Edge AI Drives Line Clearance in Pharmaceutical Production

◀ Machine learning is changing the way pharmaceuticals are produced and inspected.

42 Technology Ltd.

Deep learning, often powered by neural processing within silicon devices, is enabling automated inspection and defect detection throughout the drug-making process.

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Line clearance is a critical, highly regulated process in pharmaceutical and consumer health manufacturing, yet this procedure has historically relied on time-consuming manual inspection methods. Recent advancements in edge AI now offer a secure, cost-effective, and high-performance automated visual inspection alternative.

By combining powerful on-device deep learning, multimodal computing, and no-code model training tools, edge AI systems can enable automated line clearance alongside continuous defect and anomaly detection. These compact, self-contained devices sidestep the cost, cybersecurity, latency, and infrastructure barriers that have historically limited both cloud-based and traditional on-premise solutions.

The basics of line clearance

Manufacturing any product often includes multiple process steps, complex production equipment, and various points within an operation at which product quality and integrity can be affected. This is particularly challenging in the production of pharmaceutical products, which have extremely tight specifications, minimal ability to rework, and the risk that an entire batch can be lost due to a single point of failure. Such risks are particularly pronounced when multiple products are produced on the same line, requiring exceptionally careful management of changeovers between products.

In most fast-moving consumer goods production processes, a level of line check, referred to as line clearance, is required to ensure the line is decontaminated and clear of debris from frequent and varied production runs.

In production processes for pharmaceutical and consumer health products, line-clearance checks are a critical regulated step. The impacts of cross contamination between batches for such products are substantial. Wastage of spoiled products is minor compared with the risk of consumers receiving and taking the wrong medication.

Current challenges in line clearance

Traditionally, these checks are performed manually, with operators walk-

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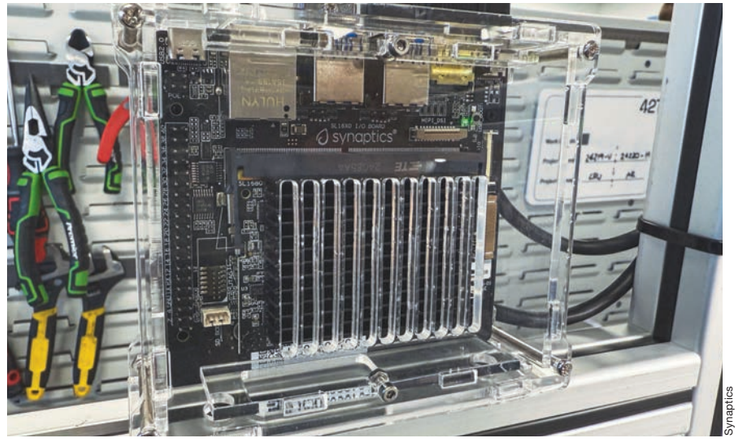


Synaptics

◀ The Synaptics Astra AI-native Internet of Things platform, which brings AI directly to product inspection.

ing each part of the production line, checking for leftover material between production runs, recording the process, and reporting any findings. This is time-consuming and prone to human error.

The rise of personalized medicine has compounded the problem. Smaller batch sizes mean more frequent changeovers and therefore more line-clearance checks each day. Manufacturers are increasingly looking to automated visual inspection, and several dedicated line-clearance solutions now exist for pharmaceutical manufacturing.

As line clearance is seen as a specific and stand-alone process, these automated solutions are often deployed as stand-alone systems, with cameras monitoring the wide-ranging areas of the production plant that require inspection. Certain manufacturers use existing closed-circuit television (CCTV) within the plant, while others install dedicated industrial cameras to capture the scene and alert the operator to any objects detected during the line-clearance checks.

However, the use of CCTV systems limits the ability to inspect all areas of the plant (capturing only what is within the camera's view) and still leaves the operator with mandatory manual checks. At the same time, the cost of fitting dedicated cameras in all required areas purely to perform line-clearance checks is prohibitive; many have failed to make the business case for such a high-capital-expenditure automation project.

The machine vision capabilities of dedicated software built on a variety of processing models have existed and been successfully deployed for these automation tasks for many years. They typically rely on large compute capabilities, either with on-site servers or personal computers, or run directly within a programmable logic controller (PLC) system to create the vision pipeline and process the data being captured.

This solution is desirable to operators because it prevents the need for data to leave the site or expose the company to cybersecurity risks from cloud connectivity; however, the cost and complexity of implementing IT infrastructure on-site — often as a retrofit project into existing PLC-driven plants — are a barrier to implementation. From an operational perspective, this implementation often requires the operators to manage the software solution on-site, build the in-house capabilities to train and deploy AI models to perform the checks, and manage a wide range of monitoring locations when changes occur. For many end users, this presents too high a risk for the longevity of the solution and negates the benefits of an automated process in which in-house resources, upskilling, and additional data management is required.

