



WHITEPAPER

Solving Processing Bottlenecks in High-Bandwidth Machine Vision Systems

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Introduction

Machine vision systems are rapidly evolving to meet the demands of modern industrial, medical, and defense applications. These systems are increasingly required to support higher resolutions, faster frame rates, and multi-camera configurations, often operating in real-time and under continuous load. While the GigE Vision® standard has long provided a reliable framework for video transmission over Ethernet, the challenge has shifted from bandwidth to processing. As data rates climb beyond 10 Gbps, the bottleneck is no longer the camera or the network—it's the host system's ability to process and manage incoming data efficiently.



This whitepaper explores the emerging technologies and architectural strategies that help overcome these processing bottlenecks. It focuses on the role of Thunderbolt connectivity, external frame grabbers, and RoCEv2 (Remote Direct Memory Access over Converged Ethernet) in enabling scalable, high-performance machine vision systems. It also introduces the upcoming 25G Ethernet embedded interface from Pleora® and outlines practical applications in industrial inspection, medical imaging, and scientific research.

The Shifting Bottleneck: From Bandwidth to Processing

For nearly two decades, GigE Vision has kept pace with the increasing bandwidth demands of machine vision. However, as applications push toward 4K and 8K video, 24/7 streaming, and real-time analysis, the pressure on host systems intensifies. The real challenge becomes ensuring that the processing pipeline—from image capture to analysis—can keep up without introducing latency or data loss.

At lower data rates, below 1 Gbps, standard CPUs can comfortably manage the workload. As data rates increase to 2–5 Gbps, CPU strain becomes noticeable, and designers often turn to GPUs or FPGAs for acceleration. In the 5–10 Gbps range, traditional PC architectures begin to falter. Frame grabbers, optimized memory I/O, and system-level tuning become necessary to avoid dropped frames and latency issues. Beyond 10 Gbps, the problem escalates. Host CPUs alone cannot handle the load, and designers must adopt strategies such as edge processing—where computation occurs closer to the camera—or advanced networking protocols like RoCEv2 that enable direct memory access.

Data Rate	Processing Considerations
<1 Gbps	Standard CPU; minimal bandwidth concerns
1–2 Gbps	Moderate CPU load; standard networking OK
2–5 Gbps	Strains CPUs; GPU/FPGA acceleration recommended
5–10 Gbps	Requires 10GbE+, frame grabbers, better memory I/O
>10 Gbps	Real-time distributed/edge processing or RoCEv2 required

Table 1: At below 1 Gbps, bandwidth isn't a concern as a standard CPU can easily handle the workload. Once we hit the 2 to 5 Gbps range, CPUs start to strain. In the 5 to 10 Gbps range, we start hitting the limits of traditional PC architectures.

Balancing Performance, Reliability, and Cost

As machine vision systems scale, designers must balance performance with reliability and cost. The goal is not just to move data faster but to ensure that every component in the system—from the camera to the processor to the display—can handle the increased throughput without compromising stability or usability.

