Setting up a Stable USB 3.0 Camera System

USB3 Vision is an industrial image processing standard released over three years ago and enjoying tremendous acceptance on the market. A growing range of camera manufacturers are working with the standard, and the number of compatible peripheral devices is rising rapidly. The USB3 Vision standard is based on the new USB 3.0 interface that is widely available on the consumer mass market. Many new laptops, PCs and even tablets and smartphones now come with a USB 3.0 interface inside. In the vision technology field, USB 3.0 is also increasingly coming to replace older interfaces such as IEEE 1394Firewire.

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1. What are the benefits of switching to USB 3.0?

Switching interfaces always involves integration costs and a certain degree of risk, so it is not something to be undertaken lightly. Even so, the many benefits inherent to USB 3.0 speak strongly for making a switch, especially when the following criteria are met:

- The previous technology is approaching the end of its product lifecycle. History shows that hardware based around end-of-life technology rises in price and, equally important, becomes more and more difficult to find.
  - This is currently the case with FireWire, and can be expected to begin in the foreseeable future with USB 2.0 as well.
- The existing bandwidth is no longer sufficient to handle the current and especially the future requirements posed by vision systems. Higher frame rates, higher resolutions and alternate image formats are required more and more and cannot be realized with the current interfaces.
  - This applies for example for FireWire (IEEE1394b: maximum bandwidth 64 MB/s) and USB 2.0 (maximum bandwidth 40 MB/s).
- The one-time costs for integration are justified by the savings on total cost of ownership.
  - This is the case with the switch from FireWire or Framegrabber-based interfaces (such as „analog“ or „CameraLink-based“), as can be seen in the sample calculation below (Fig. 1).

Every single one of those criteria speaks for the switch to USB 3.0. The following provides a detailed look into the standard and which aspects must be taken into consideration to achieve a stable USB 3.0-based camera setup.

Sample calculation in €	FireWire camera with ICX 274 sensor	ace USB 3.0 camera with ICX 274 sensor
One-time costs for software adjustments (2 worker-months)	0	18,000
One-time costs for hardware adaptation (4 worker-weeks)	0	9,000
One-time costs for logistics/parts lists adaptation and similar	0	5,000
List price for camera	1,099	729
Purchasing costs for cameras per year	109,900	72,900
Savings year 1:	0	5,000
Savings year 2:	0	37,000
Savings year 3:	0	37,000

Figure 1: Sample calculations comparing FireWire to USB 3.0

2. Technical specs for USB3 Vision

Figure 2: USB 3.0 SuperSpeed Logo

USB 3.0, also known as SuperSpeed USB (see Fig. 2), is the next generation of the popular “Plug & Play” Universal Serial Bus specification that builds on the strengths of USB 2.0 and irons out its weaknesses. The effective bandwidth available through USB 3.0 when running under the bulk transfer method totals 350-450 MB/s, depending on the host controller. That is approximately ten times higher than USB 2.0 and five times higher than the bandwidth of IEEE1394b. USB 3.0 uses nine pins/wires in all (five more than present in USB 2.0) in the USB 3.0 plug and cable, as well as a „Unicast Dual-Simplex Data“ interface that allows for bi-directional transfer of data. That represents an improvement over the unidirectional transfer model of USB 2.0 and resembles the transfer model of standards such as FireWire/DCAM and GigE Vision.

USB 3.0 also works with a „host directed“ protocol that sends out asynchronous notifications and route packets explicitly. The cameras can then use an asynchronous process to inform the host when ready to transfer data. This mechanism reduces system overhead as well as the CPU load when compared with the „polling“ mechanism in USB 2.0. This also makes USB 3.0 comparable with FireWire at the same time. Big-name manufacturers of cameras, cables and software solutions came together to found the USB3 Vision standard and introduce the USB 3.0 interface to the machine vision market. Basler helped spearhead and shape this movement. The standard has clear benefits for all users: there is greater flexibility because the software and hardware can be swapped in and out. There‘s a certainty that all functions are securely available and that stability can be expected in the image transmission. The Automated Imaging Association (AIA) is responsible for the standard and compliance with it. The official logo of the USB3 Vision standard (see Fig. 3) may only be used by manufacturers who have tested and registered their devices or cables for conformity.

