Whitepaper about UBS3 Vision cameras and transmission security aspects

Better safe than sorry

The consumer interface USB 3.0 was introduced in 2010 and is very popular not only for the USB 2.0 backwards compatibility. The USB 3.0 interface supports a gross bandwidth of 5000 MBit/s, however, maximum cable length of 3.5 m (using consumer cables) is only supported (8 m is possible with good cables). But there are other ways to extend the length. This white paper provides an overview of aspects and other things about this issue.

USB3 Vision in comparison with other interfaces

The following table (Source: Handbook of machine vision, Wiley) lists most important figures of most important camera interfaces:

Interface	IEEE-1394a	USB 2.0	IEEE-1394b	GIGABIT ETHERNET(802.3ab)	CAMERA LINK	USB 3.0
Maximum Bit Rate	400 Mb/s	480 Mb/s	800 Mb/s	1000 Mb/s	>2000 Mb/s	5000 Mb/s
Isochronous (video) mode	Yes	Yes	Yes	No	Yes	Yes
Bandwidth/total usable bandwidth	Video: 32 MB/sec (80%) Total: 40MB/s	45 MB/sec (90%)	Video: 64 MB/sec (80%) Total: 80MB/s	120 MB/sec	255 MB/s (base) 680 MB/s (full)	~400 MB/s
Topology	Peer-to-peer	Master-slave, OTG (On the go)	Peer-to-peer	Networked, P2P	Master-slave	Enhanced Master-slave
Single cable distance in copper or other media	4.5m, worst case; 10m, typical camera application; 300m GOF	5m- 8m	8m copper; 300m GOF	25m, 100m (Cat5)	10m	3m worst case, 8m possible; GOF : >100m
Max. distance copper using repeaters	70m	30m	70m	n.a	30m	~15m
Bus power	Up to 1.5A and 36V	Up to 0.5A and 5V	Up to 1.5 A and 36V	Default: None; Power over Ethernet (POE)	Default: None; Power over CL (POCL)	Up to 0.9A and 5V
Motherboard support	Many	Virtually all	Rare	Virtually all	None	Virtually all
CPU load	Very low	Low	Very low	Low to middle	n.a.	Very low

OS support	Windows, Linux	Windows, Linux	Windows, Linux	Windows, Linux	Depending on vendor	Windows, Linux
Main applications	Multimedia electronics	PC-centric serial Input/output	Multimedia electronics	Networking	High speed camera interface	PC- centric serial input/output
Camera standard	IIDC V1.3	None (?)	IIDC V1.31	GigE Vision; GenICam	CL	USB3 Vision (ref. to GigE Vision/ GenICam)
Devices per Bus	63; 4 (8) silmult. / card, accord. to 4 (8) DMA's typ	Theoretically:127; In practice: <64	63; 4 simult. / card, accord. to 4 DMA's typ	Dependant on software and available bandwidth	1 per interface	Theoretically: 255; in practice: <32

It can be seen that USB 3.0 offers very attractive performance figures as a whole.

Transmission security by design

USB 3.0 in combination with USB3 Vision offers

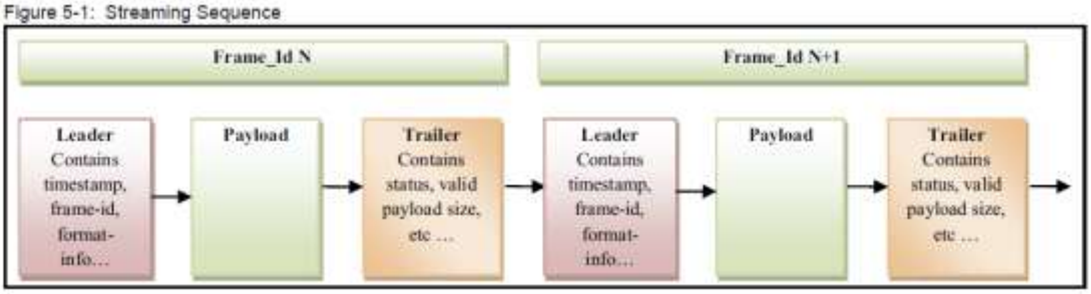
- up to 400 Mbyte/s interface bandwidth using bulk transfer mode with guaranteed delivery (but no guaranteed timing or latency!)
- efficient methods to reduce CPU load for image transfer via Zero Copy principle: Only the first and the last packet per image generate CPU intervention, the data is transferred via DMA into the computer's memory
- a better protocol (less polling needed),
- more bus power (4.5W (2.5W@USB 2.0))

