WP527 (v1.0)

New UltraScale+ Devices in InFO Packaging Enable Compact Industrial Cameras

Xilinx's new Zynq UltraScale+ MPSoCs in InFO packaging enable the full range of industrial performance, including custom image processing, application-specific and AI acceleration, and industrial-grade life cycle, reliability, safety, and security—all in a compact form factor offering high compute density.

ABSTRACT

Vision applications across industrial and medical markets are demanding improvements in camera size, speed, intelligence, and power consumption. Additional requirements for industrial markets include safety, security, and extended temperature performance and life cycles. This white paper explores some of those requirements, in applications including machine vision, factory automation and robotics.

New Zynq UltraScale+ MPSoCs from Xilinx in InFO packaging offer increased performance/watt, unlocking intelligence, resolution, and speed for compact form factor cameras, that in the past would have been limited to 1080p or even 720p resolution and 30 fps. These new products enable the full range of industrial performance, including custom image processing, application-specific and AI acceleration, and industrial-grade life cycle, reliability, safety, and security.

Introduction

Industrial camera manufacturers are constantly challenged to design smaller products. Unlike consumer camera solutions, machine vision and, in particular, factory automation cameras, must comply with a stringent set of standards and requirements. These include those focused on low-light performance, high frame rates to enable high-speed production and response, and superior optical qualities from the lens and sensors, on top of water-resistance and other specific long-term reliability demands for an industrial application. Machine vision systems also often support complex industrial communication standards such as Time-Sensitive Networking (TSN), GigE Vision, and CoaXPress.

Machine Vision Camera Requirements

Machine vision camera applications often require the use of larger, higher performance components than are used in consumer applications. For example, image sensor size—unlike pixel resolution—is directly proportional to the amount of light being captured by the camera, so a larger sensor generally delivers a higher image quality. However, high resolution in a sensor also produces more detailed images, and a higher frame rate enables faster image capture and potentially speeds up a production line or robot operation. Those high resolution and faster sensors generate high pixel data rates, thereby increasing the image processing workload further along the pipeline. See Figure 1.

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Figure 1: **Xilinx SmartCamera+ Demonstration Platform**

In addition to sensing, processing, and optimizing images, the camera must also support high-speed interfaces common to machine vision cameras, such as GigE Vision, USB3 Vision, CoaXPress, Camera Link, and Camera Link HS. Trade-offs include bandwidth, cable length, cost, and complexity. See Figure 2.

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Figure 2: **Camera Interface Standards**

Industrial cameras must also comply to more stringent levels of security and reliability than the average consumer product. For example, most industrial cameras are:

- Warrantied for at least three years (but are generally operated for longer)
- Operate over extended temperature ranges (often –40 to +85°C)
- Certified by multiple industrial standard bodies, such as ISO, TUV, RoHS, and CE.

Industrial camera users are also increasingly demanding functional safety and cybersecurity requirements, particularly as these cameras become part of a complex networked system that can include human co-workers.

Camera optics, i.e., the lens system, also play a major role in the size of the camera. Analogous to the sensor, a larger lens generally captures more light for the camera system, as do higher quality lens materials and a more complex optical design. Other considerations in selecting a lens include requirements for aperture, focal length, specific lens mount compatibility, wavelengths of interest, as well as matching with the chosen image sensor.

These requirements differ greatly to those of the average consumer mobile phone camera. For example, many consumers tend to replace their cell phones about every other year, so the lifespan is significantly shorter. Cost is constrained as an acceptable percentage of the phone's total bill of materials (BOM). And though the advent of the smartphone stopped the race for the tiniest phone in the 1990s, the pressure to keep phone cameras (sensors and optics) thin has continued.

Beyond cost, size, and lifespan, other requirements for a consumer camera are also different than those of an industrial camera. Paramount is the ability to capture a "good" image, at least as far as the typical phone user is concerned. Interestingly, this is one area where beauty is *definitely* in the eye of the beholder, because the human eye has specific biases about what constitutes a good image. For example, is it better for the camera to accurately capture colors—or make the user look good in a selfie? [(1)] See Table 1.

