Solution Brief

MAXIMIZE PRECISION AND THROUGHPUT WITH 3D VISION FOR MANUFACTURING AND INDUSTRIAL ROBOTICS

Reduce System Cost, Power, and Complexity with an Integrated 3D, Single-sensor Solution

Overview

Manufacturing and industrial robotic systems are increasingly expected to operate in dynamic, space-constrained, and unstructured environments, where reliable 3D perception is essential for tasks such as bin picking, pick-and-place, grasping, palletizing, and in-hand manipulation. Many of these applications take place in the near-field working range of roughly 10 to 50 cm, extending to contact at the end effector. The end effector is the point where the robot interacts directly with the object, making high spatial resolution and precise edge detail critical.

Traditional 3D sensing approaches such as active stereo, structured light, and time-of-flight often require trade-offs in system size, power consumption, cost, and mechanical integration, especially when deployed close to the robot end effector. These limitations create challenges for compact, efficient, and scalable robotic designs.

The Airy3D and Lattice compact integrated 3D vision solution addresses these constraints by enabling low power, space-efficient 3D sensing that can be deployed directly at the edge, close to the end effector. See Figure 1.

Figure 1: Precision Handling by a Robotic System

Near-field 3D Perception with a Single CMOS Sensor

Near-field perception is essential for robotic grasping, manipulation, and industrial automation. However, many conventional 3D sensing approaches are difficult to deploy close to the end effector due to camera size, power consumption, external illumination requirements, and minimum working-distance limitations.

KEY CHALLENGES

- Minimum distance constraints (minimum Z) limit near-field deployment, requiring longer-range sensing that increases system cost and reduces robustness in dynamic environments
- Camera size, mechanical complexity, and higher system costs are driven by multi-sensor designs, emitters, active components, high-end processors, and tight alignment requirements that increase overall system BOM and complicate industrial integration
- Power and thermal constraints that limit compact, fanless, always-on operation in dense robotic and industrial environments
- Integration challenges caused by nonstandard interfaces and complex software stacks that slow system bring-up and validation
- Compute contention where depth processing competes with perception, planning, and control tasks, reducing responsiveness and efficiency
- Interference in multi-sensor environments due to cross-interference between active components, complicating multi-device deployment
- Calibration drift and maintenance overhead that drive downtime as 3D systems lose alignment over time

LATTICE SOLUTION

- A CMOS sensor delivers an aligned 2D image and depth map using a single passive device
- FPGA-accelerated depth processing offloads key workloads, reducing application processor demand and freeing resources for higher-level tasks
- Ultra-compact 3D vision module designed for end-effector and space-constrained integration
- Wide field of view with no occlusion enables reliable near-field perception
- Standard MIPI camera interfaces simplify system integration and reduce development effort
- Cost-efficient integrated architecture supports scalable 3D deployment across industrial systems
- Future-ready FPGA edge processing enables additional ISP and image processing offload, further reducing system compute load

The Airy3D and Lattice solution overcomes these barriers by enabling near-field 3D perception using a single passive CMOS image sensor. Airy3D's DepthIQ™ technology optically encodes depth information directly into each captured image, eliminating the need for complex multi-sensor or active illumination setups. Key depth processing stages run on a Lattice CrossLink™-NX FPGA located close to the sensor, offloading the application processor and enabling efficient, deterministic performance at low power. The system connects through standard Mobile Industry Processor Interfaces (MIPI®), simplifying integration while supporting ultra-compact module designs for deployment at the edge.

In traditional industrial robotic arms, 3D cameras are often mounted away from the end effector due to minimum distance and occlusion constraints. This leads to a sequential "perceive then act" workflow that can reduce responsiveness and robustness in dynamic environments such as conveyor-based picking. Similarly, humanoid and mobile robots typically place vision sensors on the head or torso for navigation, which can result in occlusion and limited visibility during close-range manipulation.

By enabling compact, single-sensor 3D vision without stereoscopic occlusion, the Airy3D and Lattice solution brings continuous depth sensing closer to the point of interaction. This approach improves precision, adaptability, and real-time responsiveness across a wide range of robotic architectures.

Barriers to Scalable, Near-field 3D Vision in Manufacturing and Industrial Robotics

Deploying 3D perception in manufacturing and industrial robotic environments exposes fundamental limitations in today's sensing architectures. These challenges are especially pronounced in near-field applications, where systems must operate close to the end effector while meeting strict requirements for size, power, cost, and real-time performance. Maintaining reliable visibility during physical interaction further adds to system complexity.