Ideal preconditions for interfacing machine vision cameras.

Bulk transfer was chosen, because it offers the highest amount of bandwidth in conjunction with the fact that the companion link layers of a camera device and the host handle the transport of the individual and multiple 1024 byte (within 125µs) bulk packets with hardware calculated CRC checksum and hardware based resend algorithms. This is invisible to the OS and requires no interaction from the driver. This can be seen as an important advantage compared to say FireWire with isochronous transport (fire and forget → CRC check, but no resend possible!) and GigE which offers an optional resend mechanism based on driver level requiring time critical CPU intervention. Bulk Transfer offers much more bandwidth than a single triggered application usually needs ensuring transmission security through bandwidth overhead.

On the other hand, it requires that the camera features a built in FIFO memory, just in case that the image sensor is finishing exposure and requires readout but bulk data cannot be transferred because USB 3.0 is already busy with prioritized data transmission. Consequently MATRIX VISION's mvBlueFOX3 cameras come with 256 Mbyte built in buffer in the camera. The Zero Copy Principle highlights another very important aspect of transmission efficiency: while leader and trailer define image start and stop properties and thus have to generate interrupts for the OS to be examined by the CPU, the payload itself is transferred into the host memory by DMA (Direct Memory Access) in packets sizes of typically 128 kByte with little interaction by CPU and OS. This host memory can be the actual memory of the application, so no copying from one memory location (which assembles the image) to another one (which holds the image for the application) is required.

Figure 5-1: Streaming Sequence



This is illustrated in the diagram above taken from the USB3 Vision standard document.

Zero buffer copy makes the image transfer very efficient, as there is no buffer copying for the payload required (as is for a typical GigE network stack) and very little CPU load. The table below shows a comparison between a GigE and a USB 3.0 camera with the same sensor and frame rate. It can be seen that even in the best settings of an Intel network adapter (which is Jumbo Packets set to 9044 byte, and Interrupt Moderation = Extreme) it requires more interrupts and CPU load for a GigE camera than for a USB 3.0 camera.

