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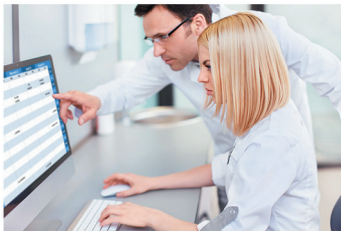

The Dusk of FireWire - The Dawn of USB 3.0

Advancements and Critical Aspects of Camera Interfaces for Next Generation Vision Systems

WHAT'S INSIDE

EXECUTIVE SUMMARY

When designing an imaging system, one of the most important factors to consider is the camera interface. Besides important parameters like resolution, frame rate, sensitivity and read-out technology, the video and control interface is one of the most critical components needed to meet the performance, price and design requirements of a camera.

When using a digital camera, the transmission of image data and the exchange of control commands between the host and the camera are usually connected with one interface and a single cable. This simplifies the system setup and reduces overall cost.

Before 2011, many system designs were built on the most popular interface at the time: FireWire. However, this technology is slowly becoming obsolete and is commonly being replaced by USB 3.0, the new predominant interface for industrial and scientific cameras. In this paper we will outline why people are making the upgrade from FireWire to the USB 3.0 interface, and why USB 3.0 is here to stay.

Criteria for
SELECTING THE RIGHT CAMERA INTERFACE TCHNOLOGY

When selecting the right camera, the image sensor is deemed to be the most critical component since it widely defines the camera's maximum resolution, the achievable image quality and the frame rate. Today, most image sensors are designed in cameras with different interfaces, offering system designers the freedom to consider technical features, system costs and development efforts.

The maximum bandwidth required for a camera is typically calculated by the maximum resolution of the sensor, bit depth and frame rate. Camera manufactures also take into consideration the maximum length and flexibility of the cabling as well as the system design of the host PC, which needs to receive and process the video data from the camera before selecting an appropriate data interface. USB 3.0 is an ideal interface since it permits high bandwidth data transfer power over the same cabling and can support long distances with active cable extenders.

The interface of a camera influences the overall hardware costs of a system via the cable requirements, and the possible need for dedicated interface cards or upgraded processing power and memory on the host computer. A high level of standardization is also beneficial, because it ensures the interoperability between products from different manufacturers and thus, the freedom to exchange components for cost reduction or adoption of new quality requirements with insignificant impact on the software implementation. System development costs are also reduced by the standardization and the maturity of an interface technology, as major software libraries natively support dominant camera interface standards.

Important Parameters of a Digital Camera Interface

- Max. bandwidth
- Max. cable length
- Multi-camera options
- Standardization in hardware, software and protocol
- CPU usage
- Real-time capabilities
- I/O synchronization
- Power supply
- Sustainability and technology roadmap
- Total costs (incl. cables, interface cards, etc.)

The Dependency of Industrial Cameras on Consumer IT

Since the production volume of devices for the industrial imaging sector is still relatively low when compared to the mass consumer market, the spread of an interface technology in the global mass market of consumer IT is important for a proper alignment of interface technologies on the device and host platforms. Leveraging interfaces used in popular consumer products results in lower hardware costs, higher availability of chipsets from several OEMs, and a standardized technology.

In 2000, FireWire started its triumphant procession as a new high-speed interface with simplified cabling and a well-standardized bus protocol (IEEE1394). With data transfer rates between 400 and 800 Mbps it was considered a major step forward from the 12 Mbps throughput of USB 1.1. During this time period, several industrial camera developers started to adopt FireWire as it became the fastest consumer driven and widely standardized interface on the market. Within a few years of this adoption, industrial digital cameras with the FireWire interface highly visible on the market. Cameras with the USB 2.0 interface with a data transfer rate of 480 Mbps were also widely used during this time period. In 2010, along came the USB 3.0 interface, which promoted a maximum bandwidth of 5 Gbps.

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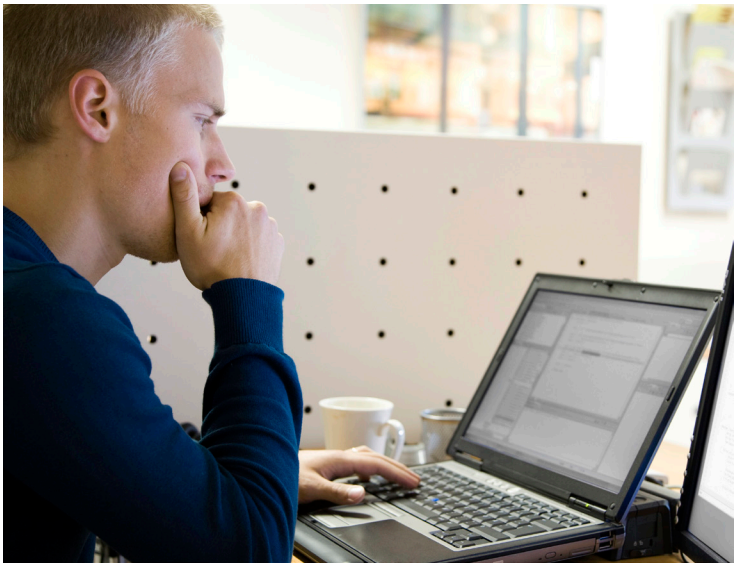


