A Practical Guide to USB 3.0 for Vision Applications

WWW.PTGREY.COM

Introduction

- Introduction and Overview
- The “What”: USB 3.0 Technical Primer
- The “Why”: USB 3.0 in Machine Vision
- The “How”: Practical Considerations

About Point Grey

- Leading designer and manufacturer of USB, GIgE, and FireWire cameras
- Founded in 1997 - with offices worldwide
- Extensive experience with USB 3.0
  - Demonstrated the world's first USB 3.0 prototype camera in Sept 2009 (right)
  - Proprietary USB 3.0 technology
  - Began series production in 2011 of ultra-small Flea3 USB 3.0 camera

TESTED

The “What”:
USB 3.0 Technical Primer

WWW.PTGREY.COM

USB 3.0 Technical Primer

- SuperSpeed USB (aka USB 3.0 or USB3) is the next generation of the plug-and-play Universal Serial Bus serial communication spec
- Managed by the USB Implementers Forum (USB-IF)
- Designed to build on the strengths of USB 2.0 while addressing many of its limitations

BANDWIDTH AND ARCHITECTURE

- Maximum streaming bandwidth via bulk transfer is around 440 MB/s; max via isochronous is 384 MB/s
- Bulk guarantees delivery; isochronous guarantee bandwidth
- Host-directed (master-slave) protocol – same as USB 2.0
- Dual-simplex signaling – USB 2.0 is only half-duplex
- Asynchronous notifications – no traffic flow polling
- Two cameras can sustain 1.3 MP 120 FPS each, for a total of 340 MB/s, into a single $60 USB 3.0 interface card with no dropped data