> In production processes for pharmaceutical and consumer health products, line-clearance checks are a critical and regulated step.

Problems in the cloud

In recent years, cloud connectivity to send data off-site for near-real-time processing has been used to deploy more powerful machine learning models. This approach provides software solutions that enable remote model training, enhanced connectivity, and remote monitoring.

However, the use of remote cloud services adds latency to a process, is susceptible to data link failure, and presents data and cybersecurity risks that continue to be unacceptable to pharmaceutical manufacturers and others, preventing widespread adoption.

The edge computing option

Edge processing — in this context, computing right next to the data source — is evolving rapidly, with many native AI solutions that can run on edge processors leveraging neural processing units (NPUs). These are embedded in a single-board computer, with powerful graphics processing units performing substantial workloads across consumer, medical, and industrial product lines.

These edge devices, when coupled with camera systems, are increasingly providing the capabilities typical of server, PC, and cloud-hosted machine learning solutions for automated object, defect, and anomaly detection — all from a single-board computer. This system design addresses many of the challenges of implementing automated visual inspection for processes such as line clearance.

At the top end of the market, edge AI single-board computer devices are available as multi-TOPS (trillions of operations per second) units capable of running powerful deep learning models, such as NVIDIA Jetson. Such solutions, although impressive, can be expensive for operators with applications that require multiple inspection points and fail to show the return on investment needed to transition from manual to automated inspection.

This is an issue across manufacturing industries in which low-margin product production has multiple inspection points that could be automated, including food and beverage, paper and pulp, and personal care products.

Many operators have turned to lower-cost edge solutions, such as the Raspberry Pi, where AI inferencing is run on a traditional CPU. But the performance limitations this creates, coupled with the requirement to build model capabilities from the ground up, leave many of these solutions falling short of the performance required for visual inspection tasks in fast-moving, always-on production processes, such as in pharmaceutical line scanning.

A new class of NPU-enabled silicon devices is emerging, specifically suited to vision-based deep-learning processing. With single-digit TOPS that can effectively manage these workloads, these devices are positioned at a price point significantly lower than the high-end offerings. This advancement in material and system design is coupled with the implementation of AI inferencing and deep learning models on these devices using open toolchains and development environments. This allows cost-effective compute and deployment of AI models without locking users into a restrictive development environment.

With this new generation of silicon now available in industrial-grade single-board computers, companies have the opportunity to automate line clearance using edge devices. But why is this necessary when on-premise or cloud-based solutions already exist?

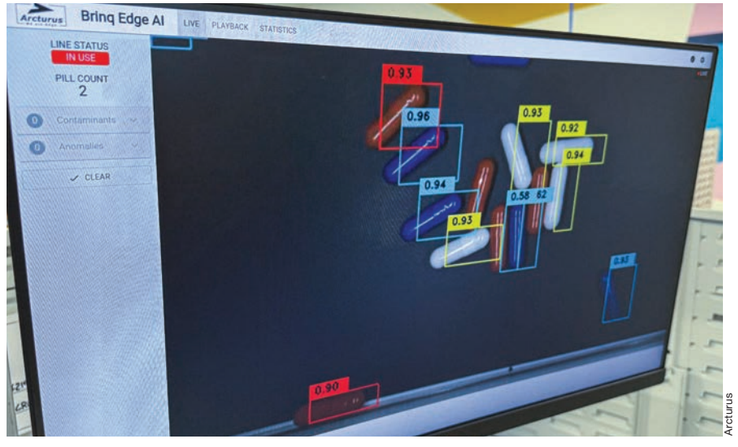
First, edge processing is secure by design. Once models are trained, edge devices can run without the need for cloud connectivity and may not even require networking into the plant's IT system. This prevents the system from being an access point for potential hackers trying to enter the site's secure network. Second, scalability: All AI inferencing is performed on the edge devices, with the ability to run each device independently or as a networked solution, without the need for additional compute, data storage, and connectivity to scale with the number of inspection points.

For those wanting integration into existing PLC and digital security control systems on-site, commercially available edge AI solutions with associated software are emerging that can provide the fleet management of multiple devices. These solutions include open application programming interfaces, allowing connectivity into the core functions of the system — for example, identification and alerting of materials found during a line-clearance check.

There are three ways to introduce AI capabilities to a line: cloud, centralized server, or distributed edge AI. The last option is more secure, scalable, cost-effective, and compatible with existing infrastructure.

