High-Speed Camera Recorder Powered by MLE's Fast FPGA RAID (FFRAID)

An Excelitas Technologies Brand

Excelitas PCO offers two distinct platforms for high-speed cameras:

The pco.dimax cs high-speed cameras are specifically designed for demanding car safety applications. With high frame rates and up to 4 MP resolution, these rugged, compact cameras provide exceptional light sensitivity, image quality, and color rendering, making them ideal for both on-board and off-board crash testing. Available in three models, they feature secure trigger synchronization, automatic image calibration, HD-SDI output, integrated lens control, and a quick-change lens adapter. These cameras are well-suited for airbag analysis, crash testing, fuel injection analysis, and more.

The pco.dimax 3.6 ST is the latest addition to the pco high-speed camera family, offering advanced streaming capabilities with a recording speed of over 2000 fps at full 3.6 MP resolution. This new model is designed for a wide range of industrial, scientific, and aerospace applications.

Challenge:

The new pco.dimax (https://www.excelitas.com/product/pcodimax-36-st-high-speed-camera) series offers a unique platform of high-speed streaming cameras that enable clear images with a recording speed of over 2000 fps at a full resolution of 3.6 MPixel.

Equipped with a Camera Link HS (CLHS FOL) data interface, it ensures real-time, uncompressed 10-bit data transmission over 8x10Gb optical fiber, preserving lossless image quality.

This massive raw data rate of about 80 Gigabits per second (2166 frames per second * 1984 * 1808 pixels per frame * 10 bits per pixel) comes with the challenges to record this image data gapless and lossless!

Today's off-the-shelf Network Attached Storage (NAS) systems max out at sustained write speeds above 60 Gigabits per second. The reason is not so much performance limitations of the NVMe SSDs neither limited by the integrated RAID cards but a fundamental limitation of the underlying computer architecture:

The streaming datapath runs through software, i.e. the operating system and the user-space application, which creates a performance bottleneck.

The Need for Domain-Specific Architectures:

Computer architecture traditionally focuses on general-purpose processors (CPUs) designed to handle a wide range of tasks. However, the increasing demands of specific applications have led to the development of so-called domain-specific architectures (DSAs). DSAs are tailored to excel in a particular domain, often achieving significant performance and energy efficiency gains compared to general-purpose CPUs.

One technique to improve performance or energy efficiency (or both!) is offloading computationally intensive tasks from the CPU to specialized hardware accelerators. Field-Programmable Gate Arrays (FPGAs) offer a flexible platform for implementing

these accelerators, allowing for customization and optimization of the hardware to match the specific algorithms and data structures of the target application. This combination of CPUs and FPGA-based acceleration enables systems to tackle complex workloads more efficiently.

Open source has revolutionized software development, enabling free use and modification. To minimize costs, risks and ensure compliance in modern automotive, industrial, medical, or telecommunications systems, software reuse is essential. Leveraging existing code, whether open source or internal, reduces development time, bugs, and simplifies meeting legal and security standards.

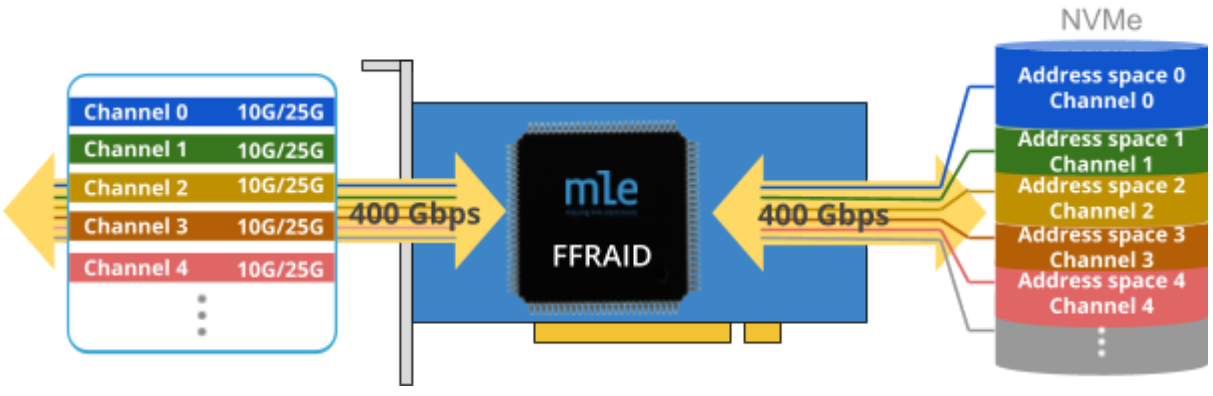
MLE has been working on the intersection of those three topics: Domain-Specific Architectures where - mostly open source - software shall be accelerated via the use of FPGAs. Hence, computations move from Software to Silicon - MLE's mission!