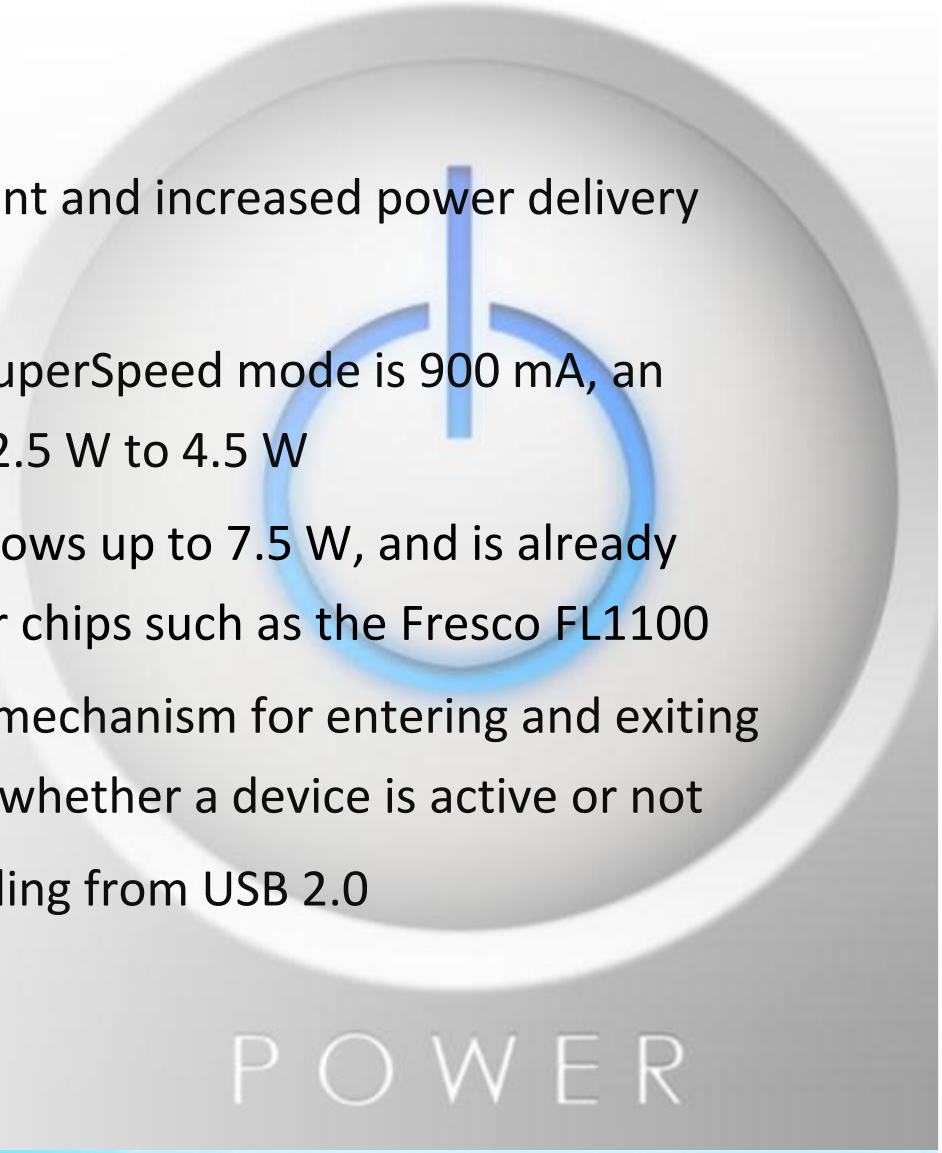
TESTED

BACKWARD COMPATIBILITY

- USB 3.0 cable contains five new wires
- Backward-compatible with USB 2.0
- USB 3.0 Standard-A receptacles are backward-compatible with USB 2.0 but add new pins for USB 3.0 signals
- New Standard-B and Micro-AB receptacles are backward-compatible
- USB 3.0 introduces new Micro-B and Micro-A plugs and receptacles

POWER MANAGEMENT

- More efficient power management and increased power delivery over USB 2.0
- The amount of current draw in SuperSpeed mode is 900 mA, an increase in power delivery from 2.5 W to 4.5 W
- USB Battery Charging 1.2 spec allows up to 7.5 W, and is already available on some host controller chips such as the Fresco FL1100
- USB 3.0 also offers an improved mechanism for entering and exiting low-power states, depending on whether a device is active or not
- Eliminates power-consuming polling from USB 2.0



USB 3.0 Technical Primer

	FireWire	Gigabit Ethernet	USB 2.0	USB 3.0	Camera Link
Bandwidth	80MB/s	100MB/s	40MB/s	440MB/s	680MB/s
Cable length	10m	100m	5m	3m	7m
Consumer acceptance	Declining	Excellent	Excellent	Excellent	None
Multiple cameras	Excellent	Good	Fair	Excellent	Fair
Power delivery	Excellent	Excellent (POE)	Fair	Good	None
Vision Standard	IIDC DCAM	GigE Vision	No	USB3 Vision	Camera Link

Note that some of the information presented in this table is subjective and that performance of each interface will depend on the exact system configuration it is used in.

USB3 VISION

- Communication interface for vision applications based on USB 3.0, managed by the AIA trade association (they also manage GigE Vision)
- Allows for easy interfacing between the USB3 Vision device and a computer using standard USB 3.0 hardware
- Will define standards for data transport, mechanical specifications, etc.
- First draft of the standard has been completed and is under review

USB-IF USB 3.0 Compliance logo

Machine vision standard logo

Point Grey's USB 3.0 logo

USB 3.0 port label

(USB3.0 ports are colored blue)

