WHITE PAPER

USB 3.0 Interface and USB3 Vision Standard — Data, Facts, Setup and Migrating to USB 3.0

USB 3.0 has become the standard of choice for PC hardware makers, with the number of peripheral devices featuring the technology continuing to climb sharply. Industrial cameras have also been rolling out USB 3.0 as their camera interface. This white paper is intended to present USB 3.0 as an interface for the industrial camera market. It describes the benefits of the USB3 Vision Standard, shows how USB 3.0 cameras can be integrated into a system and demonstrates who will benefit from a switch away from the previous camera interface technologies.

1. Introduction of USB 3.0

USB 3.0, also known as SuperSpeed USB, is the next generation of the popular 'Plug & Play' Universal Serial Bus specification, building on the strengths of USB 2.0 while also correcting its weaknesses. When using the bulk transfer method, the effective available bandwidth provided by USB 3.0 totals approx. 400 Mbytes/s. This is roughly ten times the bandwidth of USB 2.0 and five times greater than the bandwidth of IEEE 1394b (FireWire-b). USB 3.0 also offers the potential for delivering a greater volume of power to the connected devices. At 900 mA (compared with 500 mA for USB 2.0), this is a major benefit since it allows for the operation of numerous devices with no active power supply. At the same time the energy management has also been improved. USB 3.0 allows devices to be moved from various standby modes into a suspend mode, which saves a significant amount of energy.

USB 3.0 uses nine pins/wires (five more than in USB 2.0) within the USB 3.0 plug and cables; it also employs a "Unicast Dual Simplex Data" interface to allow for bi-directional transmission of data. This represents an improvement over the unidirectional transmission model of USB 2.0 and resembles the transmission model for standards such as FireWire/DCAM and GigE Vision. USB 3.0 is also a "hosted device" protocol that sends notifications asynchronously. Cameras can thus inform the host about readiness for data transmission. This mechanism significantly reduces system overhead and CPU load in comparison with the "polling" mechanism of USB 2.0 and puts USB 3.0 on comparable footing with FireWire.

Similar to USB 2.0, the USB IF ("Implementer's Forum") conducted the rollout of USB 3.0, ensuring clear rules on the production of compliant end user hardware. USB 3.0 products certified based on the USB IF standards bear the following symbol:

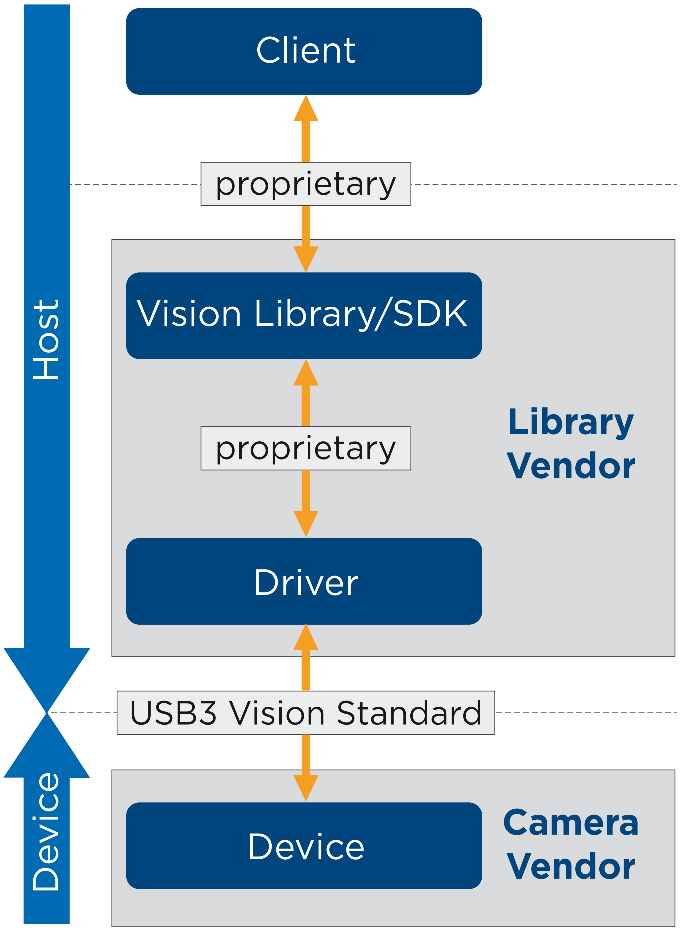
The list of USB 3.0 supporters is long and extends from Microsoft and Intel to Renesas and Texas Instruments.

