticated updates and maintenance process

PSA built such a system on a powerful Nvidia Jetson board and provided PoE powering. For acceleration of video recording, it was critical to provide an M2 slot and utilize an SSD drive instead of the microSD used before. Additionally, we were also handling device protection against external objects, increased power consumption and subsequent heat distribution, alarm features, lighting control, camera placement, licensing issues, and additional visual standards implementation for advanced image processing.

HOW TO MAKE THE SOLUTION EVEN MORE ADVANCED?

By delivering the relevant product, you empower the end customer with the invaluable tool to prevent the delivery of defective items while the inspection rate increases. You can easily go further and simplify defect management by offering defect classification, advanced defect analytics functionality to identify the most common ones, compose data to define dependencies and automatically create statistical reports. This would allow the end customer to rapidly detect and remove the defects' root causes.

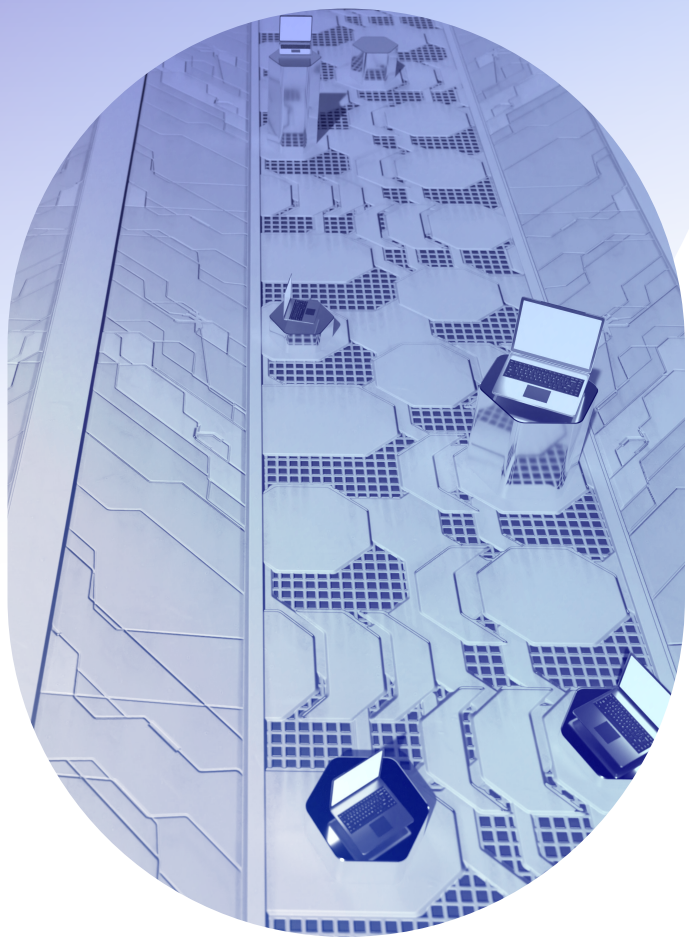


PSA PROMOTES A BALANCED DEVELOPMENT APPROACH | 04

For your NN-based Machine Vision product to succeed, you require a comprehensive view from the very beginning to reflect all the potential nuanced dependencies of the neural networks for other product components. At PSA, we offer a turnkey development of IoT-enabled solutions integrating cutting-edge technologies of any complexity to respond to enterprise-scale demands.

What you can count on with PSA assistance:

- A multilateral feasibility assessment for your NN-based project
- Suggestion of the most relevant architecture option for implementation
- Components selection under business goals
- Full scope of development activities to deliver operable prototype
- Custom testing approach with custom test fixtures if required
- Manufacturing support to ensure full compliance with specifications
- Commercialization support and increase of the market visibility



With PSA's robust assistance, you gain a reliable and competent integration of a resource-intensive Neural Network into the Machine Vision device considering the custom environment of the target application. Our turnkey expertise allows us to evaluate multiple combinations for your product to be implemented to comply with business goals, efficiency indicators, industry standards, and desired ROI.

REACH OUT FOR A SOLID CONVERSATION!

John Hertrich
CEO

Direct +1.727.724.0000 x200
Cell +1.810.338.0000
E-mail / MS Teams john@psa.inc

Main Office 28050 US HWY 19 N Suite 507, Clearwater, Florida 33761 USA
Telephone +1.727.724.0000
E-mail sales@psa.inc

Irina Tuzhikova
Head of EIoT Business Unit

Cell +375.29.141.0072
E-mail / MS Teams
irina.tuzhikova@psa.inc