The “Why”:
USB 3.0 in Vision

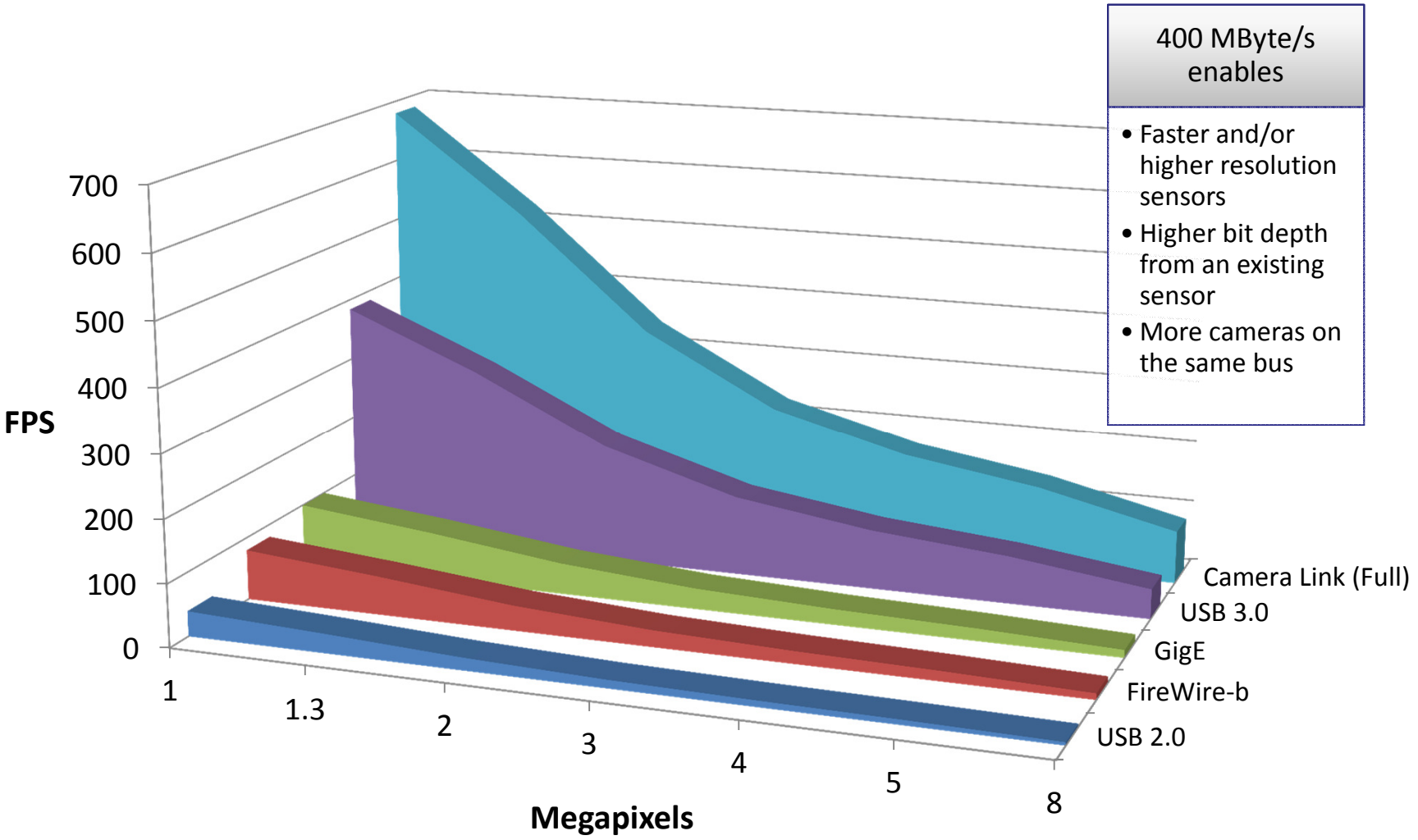
WWW.PTGREY.COM

USB 3.0 in Vision

USB 3.0 ADDRESSES THE NEED FOR:

- Higher **bandwidth**
- A **reliable** imaging pipeline
- Lower overall system **cost**, without sacrificing performance
- More **processor time** dedicated to the vision application
- Interface **availability** on a range of systems
- Application **compatibility** with cameras from multiple vendors
- Applications requiring **multiple cameras**
- Taking advantage of **new image sensor technology**