- **Near-field Deployment Limitations:** Conventional 3D sensors struggle at close working distances due to minimum range constraints (minimum Z), self-occlusion, and bulky hardware. These limitations make it difficult to position sensors at robotic end effectors, grippers, or within industrial hands. As a result, many industrial systems mount 3D cameras on the robot base, capturing depth data only before motion begins. This approach reduces adaptability in dynamic or moving environments and limits robustness during real-time interaction.
- **Camera Size and Mechanical Complexity:** Stereo and active 3D approaches rely on multiple sensors, emitters, and precise optical alignment, which increase camera size and mechanical complexity. These requirements add design effort and calibration overhead, making them less suitable for compact, ruggedized industrial systems.
- **Power and Thermal Constraints in Industrial Cells:** Depth processing pipelines that rely on CPUs or GPUs consume significant power and generate heat. This limits their suitability for compact, fanless, always-on operation in dense robotic cells and thermally constrained industrial environments.
- **Integration Challenges with Industrial Vision Systems:** Many 3D solutions rely on nonstandard interfaces or complex middleware, making integration with existing MIPI-based camera pipelines, industrial processors, and real-time robotic control systems more difficult.
- **Cost Barriers to Scalable Factory Deployment:** Multi-sensor designs, active illumination, and high-end processors increase bill-of-materials (BOM) costs. These added expenses make it difficult to scale 3D vision across multiple robots or production lines in cost-sensitive manufacturing environments.
- **Compute Contention with Robotic Workloads:** Depth processing often competes with perception, planning, and control workloads on the application processor. This competition can impact deterministic performance, increase cycle time, and reduce overall system responsiveness.
- **Interference in Multi-sensor Environments:** Active 3D technologies (e.g., ToF and structured light) can interfere with each other when multiple devices operate in proximity, complicating deployment in multi robot or multi camera industrial settings.
- **Calibration Drift and Maintenance Overhead:** Stereo camera systems are sensitive to mechanical and thermal variation, which can lead to calibration drift over time. This increases maintenance requirements and can result in added downtime in industrial systems.

Compact, Low Power 3D Vision for Scalable Deployment

The Airy3D and Lattice solution, shown in Figure 2, delivers a compact, integrated 3D vision system designed for manufacturing and industrial robotics. It combines a CMOS image sensor and FPGA-accelerated depth processing on a Lattice CrossLink-NX FPGA to provide high-quality 3D perception and deterministic near-sensor processing.

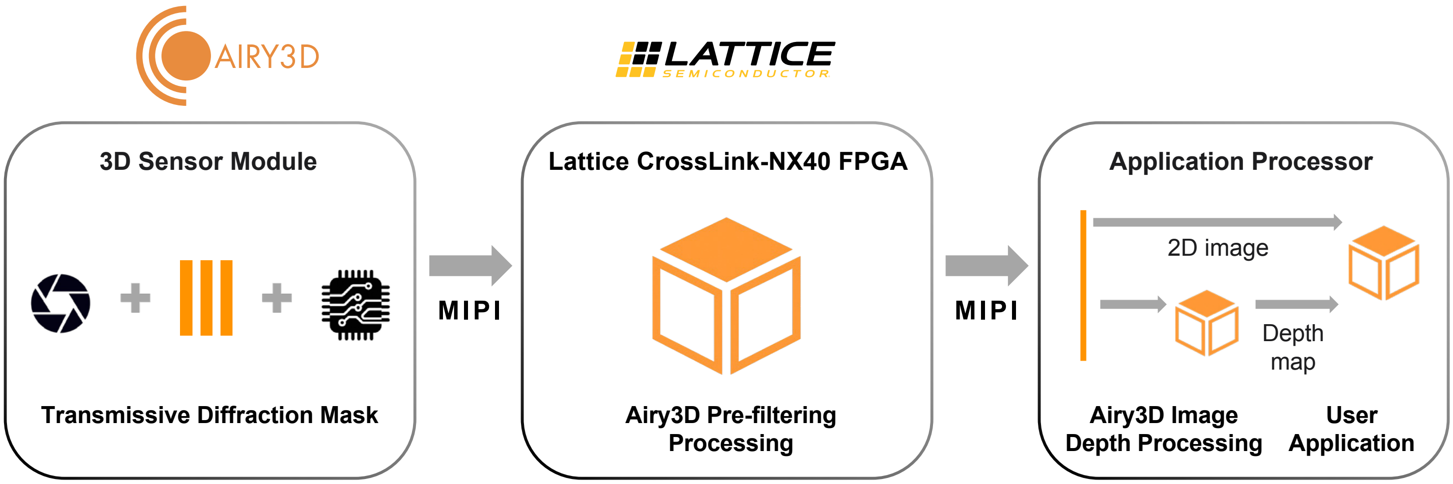
DepthIQ technology transforms a standard CMOS sensor into an RGB plus depth sensing device by adding a micron-thin Transmissive Diffraction Mask (TDM) on top of the sensor's microlens layer in the optical path. This approach encodes depth information into each captured image while preserving native 2D resolution and image quality.