1. Webinar: Break the Bounds of Standard ISPs: A Xilinx Introduction to Custom ISPs

Table 1: **Typical Industrial Camera Requirements**

Feature	Requirement
Sensors and Optics	>1/3"
Shutter Type	Global or Rolling Shutter
Dynamic Range	High Dynamic Range
Image Processing	Application Specific
Camera Interfaces	GigE Vision, USB Vision, CameraLink, CoaXPress
Added Features	Machine Learning, Adaptability
Lifespan	3+ years
Certifications	Multiple, including ISO, TUV, RoHS, CE

New Trends in Industrial Camera Technology

The classic machine vision camera usage model is of a camera in a factory, inspecting products as they pass through an automatic production line. The factory of today, however, expects higher performance, speed, safety, and security, all of which modern industrial cameras need to support, without sacrificing size, power, or cost. There is increasing use of machine learning (ML), and cameras must be able to deploy trained machine learning models in order to automatically classify, detect, or segment features of objects faster and/or more accurately than human workers can. Cameras inspect food and beverages, help robots pick and pack boxes, ensure medication is labeled correctly, and sort recycled materials in waste management facilities. See Figure 3.

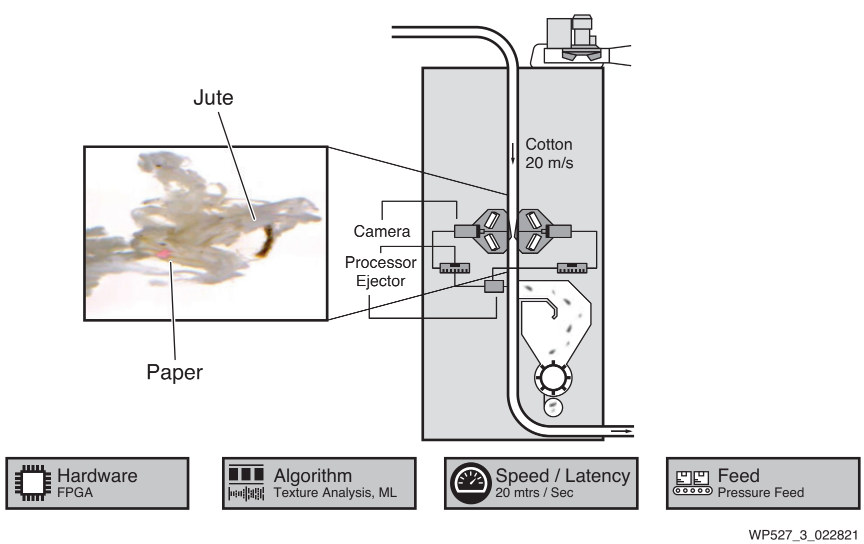

Figure 3: **Cotton Contamination Sorting System by YantraVision**

Machine vision cameras are also moving out of the factory. Industrial cameras are a key enabler of autonomous mobile robots (AMRs) being used for package delivery, hospitality, warehouse management, construction, agriculture, cleaning, and a plethora of other applications. See Figure 4. As mobile systems, AMRs not surprisingly have strict requirements for low power and size. Even in the factory, machine vision cameras must work side by side with robots and humans, limiting size and power.

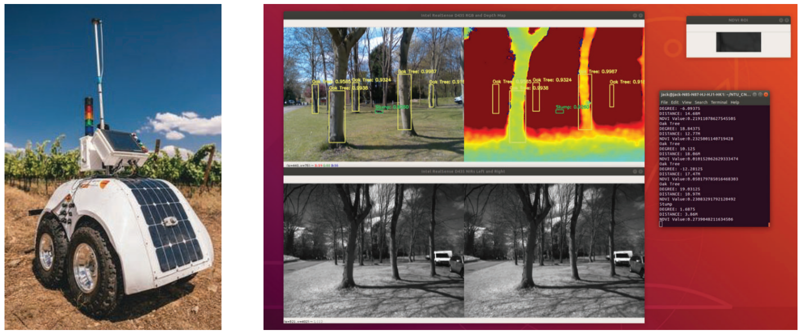

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Figure 4: **VineScout Vineyard Monitoring Robot[1]**

1.Blog: https://forums.xilinx.com/t5/AI-and-Machine-Learning-Blog/Xilinx-Zynq-Devices-Take-Charge-of-Robots/ba-p/1015700

Some Recent Innovations

Like consumer cameras, machine vision cameras are reaching new resolutions. Sony image sensors for high-end machine vision are now available up to 25 and 31 megapixels, and Canon is promoting a 250 megapixel industrial image sensor. Other innovations are happening in the type of sensors and the light data being captured. Conventional cameras are based on silicon-based CMOS technology, optimized for visible light imaging with red, green, and blue (RGB) pixels. But for many applications, other types of sensors can offer improved and enhanced capabilities. Polarization sensors can "see" through water and reflections. Short-wave infrared (SWIR) sensors can detect and see through certain materials, and thermal sensors can capture temperature instead of visible light data. Also, temperature measurement applications have been of keen interest recently, in light of Covid19 screening requirements. See Figure 5.