Higher Bandwidth



Better Reliability

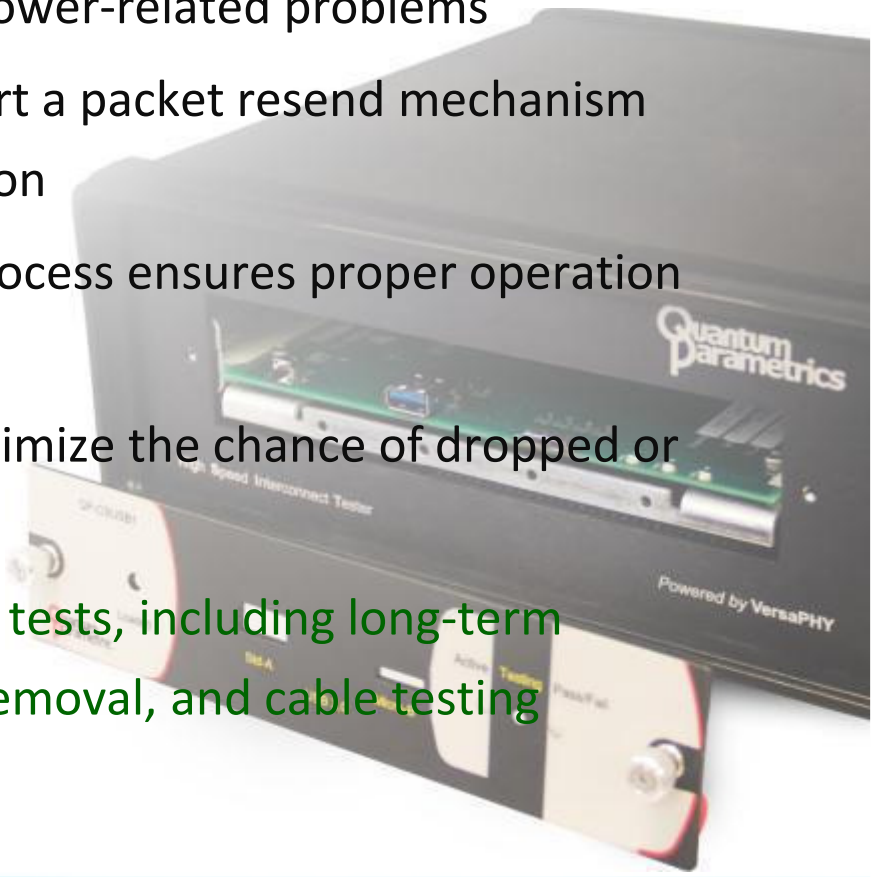
- Cameras and cables with screw lock connectors, which ensure a secure connection, are common
- Increased power delivery reduces power-related problems
- USB 3.0 xHCI host controllers support a packet resend mechanism to address issues with data corruption
- The SuperSpeed USB Compliance process ensures proper operation of USB 3.0 peripherals

TIP!

- An on-camera data buffer helps minimize the chance of dropped or corrupt data

TESTED

- Point Grey has performed countless tests, including long-term camera streaming, camera arrival/removal, and cable testing



Lower System Cost

	FireWire-b	GigE	USB 3.0	Camera Link
Frame grabber	$95[1]	$60[1]	$60[1]	$895[2]
Cable (3m)	$25[1]	$35[1]	$10[1]	$160[2]
Power supply	N/A	$65[1]	N/A	$75[2]
Cost for single camera solution	$120	$160	$70	$1130
4-port frame grabber	$300	$300[3]	$70[3]	$1K+
Cost for 4-camera solution[4]	$400	$700	$110	$2K+

[1] List price from Point Grey online store

[2] List price from Edmund Optics online store

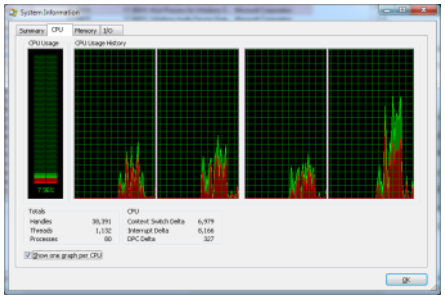
[3] List price from StarTech online store

[4] Including extra cables and power supplies

This table uses, where possible, publicly available list prices of industrial-grade products (e.g. cables with screw locking). Camera Link, in this example, assumes Base (~255 MB/s) configuration.