2. The USB3 Vision Standard

Although USB 2.0 has for years served as an acknowledged, widely accepted standard in the end customer realm, it failed to gain real traction on the industrial market. Image processing in particular had an uneasy relationship with the technology. One reason was the lack of a standard to define the interfaces and interoperability. The lesson was learned here: all major manufacturers of cameras, cables and software solutions came together to establish the USB3 Vision Standards for the introduction of the USB 3.0 interface onto the image processing market. Basler had a key role in the shaping and promoting of this standard. One benefit of the standard is that all users are fully aware of what is involved: it remains flexible because the software and hardware can be swapped out interchangeably, and it is completely reliable in terms of function and stability during image transmission.

The Automated Imaging Association (AIA) is responsible for the standard and compliance with it. The following logo is the official logo of USB3 Vision Standard and may only be used by manufacturers who have had their devices or cables tested for conformity and appropriately registered.

The following schematics show the structure of the USB3 Vision Standard. This standard is also described as “on-the-wire.” It affords significant advantages for embedded systems and offers the host-side software complete control over image transmission. The USB3 Vision Standard also includes communication via GenICam to read and write to registers.



Unlike previous standards such as Camera Link and GigE Vision, cable connections and other key requirements for the cable were included in the definition of USB3 Vision. This offers the major benefit of stability and reliability for the user when they install accessories compliant with the standard. While cable connectors are defined in the USB3 Vision Standard, maximum cable lengths are not. The standard instead describes the correlation between high frequency properties and maximum cable length that produce the so-called USB 3.0 ‘voltage drop.’ This is based on findings that a USB 3.0 cable can measure up to 5.3 m in length and still fulfill the USB 3.0 specification. Basler has tested and certified various cables from various manufacturers and will offer passive cables with screw locks measuring up to 10 m in length.

In summary, the USB3.0 Vision Standard offers the following technical benefits:

- **Low CPU load:** The use of zero copy (Direct Memory Access — DMA — is available) keeps the necessary CPU load for image retrieval very low
- **Variable image size:** Allows for the sending of images in variable sizes by providing the host with information about the image in advance
- **Low latency and jitter times:** the bi-directional communication possibilities allows the host to initiate actions at any time without any expectation of delays
- **System stability:** The uniform definitions of the requirements for the cable and other accessories prevent potential malfunctions during data transmission.

3. How Does a USB 3.0 Camera Setup Function Within a Vision System?

Before implementing USB 3.0-compatible cameras into a system, several aspects should be considered in advance:

- What kind of PC hardware is being used? Which components will be used, or is retrofitting necessary?
- Which cables are required and is an active or passive USB 3.0 cable necessary?
- Should multiple USB 3.0 cameras be used?
- Which software will be used for simple connection to the camera?

PC Hardware

The practical USB 3.0 bandwidth depends on which USB 3.0 chipset and motherboard chipset are being used. There is always the option of connecting cameras to motherboards using integrated USB 3.0 connections (such as on those from Intel starting with the Ivy Bridge family).