Depth processing is offloaded to the Lattice CrossLink-NX FPGA, which performs key stages of the Airy3D pipeline close to the sensor. This reduces reliance on the application processor and improves overall system efficiency. The final depth output is generated on the application processor through the Airy3D software development kit (SDK).

By removing stereo camera pairs, external illumination, GPU-intensive processing, and bulky sensing hardware, the solution delivers an ultra-compact, power-efficient 3D vision module. This compact form factor makes it ideal for deployment at robotic end effectors, grippers, and other space-constrained locations, improving both responsiveness and precision in industrial automation systems.

Its wide field of view, combined with the absence of self-occlusion, enables reliable near-field 3D depth perception. This supports applications such as grasping, pick-and-place, bin picking, and in-hand manipulation. As a result, manufacturers can scale deployment more easily across cost- and power-sensitive environments while simplifying system integration.

Figure 2: Airy3D and Lattice 3D Vision Solution



Key Capabilities

- **Single-sensor Aligned 2D and Depth Output:** Time-synchronized, pixel-aligned 2D images and depth maps are generated from a single passive CMOS sensor using Airy3D DepthIQ technology. This inherently aligned data simplifies calibration and streamlines deployment in industrial robotic systems.
- **FPGA-accelerated, Compute-efficient Depth Processing:** Key stages of the depth processing pipeline run on a Lattice CrossLink-NX FPGA, reducing the load on the application processor. This approach isolates depth extraction from perception and control workloads, freeing up compute resources for higher level functions.
- **Ultra-compact 3D Vision Module:** The elimination of stereo baselines and external illumination enables a compact design that integrates easily at robotic end effectors, grippers, and other space-constrained locations in industrial automation equipment.
- **Wide Field of View with No Occlusion:** A wide field of view and the absence of self-occlusion enable reliable near-field perception for grasping, pick-and-place, bin picking, and in-hand manipulation, even at close working distances.
- **Standard MIPI Interfaces for Easy Integration:** Native support for standard MIPI interfaces simplifies integration with existing camera pipelines and industrial processors, reducing both software complexity and overall system development effort.
- **Cost- and Power- Efficient Architecture:** Combining 2D and 3D sensing in a single sensor without external illumination lowers system cost and power consumption, enabling scalable deployment across manufacturing platforms.
- **Future-ready FPGA Edge Processing:** The FPGA can support additional edge processing functions such as image signal processing (ISP) and image scaling. This capability can further offload the application processor and improve overall system efficiency.

By addressing the practical constraints of near-field deployment, the Airy3D and Lattice architecture delivers system-level advantages that improve sensor placement, system efficiency, and integration across manufacturing and industrial robotic systems.

System-level Advantages for Industrial Robotics

- **Higher Throughput and Operational Efficiency:** Continuous, close-range 3D perception enables robots to operate effectively in dynamic environments such as moving conveyors. This reduces reliance on “capture then act” workflows and improves overall productivity.
- **Lower System Cost and Total Cost of Ownership:** A single-sensor, passive design eliminates the need for multiple cameras, active illumination, and high-performance processing platforms. This approach reduces hardware cost, power consumption, and overall system complexity.
- **Simplified Integration and Scalable Deployment:** FPGA-accelerated processing reduces demand on the application processor and simplifies system partitioning. Combined with SDK-based depth output, this enables faster integration and efficient scaling across multiple robots and production systems.

Competitive Landscape and Deployment Tradeoffs

Several established approaches are used to enable near-field 3D perception, each optimized for specific operating ranges, environments, and system constraints. While these technologies perform well in their intended use cases, they introduce tradeoffs in size, power consumption, compute demand, cost, and integration complexity. These limitations become more pronounced when depth sensing must be deployed close to the point of interaction in manufacturing and industrial robotic systems. The following outlines the primary alternative approaches to near-field 3D perception and their key limitations.