Lower Processor Usage

- USB 3.0 uses asynchronous signaling, rather than the polling mechanism of USB 2.0
  - This significantly reduces system overhead and CPU usage, which is less than USB 2.0, generally similar to FireWire

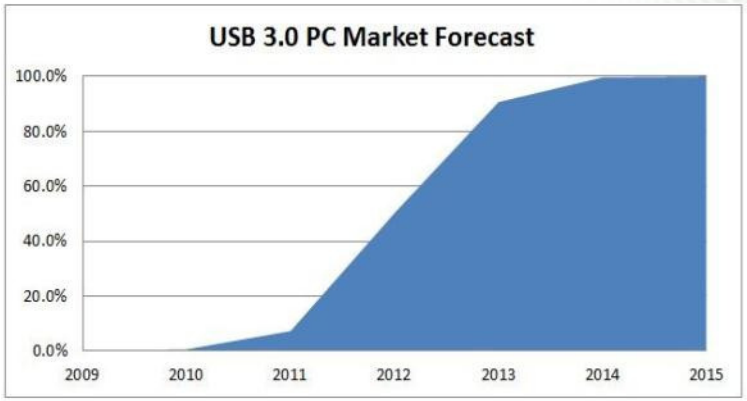


- USB 3.0 supports DMA transfers
- Increased bandwidth allows more data to be transmitted, such as full color processed images e.g. 1.3 MP 60 FPS RGB24 = 180 MB/s
  - This removes the requirement for the host system to perform this processing
- In one test with a camera generating 280 MB/s on a PC with an Intel i7 processor, the CPU usage was between 1 and 2%

TESTED

Interface Availability

- USB 3.0 is a low-cost consumer-driven technology, like FireWire and GigE
- USB is the most popular interface of all time; USB 3.0 is forecasted to be in every PC by 2015
- Virtually all major computer system manufacturers provide systems with USB 3.0 on the motherboard
- AMD and Intel both have certified USB 3.0 chipsets



Access to New Sensors

- Important to consider future bandwidth requirements, which are often driven by the image sensor technology
- Many new sensors require greater than 100 MB/s data rates

	Sony ICX674	Sony ICX694	Sony IMX136	e2v EV76C570	On Semi VITA1300
Type	CCD		CMOS		
Size	2/3”	1”	1/2.8”	1/1.8”	1/2”
Pixels	2.8 MP	6 MP	2.3 MP	2 MP	1.3 MP
Max FPS	50 FPS	25 FPS	108 FPS	60 FPS	150 FPS
Data Rate[1]	140 MB/s	150 MB/s	248 MB/s	120 MB/s	195 MB/s

[1] Data rate at 8 bits per pixel

USB 3.0 Interoperability

- Interoperability between cameras, cables, software, etc. provides flexibility of choice
- USB3 Vision will draw many of its specifications from GigE Vision, and will also rely on GenICam
  - Cameras will have an XML file that defines supported features
- Transport mechanism will be bulk; future versions may add isochronous as an option
- Backward compatibility with USB 2.0 is not required
- The standard is designed to support ‘zero copy’ – unlike GigE which copies every packet
- Also defines a standard for screw-lock connectors on cables

Multiple Camera Support

- Theoretical number of devices on a network is 255 units
- System processing speed is a key consideration for multiple camera applications due to the amount of data coming into the system
- Camera frame buffer is critical to ensure data is not corrupted
- Point Grey performs long term tests with 24 cameras on one PC. In the test, 3 host adapters and six 4-port hubs are used. The power to the camera is supplied by powering the hubs.