If no integrated USB 3.0 connections are available, then PCI Express cards are the next best option. To take advantage of the full potential bandwidth, Basler recommends the use of motherboards that support at least PCIe 2.0/2.1 (with a maximum data rate of up to 500 MB/s per lane). In the event that the motherboard only supports a PCIe 1.0/1.1 connection, then the data rate is reduced to a max. 250 MB/s per lane. In that situation Basler recommends PCI Express cards with multiple lanes (such as PCIex4). The PCIe slot generally provides power to connected devices, such as a USB 3.0 adapter. According the specification, the delivered output for a standard slot is maximally 25 W, while for low profile cards it is maximally 10 W. Depending on the camera model and total number, this performance may in some cases be insufficient, thus bringing with it unexpected camera behavior or even image loss. We therefore recommend that inserted PCIe cards also use the existing power supply connected with +12 VDC from the internal power supply.

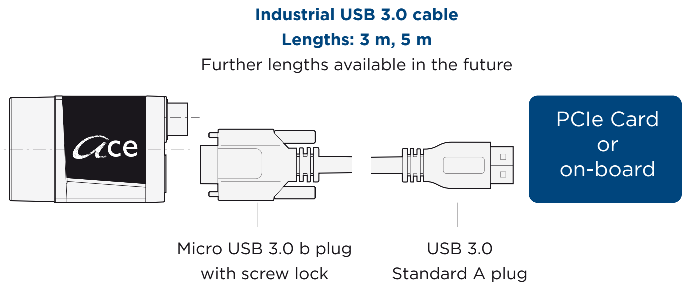
PCIe Generation	Bandwidth with PCIe x1 (Single Lane)	Bandwidth with PCIe x4 (4 Lanes)
1.0 / 1.1	250 MB/s	500 MB/s
2.0 / 2.1	500 MB/s	2000 MB/s
3.0	985 MB/s	3938 MB/s

On the whole it is beneficial when selecting hardware to refer to the white lists from the respective camera manufacturers. These lists offer recommendations that can help avoid any compatibility problems.

Cable and Multi-Camera Setups

Depending on the application, there are various requirements for the connector cable. On the camera side, a screw lock connector with micro-B USB 3.0 is used. On the hub or PC side the connector is known as USB 3.0 Standard A. Because the USB 3.0-A plug and corresponding physical port look very similar to the USB 2.0 version, symbols or blue coloration on the plug or jack are used to signalize the USB 3.0 functionality. The following symbol always signalizes that an interface is USB 3.0 SuperSpeed:

When selecting a cable length, primary consideration should be given that the cable has been tested for conformity with USB3 Vision. Passive cables may run up to a maximum of 10 m in length. Active cables (where power is being supplied through the cables) are also available up to 20 m, but increase the system costs significantly. Consideration should be given in that situation whether GigE cameras would represent a more affordable alternative. If highly complex setups with many cameras are to be established, then it may well be worth considering the use of GigE cameras. The GigE camera interface is clearly the better choice for very long cables and multi-camera setups. Basler makes the choice easier for users since the ace series of cameras offers both interfaces.



Typical setup with one camera

Software

Good software that conforms to USB3 Vision should make the migration to USB 3.0 simple and easy. One important component on the software side is a configuration tool. This kind of tool can make connecting USB 3.0 cameras very simple, since the corresponding driver environment as well as additional informational options such as the hardware topology (nodes and controls) and bandwidth measurements are made available. Basler offers the pylon software environment for free download at www.baslerweb.com/pylon. It offers a USB configuration tool as well as an SDK (Software Development Kit) environment and a camera viewer.

4. Migration From an Older Interface to USB 3.0

Switching from previous camera interfaces always brings with a certain degree of integration costs within the system. These costs can be worthwhile if the following criteria are fulfilled:

- The technology is at the end of its lifecycle. Hardware is getting more expensive and more difficult to acquire. This is currently the case with FireWire.

- The bandwidth is no longer sufficient to cover current or future requirements for the vision system (high frame rates, higher resolution or other image format). This is the case for FireWire (IEEE1394b: max. 64 MB/s) and USB 2.0 (max. 40 MB/s), for example.

- The savings in the overall system justify the one-time integration costs by allowing lower production costs. This can be the case when migrating from FireWire or frame grabber-based interfaces such as “analog” or “Camera Link base.”