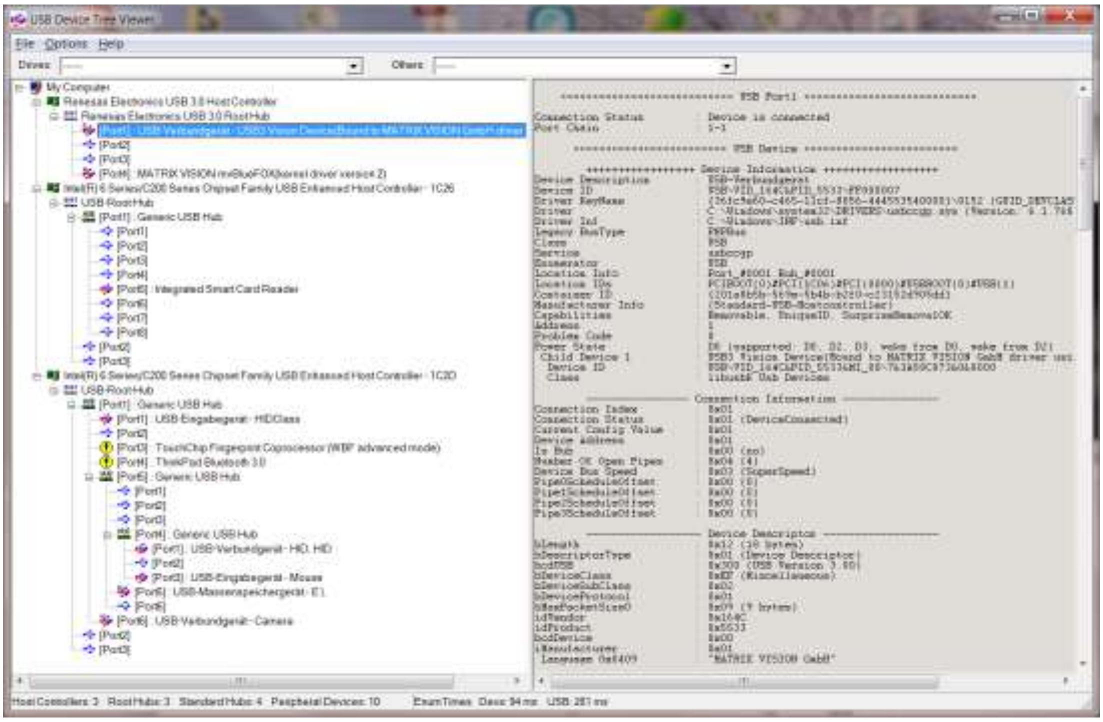
	mvBlueCOUGAR-XD104DG (single lane) 1936 x 1216 @ 50 fps	**mvBlueFOX3-2014G**
Interrupts/s	1900	1500
CPU load (wxPropView; no display, image to memory only)	<2%	<1%

With interrupt moderation = OFF approximately ~15k interrupts/s are required for the image intake using GigE. MATRIX VISION has made detailed measurements on achievable bandwidths for the various OS and chipsets, which can be made available upon request. Notice that these differ among OS version and chipset used. Generally Intel XHCI based chipset USB 3.0 ports and Windows 8/10 OS drivers or Intel drivers for Windows 7 offer the highest bandwidth.

Transmission security aspects: The host side

In order to minimize latency when using bulk transfer it is advisable to only connect cameras to a dedicated USB 3.0 port and connecting “other” external USB 3.0 devices (e.g. USB 3.0 hard disks) to other ports. Having said that it is of interest to see how the “other ports” are/are not connected to the same root hub, which is some piece of hardware inside your computer which itself distributes a multitude of USB3 ports. How do you do that? Well to a certain extent the device manager gives you some insight but most likely it requires some extra tools (mostly free of charge though!)

Let’s look at the freeware USB tree viewer:



In my example of a 3 year old laptop we can see that USB 3.0 is realized by a Renesas USB 3.0 host controller chip, which has a built-in 4 port hub, two ports of which are physically present to the outside.

In the example Port1 is attached to a USB 3.0 camera and Port4 is used by a USB 2.0 camera from MATRIX VISION. Interestingly enough these host controller and hubs can process USB 3.0 and USB 2.0 in parallel because physically the two interfaces use separate wiring and functionality inside the chip.

Consequently these two cameras do not interfere each other.

On the other hand, two USB 3.0 cameras would interfere as they would have to share the bandwidth of this one USB 3.0 host controller which is, as measured through our experiments, around 330 Mbyte/s. More modern computers have the USB 3.0 host controller built-in the chipset itself and usually offer an even higher bandwidth and more USB 3.0 ports. Still in this case the achievable bandwidth may be shared among these ports. USB tree view (or the powerful hardware info tool) can be used to identify where these ports are located in your computer. In any case if you need the bandwidth of USB 3.0 per port it is necessary that you install a separate USB 3.0 card. These come mostly with PCI Express x4 interface and up to four independent USB 3.0 controller chips. It is possible that just one such card can fully load the PC's bandwidth transportation capabilities. MATRIX VISION offers a nice selection of cards suitable for this task.

