



Firewire & Industrial Imaging



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Industrial, medical and scientific imaging, whether for robotics, quality-control, microscopy, consumer products fitting, or motion tracking applications have been traditionally conducted on analog imaging systems. These analog systems required the use of framegrabber interfaces to convert the analog images for subsequent digital interpretation and processing. In the last few years the speed, price, quality, and overall capabilities of digital imaging solutions right from the camera have rapidly evolved, largely due to the raw bandwidth capabilities of digital communications.

Digital cameras, especially those with on-board FireWire (IEEE 1394a or 1394b) communications conforming to the IIDC (DCAM) standard have created cost-effective and powerful solutions options being used for thousands of different applications around the world. FireWire is currently the premier robust digital interface for industrial applications for many reasons, including:

- *Guaranteed bandwidth features to insure fail-safe communications*
- *Interoperability with multiple different cameras*
- *Diverse camera powering options, including single-cable solutions up to 45W*
- *Effective multiple-camera solutions*
- *Large variety of FireWire accessories for industrial applications*
- *Availability of repeaters and optical fibre cabling*
- *Forwards and backward compatibility blending 1394a and b*
- *Both scheduled realtime (isochronous) and demand-driven asynchronous I/O capabilities*

This paper is intended for both:

- *Experienced image processing professionals seeking a quick checkup on FireWire developments and trends*
- *Initial overview of FireWire for newcomers*

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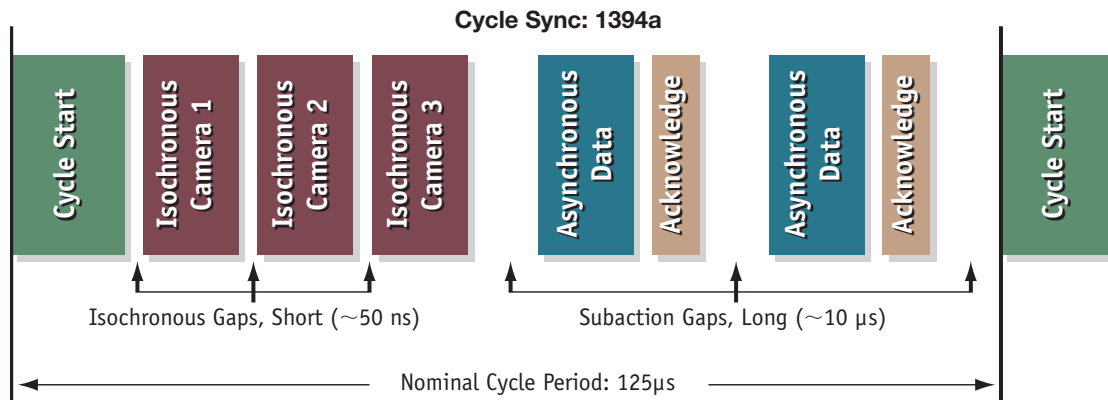
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Firewire: Overview and Capabilities

Based upon R&D from innovative Apple™, and with backing from a number of major manufacturers, IEEE-1394, or FireWire, created an industry standard for communicating uncompressed digital images. While the basic standard was established in 1995, an enhanced standard known as 1394a emerged in 2000, after which the adoption rate for FireWire rapidly accelerated.

Briefly summarized, FireWire is a very effective way to utilize a low-cost serial bus, through a standardized communications protocol, that establishes packetized data transfer between two or more devices. FireWire offers real time isochronous bandwidth for image transfer with guaranteed low latency. It also offers asynchronous data transfer for controlling camera parameters, such as gain and shutter, on the fly. As illustrated in the diagram below, these two modes can co-exist by using priority time slots for video data transfer and the remaining time slots for control data transfer.



The above diagram has been adapted from an original as provided by Texas Instruments.

Additional devices may be added up to the overall capacity of the bus, but throughput at guaranteed minimum service levels is maintained for all devices with an acknowledged claim on the bus. This deterministic feature is a huge advantage for many industrial applications where robust performance is required. Such is the case when it is not acceptable to drop images within a specific time interval.

Capabilities of 1394a include:

- 400 Mbit/s
- Hot-pluggable devices
- Peer-to-peer communications
- Direct Memory Access (DMA) to host
- Guaranteed bandwidth
- Multiple devices (up to 45 W) powered via FireWire bus

At the same time, IIDC (DCAM) Version 1.3 released a set of camera control standards via 1394a which established a common communications protocol on which most current FireWire cameras are based. In addition to common standards shared across manufacturers, a special Format_7 mode also provided a means by which a manufacturer could offer special features, such as higher resolutions, higher frame rates, or diverse color modes, as extensions to the prescribed common set.