Beyond these considerations, a review should be made whether another future-ready interface might be just as suitable as USB 3.0. While Gigabit Ethernet is restricted in terms of bandwidth to 125 MB/s, it has the major benefit that very long cables (up to 100 m) can be used with the technology; it also makes it even simpler to install multi-camera systems. Camera Link Full is based on a frame grabber setup, but offers a bandwidth of up to 850 MB/s. For more pros and cons about different interfaces, please read Basler’s white paper “Comparison of the Most Common Digital Interfaces.” The integrations costs vary from interface to interface. The closer the interfaces are in underlying technology, the simpler the migration typically ends up. For USB 3.0, this is especially true for a switch from USB 2.0 or FireWire.

FireWire in particular needs to be compared in greater detail against USB 3.0 in terms of underlying technologies. In many regards USB3 Vision resembles the FireWire standard, one of the most popular and widely distributed industrial interfaces. Just like FireWire, USB 3.0 delivers data and power over the same cable. The improved output of 4.5 W makes it possible to integrate numerous fast and high-resolution sensors that are already on the market today. The comparison of latency and jitter times when sending a software trigger shows a slight advantage for USB 3.0 over FireWire. USB 3.0 also supports the so-called DMA mode. This allows for direct writing to memory as well as reading of memory without requiring help from the processor. The asynchronous sending of messages, which replaces the “polling” mechanism in USB 2.0, further reduces CPU load, which also underscores the similarities between USB 3.0 and FireWire and which predestines USB 3.0 as a “natural” replacement for FireWire. The following graphics were all conducted with identical PC hardware under identical test conditions on the camera side and can be considered exemplary for the CPU load between FireWire and USB 3.0. Numerous test runs provided demonstrably that the CPU last remained constantly below one percent and that there was no measurable difference between FireWire and USB 3.0. In another test, a tripling of the data volume under USB 3.0 showed no noticeable increase to the CPU load.

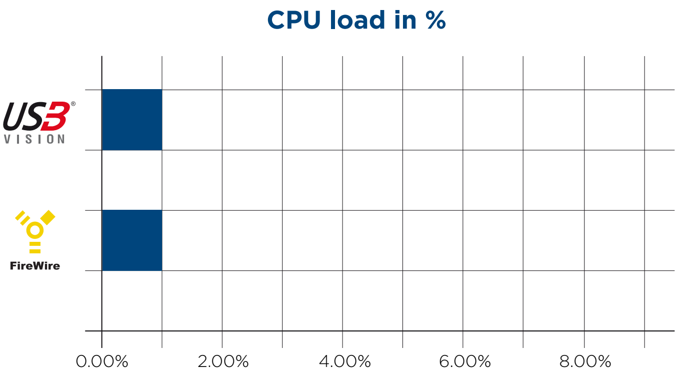


Illustration 2 — Comparison of CPU load

[1]HP computer, Windows 7 Professional, x86Intel Core i5 650, with only one core active, no hyperthreading, 4GB RAM, USB3.0 Host Controller: Renesas Electronics (5Gb/s), CPU load was measured using "perfmon," a standard Windows tool, Average values over 10min of measurement, driver: Win USB 3.0 and IEEE 1394 Basler Pylon

[2]AOI= 1600x1000, Pixel Format= Mono12 (16bit pro Pixel), Framerate= 16 fps at 48.8 MB/s

Beyond these considerations, mechanical and optical integration must also be taken into account. Basler's ace USB 3.0 series of cameras feature dimensions (29 mm x 29 mm x 29 mm), drill hole schematics and available sensors (CCD and CMOS) that make the switch from an older digital or analog interface as simple as possible. Depending on the applied, no adjustments to the objectives or mechanical positioning may be needed at all. This saves time and money when integrating USB 3.0 cameras.

5. Summary

In summary, the USB 3.0 camera interface was designed to fill the gap between Gigabit Ethernet and Camera Link and is poised to replace older USB 2.0 and FireWire interfaces. The USB 3 Vision Standard plays a central role in this switchover: it ensures users stability and flexibility in the setup of a vision system.

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