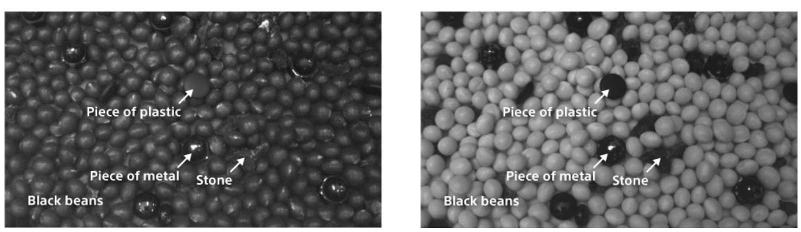

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Figure 5: **Inspection with Visible Light vs. SWIR (Source: Sony Semiconductor Solutions Group)**

Camera requirements today also go beyond simply processing sensor data into visible or usable images. Machine learning is increasingly being used to create smart factories and AI systems that can be quickly trained to determine whether a product meets quality standards—or re-trained to assemble a newly designed product. While networked cameras can certainly use cloud-based resources to store and analyze images, practical concerns around bandwidth, security, and latency can require image processing and machine learning to be done at the edge, for example in a smart AI camera.

Innovations such as these, task not only the camera sensor, but also the image processing pipeline. Standard image signal processors (ISPs) are generally optimized for conventional RGB CMOS sensors, particularly for high-volume applications, such as consumer phones, drones, and tablets. Industrial applications, as described above, represent a plethora of differing use cases and technologies, and while certain standards exist (e.g., interface standards like MIPI, GigE Vision, and PCI Express®), camera requirements can differ wildly.

Zynq UltraScale+ MPSoC in InFO Packaging

Adaptive computing devices like MPSoCs offer the compute performance and flexibility often appreciated by developers of industrial cameras but have historically only been available in larger package sizes with hundreds of pins. For example, at their initial release, Zynq UltraScale+ ZU2CG/EG and ZU3CG/EG MPSoCs smallest package size was 19x19mm, a 484-pin, flip-chip, ball grid array (BGA) with 0.8mm pitch.

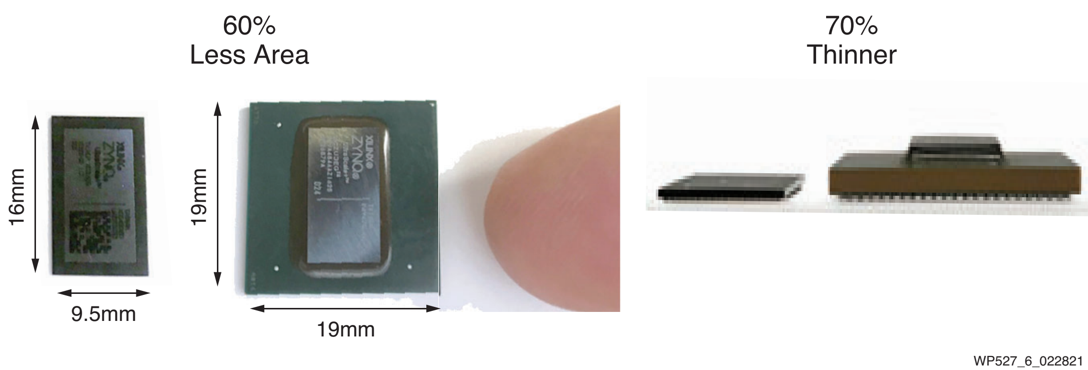

Figure 6: **Zynq UltraScale+ Devices in InFO Packaging**

The ZU2CG/EG and ZU3CG/EG MPSoCs are now available in much smaller packages. Xilinx is leveraging TSMC's Integrated Fan-Out (InFO) packaging, which significantly reduces the package size to 9.5x16mm—without losing I/Os or compromising performance. The InFO packaging eliminates the substrate from traditional chip scale packaging (CSP), enabling smaller, thinner and high density interconnect packages.

In the InFO package, the Zynq MPSoCs takes up less than half the board space and are considerably thinner, too—0.644mm instead of 2.41mm. All dimensions (x, y, and z) are critical, given some of the new form factors required by industrial applications. The InFO packaged versions of the ZU2CG/EG and ZU3CG/EG are 60% smaller and 70% thinner than their initial versions.