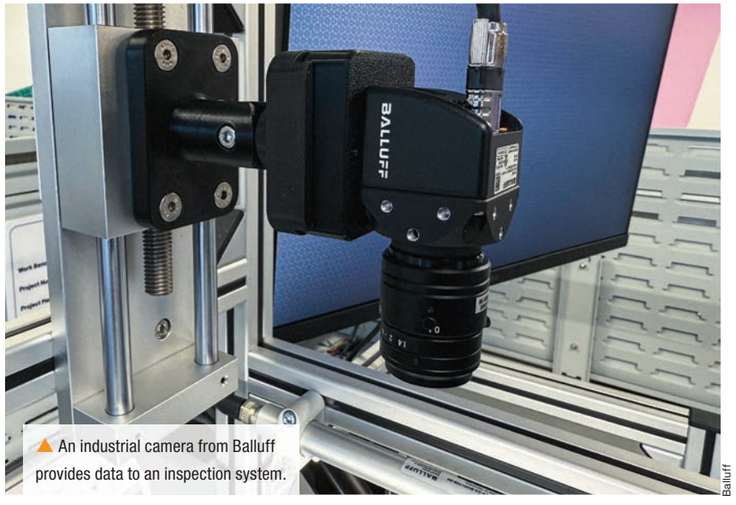
What's next for edge AI?

Operators, integrators, and smart camera providers can leverage edge AI to replicate the current manual line-clearance process. This offers clear ad-



Arcturus

▲ An Arcturus machine learning user interface.



An industrial camera from Balluff provides data to an inspection system.

Balluff

vantages for pharmaceutical and consumer health product manufacturers. Estimates show a substantial reduction in time spent on each line-clearance check when using an automated inspection system versus a manual check. The ability to perform checks of each area of the plant simultaneously — and to automatically record the findings and immediately alert operators to any leftover material — is a compelling proposition to balance against the costs of implementation.

Such edge compute can bring further benefits — including multimodal capabilities: Multiple functions can run on a single-board computer, providing users with insights beyond a single function, such as object detection.

For line clearance in pharmaceuticals, this is a significant capability. Traditionally, this procedure has operated as a stand-alone activity, with inspection systems used only during line checks between batches. For companies seeking to automate this process with multiple edge AI camera systems, many fixed-position cameras must be installed across the production line. If their only function were to inspect the lines between batches, the business case could be challenging for operators, whose capital expenditures on these solutions are heavily scrutinized.

By exploring the multimodal capabilities of edge processing systems, these permanently installed cameras could both perform line-clearance object detection and provide continuous monitoring during the production process. A multimodal edge AI model trained to perform object detection could also be trained to perform defect or anomaly detection of the actual products being produced and track products through the line. Such adaptability has been demonstrated in other types of manufacturing. Multiple types of inspection could include identifying defects in raw materials, anomalies in finished products, damaged or incomplete packaging, label integrity issues, package sealing, among others.

Edge devices and AI models are being developed that enable multiple models and functions to run on a single device, providing the potential for operators, such as pharmaceutical manufacturers, to use these multimodal capabilities to perform multiple tasks via a single vision system.

Different monitoring locations across the plant will require different camera systems. Edge devices provide the modularity to accommodate this. Each location's requirements are configured and processed locally rather than adding complexity to the centralized PLC and security control system. The result is a flexible, decentralized architecture that scales without burdening core infrastructure.

Edge AI training

One challenge remains: training the deep learning models. Most commercial solutions require data science and software engineering expertise that many operators lack in-house.

Along with the emergence of edge processing, new tools are being developed to enable no-code model training. These systems enable users to label, train, optimize, and validate models entirely on-site using data captured from their process. This alleviates a potential data security concern for many manufacturers.

These tools also support ongoing retraining to address model drift as production processes evolve, ensuring long-term reliability.

Advancements in edge AI have reached a point where automated line clearance is less constrained by cost, infrastructure complexity, and cybersecurity concerns. Vision-optimized edge processors, open development ecosystems, and no-code model training tools now enable scalable, secure, and maintainable inspection systems to be deployed directly on the factory floor.

Beyond replicating manual line clearance, these technologies unlock multimodal inspection capabilities that extend continuous value across the production lifecycle. As manufacturers seek greater efficiency, compliance, and resilience, edge AI presents a compelling opportunity to reimagine line clearance not as a stand-alone task, but as an integrated, intelligent component of modern pharmaceutical manufacturing operations.

For pharmaceutical manufacturers, this represents a potential step change. Viable automation of manual line clearance, coupled with real-time inspection during production, offers substantial improvements in uptime, yields, and product integrity. Regulatory frameworks are beginning to accommodate automated inspection, and early adopters are demonstrating that these systems can meet validation requirements while delivering measurable operational benefits.

Realizing these benefits will require vision system manufacturers, plant integrators, and edge AI specialists to work in partnership. Together, they can develop solutions that meet pharmaceutical regulatory requirements and scale across manufacturing sites worldwide.

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