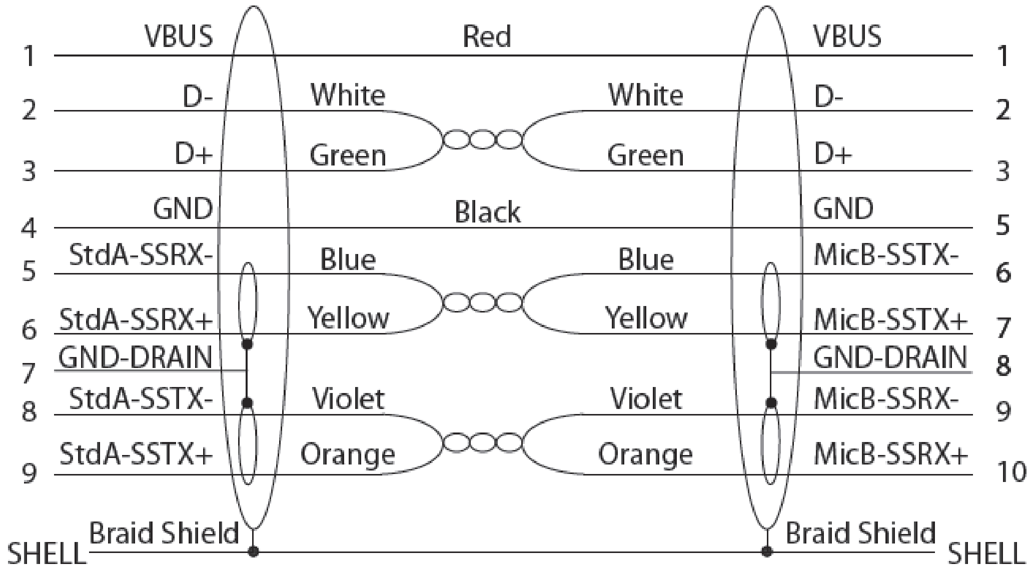
Cable length

Cable length for USB 3.0 can be considered a major difference in relation to GigE. GigE offers up to 100m copper cable length while USB 3.0 copper cable length is limited in practice to 8m. The specification does not define such a hard limit but only restricts an overall damping factor to 20dB between two USB 3.0 devices. Nor does it offer a specification for the cable itself or the connectors. This leads in practice to the situation where the maximum cable length is dependent not only on the cable's properties but also from the design and layout of the host computer mainboard and the connectors. Connect the cameras if possible directly to the mainboard connectors or the host adapter card connectors. If cable (pass through) adapters cannot be avoided assume that they also introduce HF damping and that the cable needs to be shorter. As a general rule, use good quality cables and keep them short e.g. as supplied by the manufacturer of the camera. A general rule: The longer the cable the thicker the wires! This takes also the voltage drop into account which occurs if the camera is powered by the computer. MATRIX VISION offers a good choice of cables and tests cameras with these in its 24/7 test suite. So we know that these cables are good.