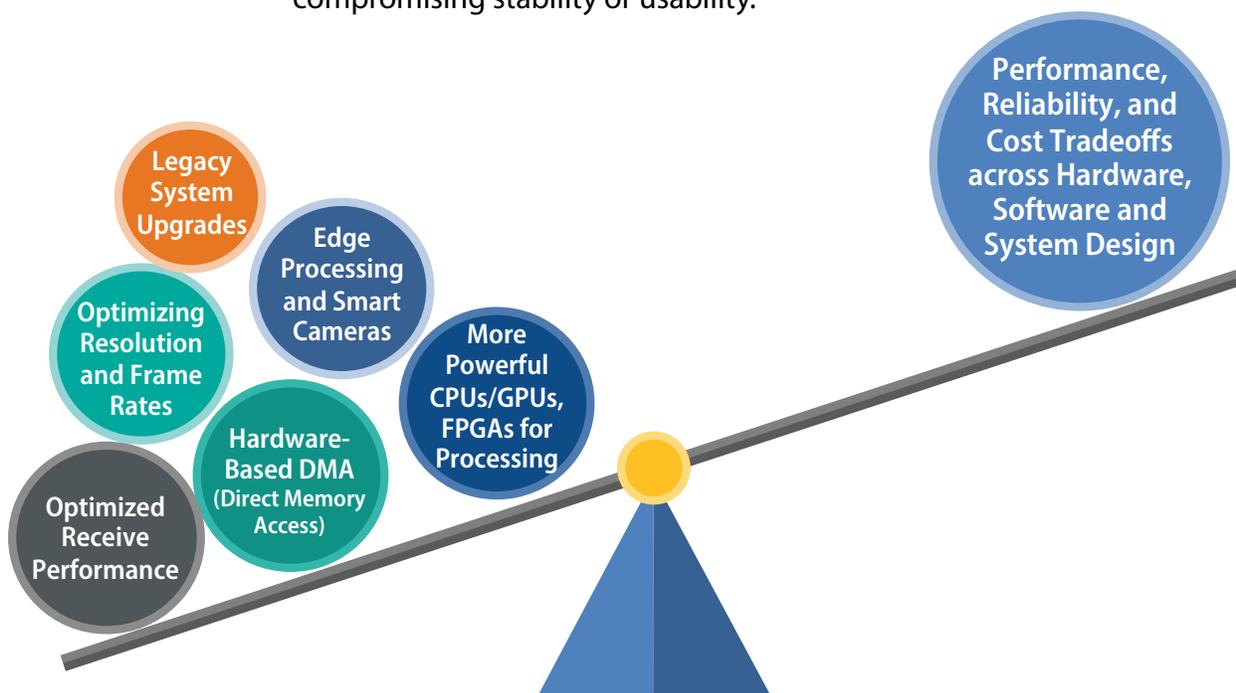


Image 1: For device designers and system integrators, as machine vision applications push into 10 Gigabit bandwidths and higher the main challenges shift from just moving images to managing system performance, cost, and reliability.

One of the first challenges encountered at 10 Gbps is poor receive performance. CPUs struggle to manage incoming data streams, leading to dropped frames and increased latency. To address this, designers must consider hardware-based DMA engines that offload data transfer tasks from the CPU. GPUs, FPGAs, and data processing units (DPUs) can handle image preprocessing workloads, while optimized Ethernet switches and NICs ensure deterministic, low-latency performance.

Edge processing and smart cameras also play a critical role. By performing some computation locally, these devices reduce the burden on central systems and improve responsiveness. However, these solutions must be carefully integrated to maintain synchronization and avoid packet loss.

Thunderbolt: A New Option for High-Bandwidth Vision

Thunderbolt technology has emerged as a compelling solution for machine vision applications operating in the 10 Gbps range. Thunderbolt 3 and 4 support up to 40 Gbps per cable, while Thunderbolt 5 is pushing toward 80 Gbps. This represents a significant leap over standard GigE Vision interfaces, which typically range from 1 to 10 Gbps.

 High-bandwidth Support	 Low Latency	 Single Cable
Up to 40 Gbps per cable – significantly higher than standard GigE Vision (1–10 Gbps)	Direct PCI Express (PCIe) tunneling between cameras and the host system	Like GigE Vision deliver data, power, and control signals over a single cable (distance: 2 meters over passive or 50+ meters using active optical cables)

Table 2: Bandwidth, latency and cabling advantages of Thunderbolt.

Thunderbolt enables direct PCIe tunneling, allowing data from the camera to be transferred directly to the host system’s memory with minimal overhead. This dramatically reduces latency, which is critical for real-time decision-making in machine vision systems. Like GigE Vision, Thunderbolt can deliver data, power, and control signals over a single cable, simplifying system design and reducing clutter.

Pleora’s GigE Vision to Thunderbolt External Frame Grabber combines the advantages of GigE Vision, PCIe, and Thunderbolt. It transmits high-bandwidth data—up to 22.5 Gbps—with low, predictable latency over standard Ethernet and USB-C interfaces. The built-in DMA engine acquires and copies full image data into the host PC’s memory, freeing the CPU for application-level processing. This solution enables the use of cost-effective platforms such as laptops, embedded systems, and single-board computers, eliminating the need for expensive internal frame grabbers or specialized industrial PCs.