Figure 3: Official logo of the USB3 Vision Standard

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

- Low CPU load: Thanks to Zero Copy (Direct Memory Access – DMA) the necessary CPU load is very low for image capture.
- Variable image size: USB3 Vision allows the USB 3.0 cameras to send images of variable sizes built from so-called „short“ and „zero-length“ packets that either complete or release outstanding URBs (USB Request Blocks). The real image size is delivered to the host through a „trailer“ packet.
- Low latency and jitter times: The bi-directional communication options allow the host to initiate actions at any time without incurring delays.
- Stability in the system: A uniform definition of the requirements for the cable and other accessories prevents potential malfunctions during data transmission.

3. Setting up a stable USB 3.0 camera system

There are some questions that should be asked before setting up a system with USB 3.0-compliant cameras:

- What PC hardware will be used? What components will be installed or require upgrading?
- Which cables are needed? Are active or passive USB 3.0 cables needed?
- Should multiple USB 3.0 cameras be used in one system?
- Which software will be used?

The early stages of USB 3.0 roll-out had their share of growing pains. Some users struggled to achieve a stable setup, especially in terms of accessories. Those growing pains have since been resolved.

The USB3 Vision Standard also defines the minimum performance specifications for the accessories. To harness the complete power of the new technology and achieve top stability, it‘s important for the individual components in the system to be selected carefully, including the camera.

Cable, cards and other components with USB 3.0 interfaces are already widely available in the world of consumer electronics, and at affordable prices. Some users may thus be tempted to use those components in their machine vision applications, not least because they are cheaper. But caution is advised: those accessories typically have not been certified based on the USB3 Vision standard, and may well be unable to handle the stringent requirements present in an industrial application. The result is frequently lost images or even complete breakdowns of systems. A defective camera often takes the blame here as the underlying cause, although in truth poorly chosen accessories probably triggered the problem.

The interplay between the individual components is tremendously important in setting up a USB 3.0-based image processing system, and must be given real consideration (see Fig. 4). For this reason, for example, Basler tests all accessory components together with all camera models, releasing them for sale only after the tests have been passed. If limitations arise in the interplay between compo-

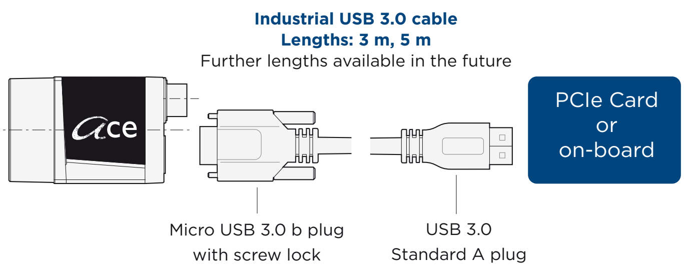

Figure 4: Typical setup with a USB 3.0 camera

nents and various camera models — such as cameras transmitting at an overly high bandwidth — then these are documented and the corresponding components are not offered for sale with that camera, or only with the limitations clearly stated. This has the major benefit that users can expect stability and reliability when they use standardized accessories throughout their systems.

3.1 Essential components

As already mentioned in the previous section, the interplay between the individual components in a USB 3.0 image processing system is mission-critical and must be selected carefully. Components that require particular attention are described below.

Chipset, motherboard and systems
Motherboards with chipsets from the Intel 7 series (Ivy Bridge), Intel 8 series (Haswell) or the Intel 9 series (Broadwell) have built-in support for USB 3.0 thanks to the USB 3.0 host controller. Chipsets from the Intel 7, 8 or 9 series are recommended for a stable USB 3.0 system setup.

Cables
Unlike standards such as CameraLink or GigE Vision, USB3 Vision also defines cable connections and the key requirements for compliant cables. The maximum cable length is defined based on the ratio between the high-frequency characteristics, and the relationship between the thickness of the copper wire and the maximum possible cable length before the so-called USB 3.0 voltage drop occurs. Basler tests and certifies its cables, ranging from passive cables of up to 8 meters in length to 20-meter-long hybrid cables with screw-down connectors, and offers them in their accessories portfolio.