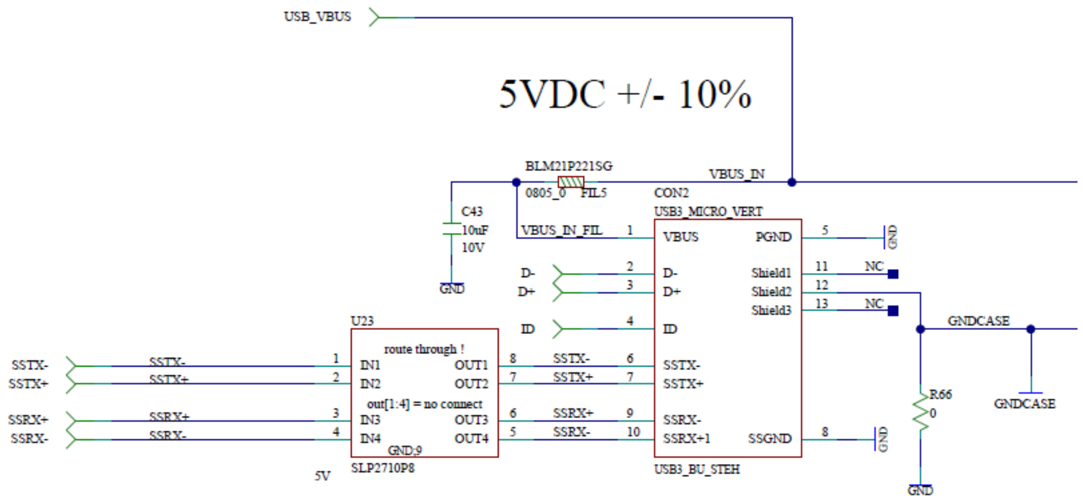
Grounding and shielding

The USB specification more or less assumes that due to the quite limited cable distances connected devices are grouped closely together, with a computer and its attached camera(s) sharing a line outlet and a common ground. USB 3.0 cables (Example: Alysium) use typically the following arrangement:

WIRING DIAGRAM



Two wires serve for the VBUS power and its associated GND, one common braid shield is connected to the metal shell and a separate USB 3.0 twisted pair shielding goes to separate pins on the connectors. USB 3.0 signals and grounding in the USB 3.0 camera mvBlueFOX3 series is as follows:



That is braid shield, USB3 GND (SSGND), USB2 GND (PGND) and GNDCASE (aka protection GND) are all tied together at the camera side. Usually industrial cameras are mounted in direct housing contact to metal parts of machines, which itself are typically earthed (protection GND) in accordance with safety standards. Please note in addition that cameras may be bus powered but can also sometimes accept external power via the Hirose connector. On the host side the grounding solution depends on the computer:

While a laptop or an industrial computer may have its USB-GND and braid shield tied via 1 MΩ resistor to protection GND, an ordinary off-the-shelf computer may be hard grounding all signals together.

The farther away an (externally powered) camera is, the more likely it becomes that it will be getting its power/ground from a different ground reference via the earth of the machine. If that's the case, the USB cable's ground wire can create a ground loop path. This introduces the risk of software hang-ups and blue screens or even burn out of integrated circuits and connectors. (Although the standard requires a connector ordering of Shield before GND before Power as a counter measure!). It is thus our task to control this situation especially for longer distance applications.

Long distance camera solutions

Cable distance problems can be easily and elegantly overcome by smart accessories such as active optical cables (AOC).

Hybrid cables

We found during our tests, that hybrid cables (optical data plus unshielded power wires) are quite sensitive to power supply noise, which means that we currently do not favor these.

Connecting multiple USB 3.0 cameras to one host

Pure active optical cables can be used to bridge even longer distances of up to 100m from a host computer and hub device in addition to multiplexing several USB3 Vision cameras into one data stream. These AOCs use optical transmission for USB 3.0 data but purposefully do not have power cords. The power instead is applied directly at the hub side and powers the hub and all cameras connected to it. The huge advantage of this solution is that it isolates the computer from the camera in terms of grounding and shielding issues offering the same level of electrical robustness as network interfaces (using transformers for isolation).

This is illustrated in the following screenshot:

Distances of up to 100m can be accommodated.

Up to 4 cameras can be multiplexed into one USB 3.0 stream assuming that the total bandwidth does not exceed ~330 Mbyte/s. The bandwidth needed per camera can easily be calculated by multiplying the image size by the image depth in byte per pixel, and then multiplying that by the frames per second. For single camera usage we recommend a cable adapter (by e.g. NEWNEX) to feed the camera locally with power without a hub. MATRIX VISION continuously tests accessories and monitors the market to offer a broad selection of reliable components to make your user experience of MATRIX VISION USB3 Vision cameras a very positive one.

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