The rise of the USB 3.0 interface has sealed the end of FireWire by offering faster data transfer rates and solid adoption by the consumer market. Steve Jobs declared FireWire dead in 2008 and as of 2012, there were very few S3200 (3.2Gbps FireWire) devices released which demonstrated the lack of interest in major companies perusing this technology. While Apple moved on to the Thunderbolt interface, a lot of other manufactures moved on to USB 3.0 because it offered obvious benefits and was universally adopted by all computer OEMs. It is not surprising that USB 3.0 is today’s camera interface with the best ratio of bandwidth, usability, reliability and overall costs. Furthermore, the USB3 Vision™ and GenICam™ standards ensure the interoperability of cameras, software drivers and libraries at an unprecedented level.

Why USB 3.0 is Better than FireWire

Cabling

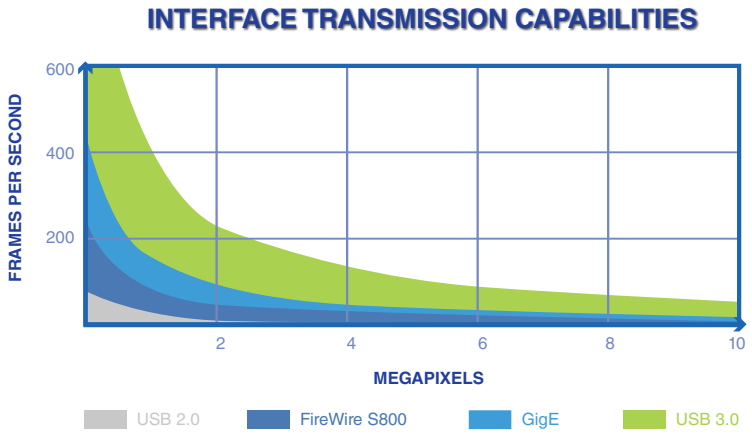
During the early days of digital imaging systems, FireWire was ideal for smaller systems such as medical devices or industrial quality inspection systems where a maximum cable length between the camera(s) and the host PC needed to stay well below 5 meters. The maximum cable length for USB 3.0 based video transmission depends primarily on the quality of the cable assembly as well as on the host controller and the camera chipset. In most setups, cable lengths of 8 meters still guarantee flawless connectivity. For longer distances of up to 20m, cabling solutions utilize the 900mA output of the USB3 .0 high-power ports for in-cable signal amplifiers or fiber converters. Active off-the-shelf USB 3.0 to fiber extenders are good for distances of up to 100m. Plug and play connectivity is not limited in length as it used to be in the past.

Bandwidth and CPU Load

The major appeal of USB 3.0 is the bandwidth of 5 Gbit/s (640 MByte/s, but its 8b10b encoding sets a practical limit of about 500 MByte/s). With a total of nine wires in the connectors and cabling, USB 3.0 utilizes a unicast dual-simplex data interface that allows data to flow in two directions at the same time. This is similar to FireWire which used just six wires and two shields. Thus, the host can transmit control signals to the camera without interrupting the video data stream and the asynchronous signaling method allows the camera to notify the host computer when it's ready for data transfer. The latter combined with Direct Memory Access (DMA) significantly reduces the CPU load compared to the polling mechanism in USB 2.0. The USB 3.0 specification preserves the USB 2.0 transfer types "bulk", "isochronous", "control" and "interrupt", but significantly increases isochronous throughput with three bursts of 128 MByte/s per service interval, for a total of 384 MByte/s compared to 75 Mbyte/s of FireWire 800 also referred to as IEEE1394b. This transfer type is typically used within industrial cameras as it can process higher frame rates and resolution. For example, USB 3.0 can support 180 frames per second (fps), at 2 megapixel resolution with 8 bit depth per pixel, whereas FireWire 800 can only deliver 37 fps at the same resolution and bit depth.

USB 3.0 is capable of fulfilling the requirements of a wide variety of demanding applications that exist today and the foreseeable future. For example: The transmission of UltraHD video signals with 8 megapixels at 45 fps.

The diagram below shows the transmission capabilities of different interfaces overlaid with the area which will be addressed by latest image sensors and those expected to come up in the next few years.