TESTED

The “How”:
Practical Considerations

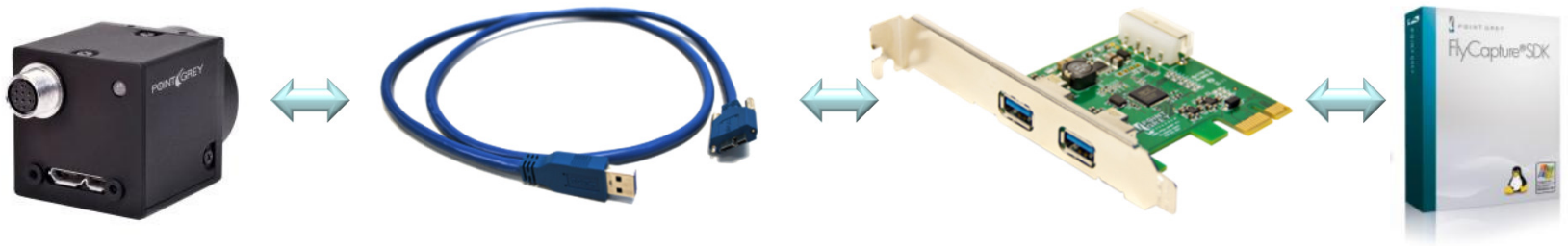
WWW.PTGREY.COM

System Requirements

- There are many components of a USB 3.0-enabled vision system, ranging from cameras, cables, hubs, cards, PCs, and software

TIP!

- USB 3.0 technology is still relatively new, so the ability to upgrade (or downgrade) firmware and software of various system components is important



Host System

- In many vision applications the end user provides their own PC; in these cases backward compatibility with USB 2.0 is critical

  - A USB 3.0 camera plugged into a USB 2.0 port will work at USB 2.0 speeds, provided enough power is provided
  - A USB 2.0 camera plugged into a USB 3.0 port will work
  - USB 3.0 and USB 2.0 cameras plugged into USB 3.0 ports will operate simultaneously at their respective speeds
- Practical bandwidth is a function of USB 3.0 chipset and motherboard chipset
  - Some motherboards e.g. Intel DH55HC, limit the PCIe Gen 2.0 x1 interface to Gen 1.0 speeds, 2.5 Gb/s instead of 5Gb/s

Host System

TESTED

- The following motherboard, CPU and chipset configurations were tested by Point Grey and found to provide optimal processing performance and full x1 PCIe 2.0 speed for USB 3.0 imaging.

CPU	Motherboard	Chipset
Intel Core i7	ASUS P8P67	Intel P67 (B3)
Intel Core i7	ASUS P6T	Intel X58/ICH10R
Phenom II X6	ASUS M4A89GTD PRO/USB3	AMD 890GX/SB850
Intel Core i5-2400	ASUS P8Z68-V-PRO	Intel Z68
Intel Core i7	Intel DH67CL	Intel H67 Express
Intel Core i7	Intel DH61BEB3	Intel H61 Express
Intel Core i3-2100	Intel BLH6710H.86A	Intel H67 Express
Intel Core i7	GIGABYTE GA-P67A-UD3-B3	Intel P67

TESTED

- Several laptop options provide on-board USB 3.0 connectivity

Dell XPS 15	Lenovo X220	Sony VAIO Z-Series
$700-1000	$1000-1500	$2000-2500

Operating System

- Microsoft: Windows 7 does not provide native USB 3.0 support, but Windows 8 will
  - To address this, Point Grey has developed its own xHCI driver
  - USB 3.0 host controller manufacturers provide their own xHCI drivers
- Apple: no announced plans to provide native USB 3.0 support
  - The latest MacBook Pro systems provide USB 3.0 support by using the Intel HM76 (Ivy Bridge) chipset
- Linux: started supporting USB 3.0 in the September 2009 release of the 2.6.31 Linux kernel
  - Very latest kernel versions appear to have video streaming capability

Software

- USB3 Vision standard will be key to ensuring USB3 Vision-compliant cameras run seamlessly with USB3 Vision-compliant software from companies like Cognex, Mathworks, Matrox, MVTec, NI, and Stemmer
- Most camera vendors, like Point Grey, provide their own SDK for interfacing with cameras

TIP!