Cables must meet different technical specifications based on their specific application. A screw-down USB 3.0 Micro B plug is used on the camera side, while a USB 3.0 Standard A is used on the hub or PC side. Since the USB 3.0 Standard A plug and the corresponding USB 2.0 jack are very similar, special symbols or a blue label on the plug or jack are used to indicate the presence of USB 3.0 functionality. The following symbol (Fig. 5) is always indicative of a USB 3.0 Superspeed connection:

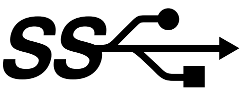

Figure 5: The USB 3.0 connection can be identified by its label

When it comes to the length of the cable, it is important that the cable has been tested for compliance with USB3 Vision. Passive cables can run up to 8 meters maximum. Active and hybrid cables are available at up to 20 meters of length, but are significantly more expensive. For any application requiring such a long cable, consideration should be given to GigE cameras as well, as they can be more affordable in that particular configuration.

Host adapter
The available amount of 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 via the integrated USB 3.0 connection (such as found in Intel processors from Ivy Bridge onward). If no integrated USB 3.0 connections are available, then PCI Express cards can be installed.

To harness the full bandwidth available, Basler recommends using motherboards that support PCIe 2.0/2.1 at minimum (for one lane, this provides for maximum data rates of up to 500 MB/s). In the event that the motherboard supports only PCIe 1.0/1.1 connections, then the data rate is reduced to max. 250 MB/s per lane. For this situation, Basler recommends PCI Express cards with multiple lanes (such as the PCIex4). The PCIe slot generally provides power to connected devices such as a USB 3.0 adapter. According to the specification, the output delivered by a standard slot totals up to 25 W, but on low profile cards only 10 W maximum. When working with low profile cards, it is thus recommended that the inserted PCIe cards also receive power via the existing power supply connector with +12 VDC from the internal power adapter.

On the whole, it is advantageous when selecting hardware to review the white lists from the respective camera manufacturers. Those lists provide recommendations to avoid compatibility problems. Basler cameras have been tested and approved for use with the following host adapters:

- Fresco Logic FL1100 Host Controller
- Renesas USB 3.0 Host Controller Chipsets
- Intel Ivy Bridge / Haswell Chipsets

Hubs
Hubs serve to connect a host on the PC to multiple USB 3.0 cameras. This connection is also referred to as a 1:n connection. Since the hub in this setup can only work with the bandwidth of a USB 3.0 „upstream“ port, care must be taken that the individual „downstream“ ports on the hub can also only „share“ that bandwidth.

3.2 What issues require special attention?

To ensure the stability of the vision system, it is important to observe the following ten points:

- Use only certified accessories. Low-quality accessories can lead to problems throughout the entire vision system.
- Use the Basler white list. The various host controllers (cards and on-board) are listed there, including their bandwidth, cable and hubs and potential limitations.

- Always use the latest drivers for the respective host controllers once they have been tested by the camera manufacturer.

- Shorter cable lengths are better than long ones. Careful consideration should be given as to the actual required cable length, as opposed to the "nice-to-have" length.

- Do not kink or twist the cable unnecessarily, as this can reduce the transmission efficiency. In the event that the cable must be moved or twisted, be sure to use a cable designed for work with robotics or cable drag chains.

- The bandwidth of all connected cameras must also be taken into consideration. Their cumulative bandwidth cannot exceed the maximum potential bandwidth of the connected components.
  - Use a bandwidth manager (such as the one found in the pylon Camera Software Suite).
  - The bandwidth should be adjusted within the manager to ensure that only the actual necessary bandwidth is harnessed.

- Monitor the CPU load on the PC.

- Avoid the use of hubs when not absolutely necessary.

- Use the port that delivers the most stable connection — this can vary between ports on the PC or the hub.

- Watch out for electromagnetic compatibility (EMC) issues in your system setup or environment that can lead to disruptions.

3.3 What problems can arise?

Certain problems can arise when setting up a vision system. Most of those problems are due to a simple cause and can be remedied relatively quickly.