Real-Time Capabilities and Multi-Camera Setups

The isochronous transmission mode of USB guarantees a certain bandwidth, making this mechanism well-suited for the transmission of time sensitive data. It provides data distribution with a low and deterministic latency, and unlike GigE, there is no jitter. The correctness of transmitted data packages is natively verified by a CRC field. However, the reception of a video frame at the host is not natively ensured in this mode, for example: when the host operating system interrupts the DMA for few milliseconds. A guaranteed delivery of each video frame requires some sort of buffering implementation in the camera that will ensure no loss of frames for minor interrupts. Once the driver at the host detects a gap in the frame counter it can call off the missing frame from the camera buffer. This "zero-loss" technology is also crucial to keep several triggered cameras synchronized, especially in applications where moving objects shall be captured from different perspectives at the same time for 3D reconstruction. The on-board camera memory is also valuable for the capture of short image sequences with the maximum frame rate of the image sensor and subsequent transmission. With USB 3.0 and the right host configuration, up to four cameras can be operated on a single host computer. As computer technology continues to evolve, even more cameras will be able to be tethered to a single computer.

Price-Performance

As with FireWire ten years ago, today's USB 3.0 cameras benefit from the omnipresence in all consumer and professional IT systems. Most computers today already provide high quality USB controller chipsets or dedicated interface cards can be added to available PCIe slots at very low costs vs the frame grabber cards required for Camera Link® or CoaXPress™ interface standards. Due to the high frequency of the transmission signals, reliable and high-performance USB 3.0 cables require engineering competence and quality materials which makes them more expensive than comparable CAT6 Ethernet cables. Even then, USB 3.0 is by far the most cost effective interface for industrial cameras on the market. A larger number of camera manufacturers provide a wide spectrum of products that range in price and performance. The major differences between camera vendor implementations are the design and reliability of drivers. Although a camera might support USB 3.0, it may not have been designed to optimize the throughput that can be achieved with USB 3.0. Lumenera USB 3.0 cameras and drivers have been designed, tested and hardened to provide the results customers expect.

Key Characteristics of USB 3.0

- Simultaneous and bi-directional bandwidth of up to 384 MByte/s transmitting, e.g. 2 MP at 180 fps
- Low and deterministic latency
- Low overhead of CPU load
- Can be extended to cover distances over 100m
- High level of maturity and low costs as default technology in consumer IT
- Long-term availability ensured through adoption of the backward compatile successor USB 3.1 at 10 Gbps

What Does the Future of USB 3.0 Look Like?

System engineers who are looking to replace their current FireWire-based imaging systems, will need to make sure that the new camera interface technology is expected to have a long life cycle. Potential high bandwidth candidates are 10 Gigabit Ethernet, CoaXPress, Camera Link HS, Thunderbolt and USB 3.1. As mentioned above, the adoption of an interface in the consumer market is beneficial for the maturity, standardization and costs of a technology. This speaks against interfaces such as CoaXPress and Camera Link, used only in the vision industry. 10 Gigabit Ethernet is today's global standard in all modern IT infrastructures but the bus and the chipsets still consume too much power and generate too much heat, which is the enemy of an imaging sensor. Thunderbolt can be considered the direct successor of FireWire, providing 3m maximum copper cable length and up to 10 Gbps per channel (20 Gbps aggregate). It used to be promoted only by Apple, but with wide adoption of USB 3.0 and a clear and simple migration path already defined for USB 3.1, Thunderbolt may fade away like Sony's Betamax format. Apple's decision to use the USB 3.0 Type-C interface as the single jack of their latest MacBook strengthens this notion.

All indicators point towards USB 3.0 being the standard camera interface of the future. The introduction of the widely compatible USB 3.1 with a speed of 10 Gbps and power transmission of 100 W will be capable of providing the bandwidth, the features and the reliability needed in a wide variety of industrial, medical, scientific and traffic imaging applications for years to come.

About The Company:

LUMENERA CORPORATION

Lumenera Corporation, a division of Roper Technologies, headquartered in Ottawa, Canada, is a leading developer and manufacturer of high performance digital cameras and custom imaging solutions. Lumenera cameras are used worldwide in a diverse range of industrial, scientific and security applications.

As a global market leader Lumenera provides an extensive range of high quality digital cameras with unique combinations of speed, resolution and sensitivity to satisfy the demands of today's imaging applications. Lumenera also offers custom design services to OEM partners requiring specialized hardware and software features.

Core competencies include digital bus technologies such as USB 3.0, USB 2.0, Ethernet, HDMI and Gigabit Ethernet (GigE) as well as a complete command of digital imaging hardware and software built around CMOS and CCD based imagers. Our diversity provides our customers with the benefits of superior price-to-performance ratios and faster time-to-market.

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