- Make sure the vendor's SDK allows the seamless connection of all their cameras, regardless of interface

TESTED

- Point Grey USB 3.0 cameras can be run at USB 2.0 speeds on Mac OS using the cross-platform Linux 'libusb' and 'libdc' libraries

Hubs

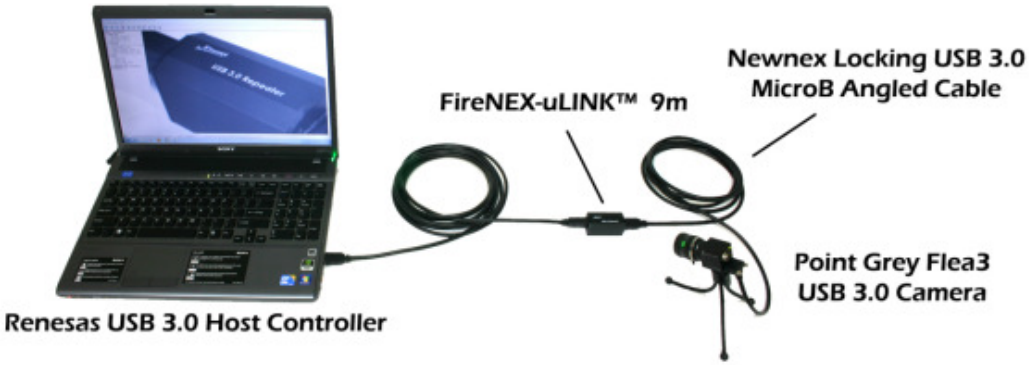
- Hub chipsets are available from VIA, TI, Genesys Logic, SMSC, and Grain Media
  - All claim to be USB 3.0 compliant, but none are officially certified since USB 3.0 compliance tests are still not defined

	Diamond USB304H	StarTech ST4300USBM	TI TUSB8040A
Ports	4	4	4
Chipset	VIA	VIA	TI
List Price	$50	$122	$199
Comments	Consumer enclosure	Industrial enclosure, screw-locking	Board-level reference design

- Hubs limit data rates, compared to direct connect into host
  - In one test a 20% drop (from 340 to 272 MB/s) was observed
  - Host controller's fairness policy results in large number of double ACKs
  - Options to minimize performance loss are being investigated

Cables

- Max length not explicitly specified in the USB 3.0 standard
- Most camera vendors provide 3 to 5-meter cables with screw-locking Micro B connector
  - 10-meter solutions are available and being tested
- Work is in progress on signal-corrected long-distance cables and optical solutions from companies like Alysium-Tech, CEI and Newnex



Other Hardware

Examples of industrial hardware applicable to machine vision supporting USB 3.0:

Adlink fanless embedded PC

with 2 USB 3.0 ports

IOI Technology

4-port USB3.0 card

Cameras

- In 2009 Point Grey was first to show a USB 3.0 camera and now offers a range from 1.3 MP to 8.8 MP. Other vendors also offer cameras.
- USB 3.0 connectors and low-power technology enable small camera designs
- Most are CMOS-based due to higher data rates, lower power requirements, and ease of implementation
- Many rely on the Cypress EZ-USB FX3™ chip for USB 3.0 connectivity

TIP!