High DPR (die area-to-package area ratio) packages like InFO require ball pitch reduction, which then in turn drives the need for compatible printed circuit board (PCB) capability. High-density interconnect (HDI) PCB with edge bonding or board-level underfill around the package are the industry norms for designing with InFO. The benefits are substantial—InFO offers the best thermal performance among the landscape of small form factor packages and can reduce the overall cost of a product through area savings while enabling exceptional compute density.

In addition, Xilinx is offering a new ZU1 option—in an even smaller package with reduced power consumption. The ZU1 is also offered in a package-migratable option with the existing ZU2CG/EG and ZU3CG/EG devices, meaning designers can select either maximum scalability (with current ZU2CG/EG and ZU3CG/EG designs not in InFO packaging) or else minimum size. See Table 2.

Table 2: **Device Resource Information**

	ZU1CG/EG	ZU2CG/EG	ZU3CG/EG
System Logic Cells (K)	81	103	154
Total Block RAM (Mb)	3.8	5.3	7.6
DSP Slices	216	240	360
Transceivers	6Gb/s (4)	6Gb/s (4)	6Gb/s (4)
Arm Cortex-A53 Cores	2 / 4	2 / 4	2 / 4
Dual Arm Cortex-R5F Cores	1	1	1
Arm Mali™-400MP2	0 / 1	0 / 1	0 / 1
InFO Package Size (mm)	9.5x15	9.5x16	9.5x16

As an example of the Zynq MPSoCs in InFO packaging in a compact industrial product, Lucid Vision Labs of Richmond, Canada, offers an industrial machine vision camera called the Triton Edge. To fit into dimensions of only 29x44x45mm, Lucid's cameras require the most compact and efficient components. Lucid's engineers have designed an innovative flex-rigid board architecture that packs an amazing amount of technology into a compact IP67 camera case. See Figure 7.

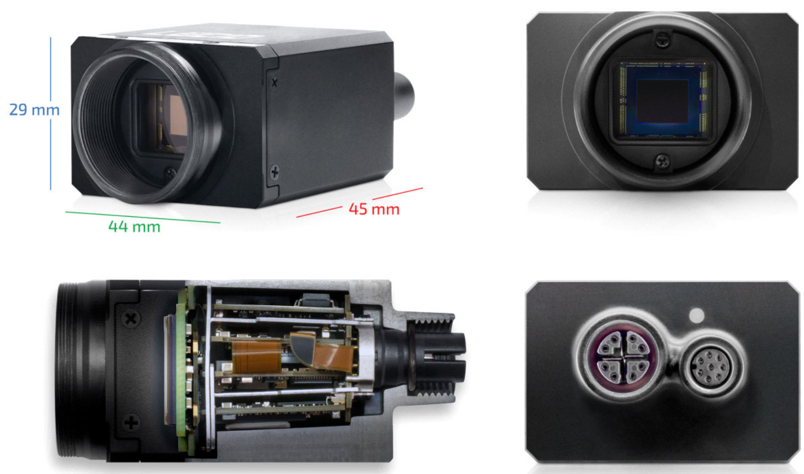

Figure 7: **Triton Edge Camera with InFO Packaging**

Triton Edge's flex-rigid board design combined with Xilinx's Zynq MPSoC inFO packaging allows Lucid to provide a deeper level of on-camera control and customizability while maintaining the camera's lightweight and compact size. Without relying on a camera manufacturer's SDK or the need to develop and run code on a host PC, OEMs can develop their own IP on the camera by creating custom FPGA image processing, including AI inference.

Beyond compact cameras, other ideal applications for Zynq MPSoC InFO packaging include those where both adaptive compute power and small size are needed. These include portable medical equipment, hand-held test equipment, and military radios.

Conclusion

Xilinx's Zynq UltraScale+ MPSoCs provide exceptional processing and acceleration for equipment manufacturers across a wide range of vision, healthcare, and industrial systems. The miniaturization of the Zynq MPSoCs in TSMC's InFO package further enables industrial camera manufacturers to broaden the reach of custom image processing, AI acceleration, and other adaptable functions into the most compact of cameras and other industrial products.

For more information about the new Xilinx products in InFO packaging, go to: www.xilinx.com/zynq-ultrascale-plus

Acknowledgment

The following Xilinx employee has authored or contributed to this white paper: Susan Cheng, marketing manager, Industrial Vision.

Revision History

The following table shows the revision history for this document:

Date	Version	Description of Revisions
03/16/2021	1.0	Initial Xilinx release.