Cable problems related to „voltage drop“
Low-quality USB 3.0 cables can cause error messages such as „lost images“ or completely dropped connections between the camera and host. This can create the impression that the USB 3.0 system is unreliable or unstable. The problem is more pronounced as the length of the cable increases. For this reason it is important to choose the cable carefully and not simply ignore that aspect.

USB 3.0 cameras with very high speeds and use of the full USB 3.0 bandwidth
When using USB 3.0 cameras that work at very high speeds and/or resolutions and thus rely on the maximum theoretical USB 3.0 bandwidth, care must be taken that the maximum theoretic bandwidth offered by the card, motherboard and/or hub is not exceeded.

Overly high CPU load on the PC
The use of multiple USB 3.0 cameras within a system carries additional risks for overloading the PC and its CPU. This can interrupt the vision system. For this reason, the CPU load should always be monitored.

Interruptions related to electromagnetic influences on the USB 3.0 system
As with all electrical devices, any USB 3.0 setup is susceptible to interference related to electromagnetic compatibility. This is typically caused by interference signals from the immediate vicinity of the camera system combined with insufficient grounding of the camera.

4. Setting up a multi-camera system based on USB 3.0 cameras

There are two fundamental approaches to setting up a USB 3.0 multi-camera system: a 1:1 connection, and a 1:n connection with the host.

4.1 The 1:1 connection

For a 1:1 connection (Fig. 6), the desired number of cameras are each connected directly to a host controller and operated in a parallel configuration. Care must be taken that the maximum bandwidth of the host controller and motherboard or PC is not exceeded, as each individual camera requires a certain volume of bandwidth. This is dependent on the performance of the camera (speed and/or resolution). The use of passive cables longer than five meters in length is not recommended for this configuration, as the entire system is then susceptible to disruptions. If the individual cameras are designed to use an excessive bandwidth, thus exceeding the maximum bandwidth of the motherboard or PC, then it is recommended that the bandwidth manager in the pylon Camera Software Suite be used to limit the bandwidth.

4.2 The 1:n connection

For a 1:n connection (Fig. 7) a camera and a hub are connected to the PC's host controller and run in a parallel configuration. Care must be taken here as well that the maximum bandwidth on the host controller is not exceeded, as the individual cameras on the one port and the hub and all of its connected cameras on the other port all draw on the same overall bandwidth pool. The total bandwidth here is also dependent on the performance of the individual camera (speed and/or resolution). The use of passive cables longer than five meters in length is not recommended for this configuration, as the entire system is then susceptible to disruptions. If the individual cameras are designed to use an excessive bandwidth, thus exceeding the maximum bandwidth of the host, then it is recommended that the bandwidth manager in the pylon Camera Software Suite be used to limit the bandwidth. In this configuration, the bandwidth of the individual cameras connected directly to the host can also be specified using the „Device Link Throughput Limit" camera parameter. This then frees up any extra bandwidth no longer available to that individual camera, for use by cameras attached to the hub on the other port. All bandwidth fed to the hub is distributed among its individual ports. Here too the bandwidth of the individual connected camera must be taken into consideration.