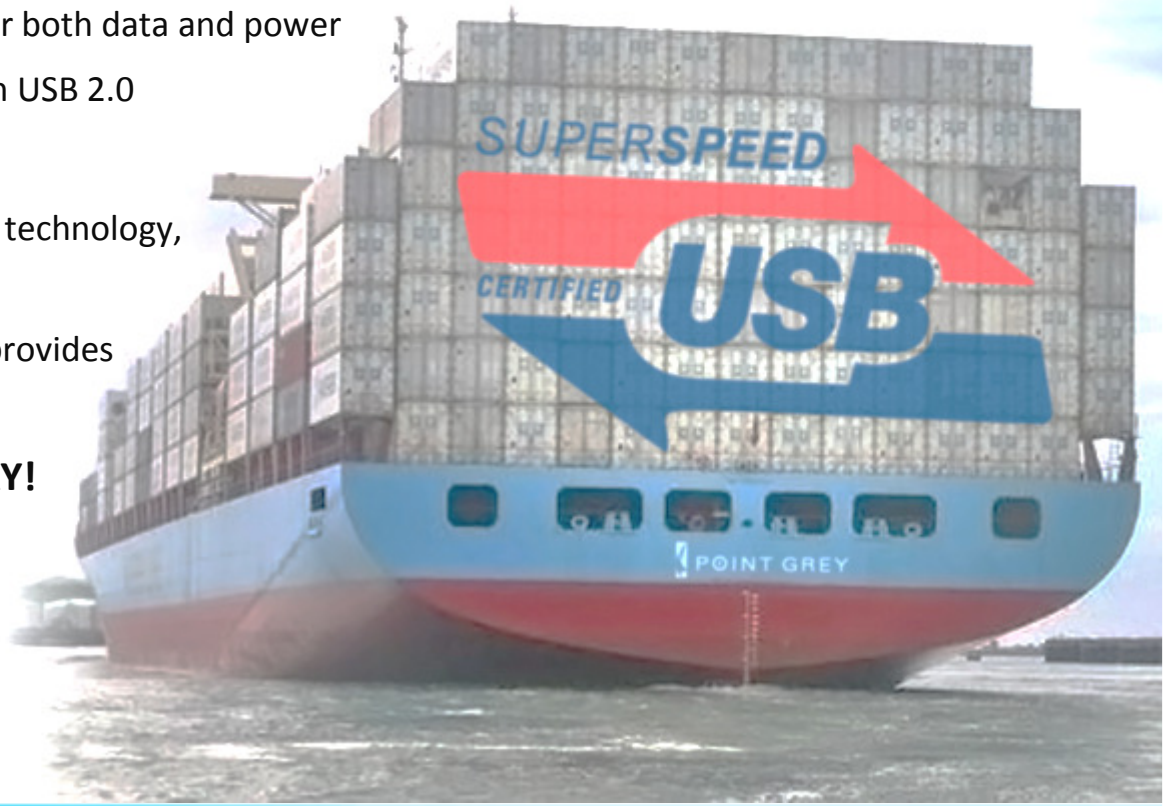
- Look for cameras with a large data (frame) buffer; key for maximizing reliability

The Future

- Availability: USB 3.0-enabled device shipments will surpass 1 billion in 2014
- Power: There is discussion among USB-IF member companies about providing even more power, up to 100 W, over USB 3.0.
- Standardization: Goal is for the USB3 Vision standard to be ratified by end of 2012. Point Grey will show USB3 Vision compliant cameras at Stuttgart show.
- Vision components: The VISION show in Stuttgart will likely see even more USB 3.0-enabled cameras, cables, and software

Conclusion

- USB 3.0 is FAST
  - 400 MB/s enables the use of faster, higher resolution sensors
  - More cameras on the same bus
- USB 3.0 is EASY
  - Plug and play, one cable for both data and power
  - Backward-compatibile with USB 2.0
- USB 3.0 is ACCESSIBLE
  - Low-cost consumer-driven technology, like FireWire and GigE
  - USB3 Vision specification provides common control protocol
- **USB 3.0 is AVAILABLE TODAY!**



Point Grey USB 3.0 Cameras

Flea3 USB 3.0 camera line:

MODEL	MP	FPS	IMAGING SENSOR
FL3-U3-13S2C/M-CS	1.3	120	Sony IMX035 CMOS
FL3-U3-13Y3M-C	1.3	150	On Semi VITA1300 CMOS
FL3-U3-13E4C/M-C	1.3	60	e2v EV76C560 CMOS
FL3-U3-32S2C/M-CS	3.2	60	Sony IMX036 CMOS
FL3-U3-88S2C-C	8.8	21	Sony IMX121 CMOS

Upcoming USB 3.0 Cameras

Upcoming USB 3.0 Cameras

Questions?

- Ready for your questions!
- For more information, contact info@ptgrey.com
- Additional USB 3.0 white papers, FAQ's, and application notes can be found on Point Grey's website at www.ptgrey.com/usb3cameras