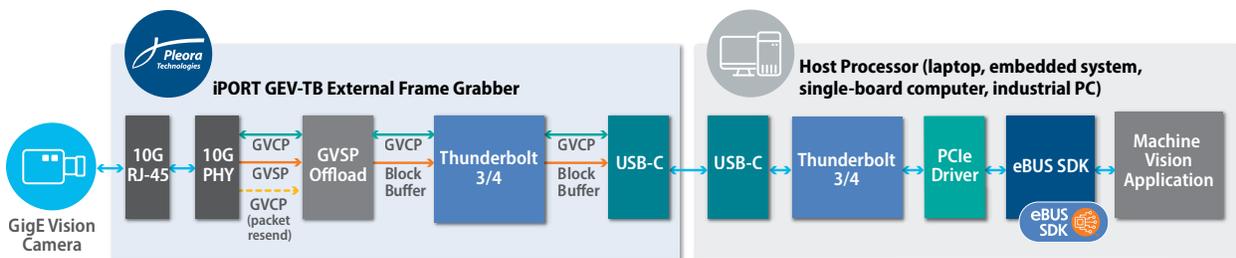


Image 2: Pleora’s external frame grabber converts GigE Vision cameras into PCIe cameras and transmits high bandwidth—up to 22.5 Gbps—imaging and video data with low, predictable latency directly to a Thunderbolt/USB 4 port or Thunderbolt 3/4 USB-C port. By eliminating the need for a traditional frame grabber, designers can reduce system size, cost, and power by using smaller form factor laptops, embedded computers, and single-board computers

RoCEv2 and GigE Vision 3.0: The Future of Device Design

To address the limitations of traditional data transport methods at very high data rates, the GigE Vision standard is evolving. GigE Vision 3.0 will integrate RoCEv2, a protocol derived from the InfiniBand™ specification that enables direct memory access over Ethernet. RoCEv2 allows imaging data to be transferred directly from the camera or sensor to the host processor’s memory without involving the CPU, operating system, or cache.

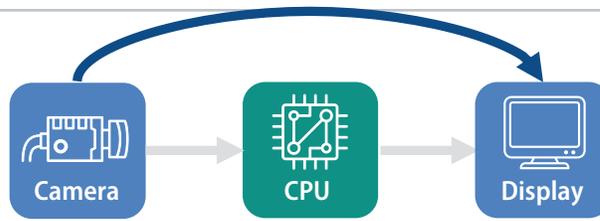


Image 3: Zero copy transfer refers to a method of transferring image data directly from the camera to the display or processing memory without routing it through the CPU. This approach significantly improves system performance by reducing latency and lowering power consumption.

This zero-copy transfer significantly lowers glass-to-glass latency and frees CPU resources for value-added tasks such as image analysis and AI inference. RoCEv2 operates over Layer 3 Ethernet, making it routable across IP networks and suitable for distributed systems. It supports high-throughput links of 25 Gbps and beyond, enabling multiple high-resolution, high-frame-rate streams with minimal CPU usage.

Step	GigE Vision (no RDMA)	RoCEv2 RDMA
Network stack	OS processes every packet	Bypassed entirely
Memory copy	1–2 extra copies	Zero-copy
CPU usage	High	Very low
Transport latency	50–300 μ s	2–10 μ s
Processing start	After full frame arrives	Can start during transfer

Table 3: This table compares the performance characteristics of traditional GigE Vision systems with RoCEv2 RDMA implementations and highlights the benefits of low latency in imaging applications.

Pleora is developing a 25G Ethernet Embedded Video Interface that leverages RoCEv2 to solve critical receive challenges in high-bandwidth imaging devices. This off-the-shelf solution reduces design time, cost, and risk, allowing R&D teams to focus on differentiating performance features. The interface supports serialized LVDS lanes, large image buffers, and GigE Vision 3.0 compliance, making it ideal for next-generation imaging systems.

Real-World Applications

Medical Imaging

One of the fastest growing markets for machine vision in the medical sector is point of care and mobile diagnostics systems. This can include bedside imaging systems for quick diagnostics in emergency rooms or ICUs without moving the patient, portable systems for veterinary diagnostics in clinics or field settings, and mobile health units deployable imaging systems for remote or underserved areas.

Portable diagnostic systems, such as bedside X-ray and veterinary imaging platforms, benefit from Thunderbolt's high-speed data transfer and compact form factor. GigE Vision cameras transmit data to external frame grabbers, which convert the signal for Thunderbolt transmission to embedded processors. This architecture supports real-time display and analysis while reducing hardware costs and improving mobility.