Fast FPGA RAID - A Scalable Solution:

To realize high-speed data acquisition and recording systems, MLE has implemented FFRAID, a Fast FPGA RAID.

The fundamental concept behind a Fast FPGA RAID is to combine two technologies: Computational storage with on-the-fly data-in-motion processing accelerated by FPGA together with Berkeley "Redundant Arrays of Independent Disks" (RAID) (https://www.computerhistory.org/storageengine/u-c-berkeley-paper-catalyses-interest-in-raid/).

The outcome is MLE's FFRAID, a channel-oriented and scalable architecture.



Channel-oriented means that you can maintain your data organization, for example streams from high-speed sensors such as Radar, Lidar, Cameras, etc - and handle those via separate, independent data streams, and yet, store or record them.

FFRAID is scalable in different dimensions because you can add multiple of those 10/25/40/50 Gigabits per second (Gbps) channels - totalling up to 200 Gbps or 400 Gbps - depending on the underlying FPGA card. Depending on your host system, we can scale by using two or more of those FPGA cards. The following shows an example system for PCIe 4.0 16 GT/sec, but FFRAID also supports PCIe 5.0. Another dimension of scalability is by reading/writing from/to a RAID of multiple NVMe SSDs.

For more details on FFRAID please read MLE's Technical Brief TB20250130 (https://devzone.missinglinkelectronics.com/application-notes/ffraid-a-fast-fpga-raid/) .

Benefits:

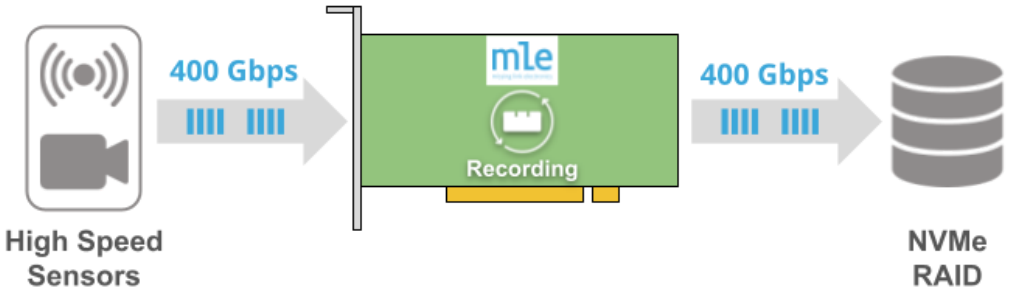
Having a highly scalable recording platform provides many benefits: First, FFRAID supports a wide range of NVMe SSDs and can be scaled from M.2 SSDs for small and light-weight embedded systems up to large 19" racks using high-performance U.2 or U.3 SSDs. Scalability also includes selecting from different SSD capacities and Drive-Writes-per-Day (DWPD) models. Here a table of possible recording times in minutes:

		Recording Speed (Gbps)						
		100	150	200	250	300	350	400
Storage (TiB)	5	7.2	4.8	3.6	2.9	2.4	2.0	1.8
	10	14.3	9.5	7.2	5.7	4.8	4.1	3.6
	15	21.5	14.3	10.7	8.6	7.2	6.1	5.4
	20	28.6	19.1	14.3	11.5	9.5	8.2	7.2
	25	35.8	23.9	17.9	14.3	11.9	10.2	8.9
	30	42.9	28.6	21.5	17.2	14.3	12.3	10.7
	35	50.1	33.4	25.1	20.0	16.7	14.3	12.5
	40	57.3	38.2	28.6	22.9	19.1	16.4	14.3
	45	64.4	42.9	32.2	25.8	21.5	18.4	16.1
	50	71.6	47.7	35.8	28.6	23.9	20.5	17.9

Besides record/replay of raw data FFRAID also supports data-in-motion pre- and post-processing that enables you to add your custom algorithms for indexing and

metadata generation, on-the-fly data decimation, or running in “spy-mode” as a transparent data proxy.

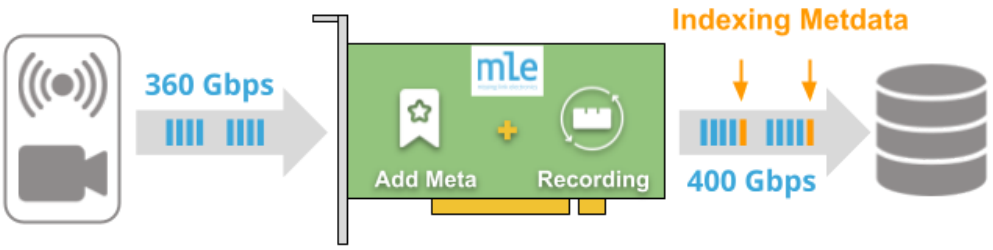
Ingress data from the high-speed sensors are transferred and recorded at-speed and as-is onto the Fast FPGA RAID.



Communication from a high-speed data source can be transported to a data sink while this data is also recorded at-speed.

Unwanted pieces of the ingress data is removed on-the-fly prior to storage. This can, for example, be a selection of certain regions-of-interest (ROI).

Ingress data can be analyzed on-the-fly to generate indexing information for later search, for example. This metadata is then recorded along with the ingress data. Metadata can, for example, be: Hardware timestamps, regions-of-interest, search indexes.



High-Speed Recorders from PCO:

PCO has licensed MLE's FFRAID for use in optimized recording systems that complement PCO's high-speed cameras.

The recorder is equipped with a high-performance SSD tray, providing fast data storage with a capacity of up to 8 TB. It supports the simultaneous connection of 1 to 8 cameras and features a 25G Ethernet connection for efficient data transfer to a PC. The system offers flexible recording modes, including Record, Pause, Play, and Circular Buffer Recording, ensuring versatile operation for various applications.

About PCO

PCO, an Excelitas Technologies® Corp. brand, is a leading specialist and Pioneer in Cameras and Optoelectronics with more than 30 years of expert knowledge and experience of developing and manufacturing high-end imaging systems. The company's cutting edge sCMOS and high-speed cameras are used in scientific and industrial research, automotive testing, quality control, metrology and a large variety of other applications all over the world.

The PCO® advanced imaging concept was conceived in the early 1980s by imaging pioneer, Dr. Emil Ott, who was conducting research at the Technical University of Munich for the Chair of Technical Electrophysics. His work there led to the establishment of PCO AG in 1987 with the introduction of the first image-intensified camera followed by the development of its proprietary Advanced Core technologies which greatly surpassed the imaging performance standards of the day.

Today, PCO continues to innovate, offering a wide range of high-performance camera technologies covering scientific, high-speed, intensified and FLIM imaging applications across the scientific research, industrial and automotive sectors.

Acquired by Excelitas Technologies in 2021, PCO represents a world renowned brand of high-performance scientific CMOS, sCMOS, CCD and high-speed cameras that complement Excelitas' expansive range of illumination, optical and sensor technologies and extend the bounds of our end-to-end photonic solutions capabilities.

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