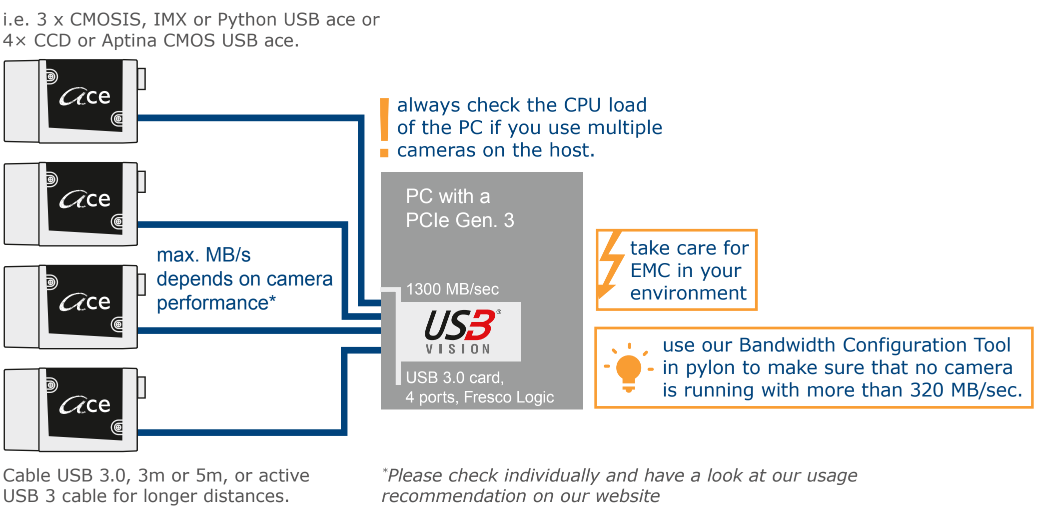

Figure 6: Setup of a USB 3.0 system with a 1:1 connection

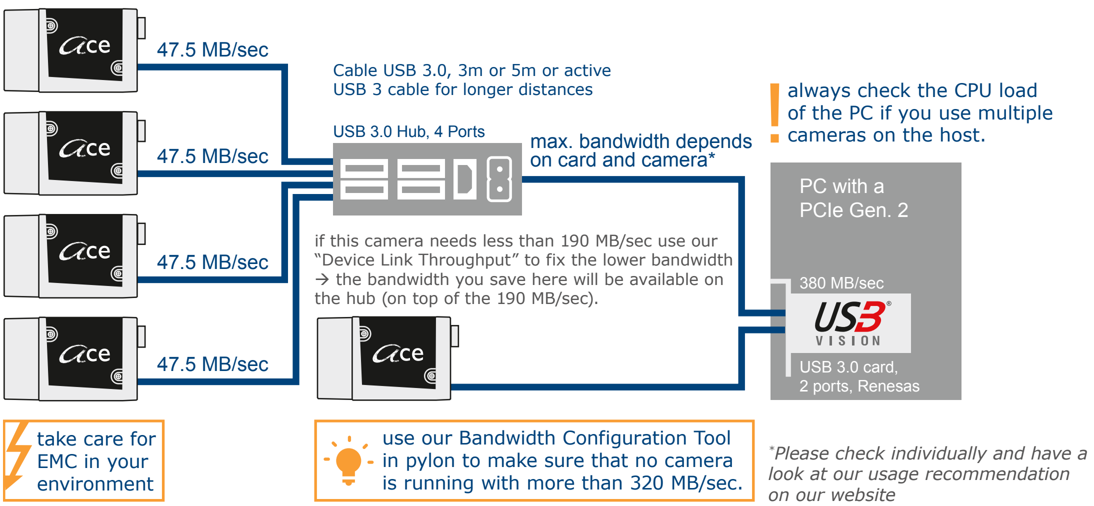

Figure 7: Setup of a USB 3.0 system with a 1:n connection

5. Summary

The USB3 Vision standard is expected to establish itself even more strongly on the market in coming years, and USB 3.0 – together with GigE – will become the dominant interface. This reflects USB 3.0's status as a stable and flexible interface. Among its greatest benefits is the simple setup and ease of use. The initial „growing pains" have now been eliminated. Once all potential stumbling blocks have been taken into account and the technical requirements achieved, then there is nothing in the way of building a stable USB 3.0 camera system.

About Basler

Basler is a leading global manufacturer of digital cameras for industrial and retail applications, medical devices, and traffic systems. Product designs are driven by industry requirements and offer easy integration, compact size, excellent image quality, and a very strong price/performance ratio. Founded in 1988, Basler has more than 25 years of experience in vision technologies. The company employs 500 people at its headquarters in Ahrensburg, Germany, as well as in international subsidiaries and offices in Europe, Asia, and the Americas.

Autor

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Jana Bartels is responsible for Basler's ace USB 3.0 camera series and its 3D cameras. She provides support for the camera models in the ace USB 3.0 product family throughout their entire lifecycle and coordinates the expansion of the current portfolio and the establishment of a 3D camera portfolio.

Jana started at Basler in 2005 as part of a work/study program in industrial engineering. After completing her degree in 2008, she first worked as a trainee in product management and then earned a master's degree from the Polytechnic University of Kiel in 2011. She's been a fixed part of the product management team at Basler AG since then.

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