- **Stereo Camera Systems:** Stereo systems use two or more cameras to estimate depth through triangulation, requiring precise alignment and physical separation between sensors. This increases module size and mechanical complexity. Performance also degrades at close working distances due to reduced field-of-view overlap and increased occlusion between cameras.

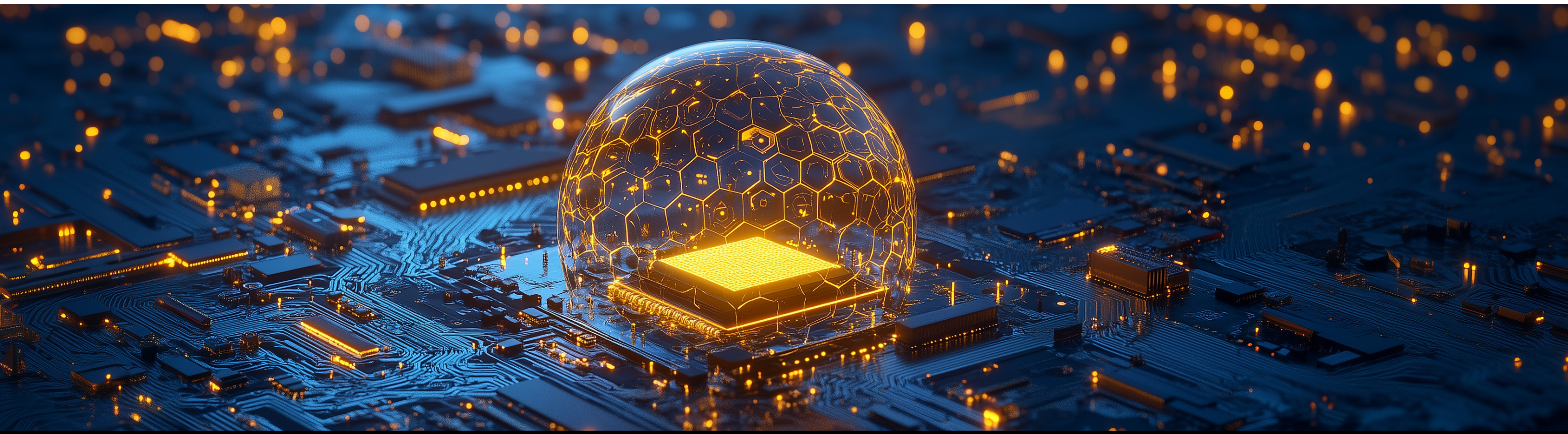
- **Active 3D Systems (Structured Light and Time of Flight):** Active 3D systems rely on projected illumination to measure depth, adding emitters and optics that increase system complexity. Their performance can be sensitive to ambient lighting and surface reflectivity. Minimum distance limitations further restrict their ability to operate in near-field applications.
- **Lidar-based 3D Sensing:** Lidar systems generate depth through laser scanning and point cloud reconstruction. While effective at longer ranges, they typically require larger sensors, consume more power, and involve higher compute and system costs. As a result, they are not well suited for close-range manipulation tasks.
- **Monocular Depth Estimation:** Monocular approaches rely on CPU- or GPU-based processing to reconstruct depth from images. While flexible, these methods are computationally intensive and consume significant power and thermal budget. They are often unsuitable for embedded or resource-constrained industrial systems and compete with perception, planning, and control workloads on the application processor.

In contrast, the Airy3D and Lattice architecture is built for near-field edge use, deriving depth from a single passive CMOS sensor and offloading processing to a Lattice CrossLink-NX FPGA. This enables 3D perception directly at robotic end effectors, improving responsiveness and precision.

Conclusion

Near-field 3D perception is becoming a foundational requirement for modern manufacturing, industrial robotics, and advanced automation systems. However, conventional 3D sensing technologies continue to struggle with the size, power, compute, and integration constraints associated with close-range deployment. As outlined throughout this analysis, approaches such as stereo vision, active 3D sensing, lidar, and GPU-centric processing introduce tradeoffs that limit their effectiveness at the point of interaction, particularly for robotic end effectors and in-hand manipulation.

The Airy3D and Lattice architecture addresses these challenges by combining Airy3D DepthIQ optical depth encoding with FPGA-accelerated processing on a Lattice CrossLink-NX FPGA. As a result, the joint solution provides a scalable, cost-efficient path for deploying near-field 3D vision in real-world industrial and robotic systems. These advantages translate into improved operational performance and greater scalability in environments where traditional 3D approaches fall short.



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