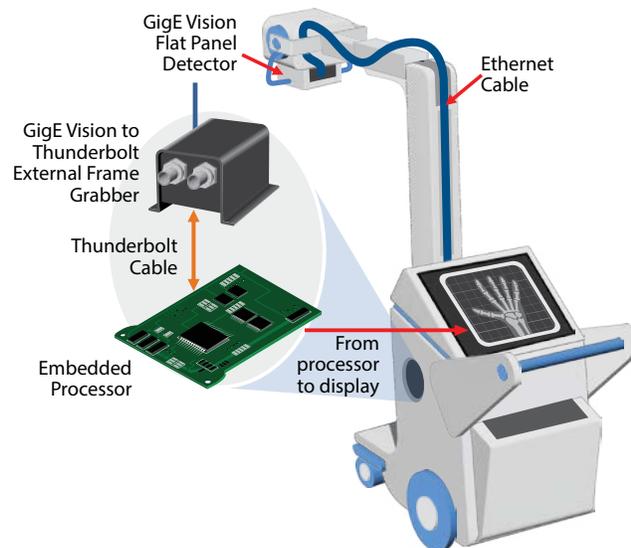


Image 4: One of the fastest growing markets for machine vision is medical point-of-care and mobile diagnostics systems. The focus for designers is combining high-bandwidth image acquisition with compact, embedded processing platforms to ensure portability, while also providing an easy to use solutions for a technician or health care provider.

Microscopy

In life sciences, ophthalmology, and quality control, compact systems using GigE Vision cameras and Thunderbolt frame grabbers enable high-resolution imaging with laptop-based processing. These systems are ideal for mobile deployments and space-constrained environments.

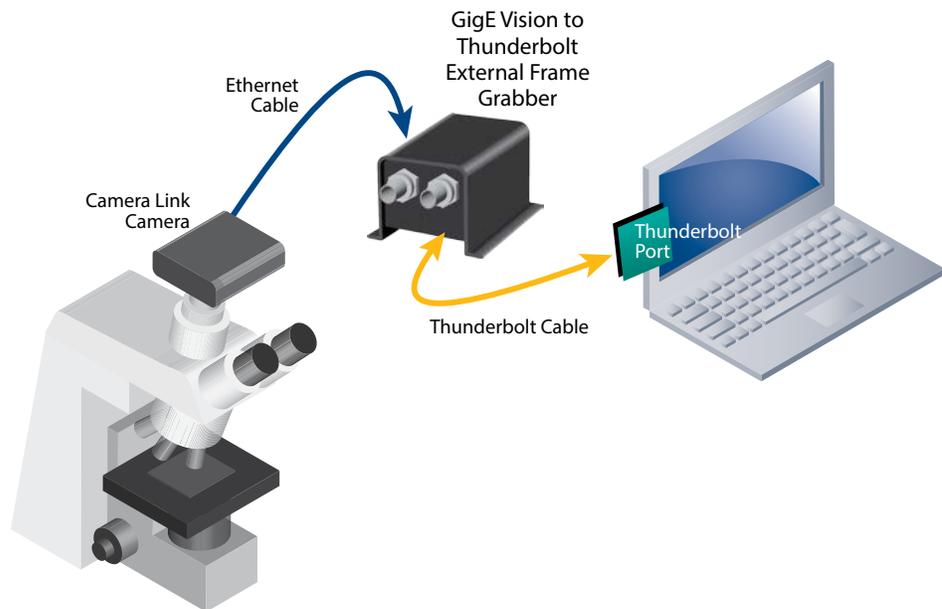


Image 5: GigE Vision over Thunderbolt solution enables the use of laptops for higher bandwidth imaging applications in fields like life sciences, ophthalmology, and quality control. The focus is on achieving portability and processing flexibility without compromising image quality or speed.

Industrial Inspection

Multi-camera setups in electronics and semiconductor inspection require synchronized, low-latency data transfer. RoCEv2 enables real-time defect detection and analysis by bypassing traditional bottlenecks and allowing parallel processing.

Defense and Surveillance

Wide-area monitoring systems benefit from RoCEv2's scalability and low latency. Distributed architectures can support multiple sensors and displays, improving situational awareness and threat detection capabilities.

Conclusion

As machine vision systems continue to scale in complexity and performance, designers must adopt new strategies to manage processing bottlenecks. Thunderbolt and RoCEv2 offer powerful tools to reduce latency, optimize CPU usage, and enable real-time imaging across a wide range of applications. Pleora's solutions—including external frame grabbers and embedded interfaces—provide a flexible, scalable foundation for next-generation vision systems.

By addressing the full processing pipeline—from image capture to analysis—these technologies ensure that machine vision systems can meet the demands of modern industry without compromising reliability or cost-efficiency.

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