Then in 2002, an even faster enhancement, 1394b was announced, providing for:

- 800 Mbit/s
- All previous benefits of 1394a (see above)
- Interoperability with 1394a devices
- Longer communications distances

Twinned with 1394b came IIDC Version 1.31 in January 2004, evolving the industry standards for digital imaging communications to include I/O and RS232 handling, and adding additional formats. At such high bandwidths it has become possible to transmit high-resolution images at very high frame rates to the PC's memory.

Comparison of Standard Interfaces

Interface	IEEE-1394a	USB 2.0	IEEE-1394B	GIGABIT ETHERNET (802.3AB)	CAMERA LINK BASE
Maximum Bit Rate	400 Mb/s	480 Mb/s	800 Mb/s	1000 Mb/s	>2000 Mb/s
Isochronous (video) mode	Yes	Yes	Yes	No	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	90 MB/sec	255 MB/s (base) 680 MB/s (full)
Topology	Peer-to-peer (On the go)	Master-slave, OTG	Peer-to-peer	Networked, P2P	Master-slave
Single cable distance in copper or other media	4.5m, worst case; 10m, typical camera application; 300m GOF	5m	10m copper; 300m GOF	25m, 100m (Cat5)	10m
Max. distance copper using repeaters	70m	30m	70m	n.a	30m
Bus power	Up to 1.5A and 36V	Up to 0.5A and 5V	Up to 1.5 A and 36V	None	None
Motherboard support	Many	Virtually all	Some	Some	None
PC load	Very low	Low	Very low	Middle	N/A
OS support	Windows, Linux	Windows, Linux	Windows, Linux	Windows, Linux	Depending on vendor
Main applications	Multimedia electronics	PC-centric serial input	Multimedia electronics	Networking	High speed camera interface
Camera standard	IIDC V1.3	None (?)	IIDC V1.31	Proposal: GenIcam	CL
Devices per Bus	63; 4 (8) simult./ card, accord. to 4 (8) DMA's typical	127; 4 simult./ card, accord. to 4 DMA's typical	63; 4 simult./ card, accord. to 4 DMA's typical	Dependant on software and available bandwidth	1 per interface

The right digital interface: Why you can count on FireWire

1. Economical.

Unlike expensive Camera Link, FireWire provides extraordinary standards-based flexibility and throughput at very affordable prices. These capabilities were unavailable at any price until the last couple of years, and the price:performance ratio is now truly compelling.

2. Plug-and-play.

Many computers have the 1394 port already built in. Alternatively, it's an inexpensive PCI (or PCMCIA) card to insert. And because FireWire provides not just data communications but also power, it eliminates the need for an external power supply for the camera(s).

3. Legacy imaging applications can often be improved upon at a lower price point.

Equally important, new imaging applications are now affordable and easier to implement.

4. Standards-based interoperability.

Because a range of useful modes and formats, e.g. for common resolution and frame-rate combinations are described by the (IIDC) DCAM standard that evolved with FireWire, software you develop for one such camera will also operate other cameras conforming to the same standard. This facilitates solutions that may evolve over time, and protects consumers since vendors are encouraged to compete on both quality and price while adhering to common standards.

5. Wide-selection of accessories and cabling options.

Since IEEE 1394 established an industry standard, multiple vendors have developed not only cameras but also a wide array of cables and accessories. These include, but are not limited to, locking cables, cables for drag chains (energy chains) or robots, hubs, repeaters, glass and plastic fibre-optics (for longer transport distances), computer interface boards, and so forth. This creates a range of flexible and affordable choices for customers to adapt overall imaging solutions from a collection of cameras and components.

6. Seamless interfaces to industry-standard image-processing software packages.

The FireWire standard is supported by each of: National Instruments Labview, MVTec Halcon, MVTec Active Vision Tools, Stemmer Imaging Common Vision Blox and Matrox Inspector, COGNEX and Neurocheck, just to name some the leaders. Why re-invent the wheel in terms of software development when you have configurable and extensible software packages in which to refine your custom application?

7. Forwards and backwards compatible.

Just as IEEE 1394 was succeeded by 1394a and then 1394b by adding new speed and capabilities while remaining backwards compatible, even more powerful 1394c standards are already in development. This will protect legacy investments in both applications and staff training, while also providing a forward migration path that takes advantage of even faster communication speeds, longer cable distances and additional features.

8. Compatible with both Windows and Linux.

Regardless of which OS environment you prefer, or in which you have legacy investments, the IEEE FireWire standards have led to the creation of software packages and developer communities around both OS options. AVT's FirePackage is completely platform independent, so that it can be ported by the customer to any OS. For example, customers have ported the AVT FirePackage to RTXDOS and PSOS.

9. Multiple camera solutions.

Some applications require two or more camera angles to achieve optimal outcomes. Because of the sophisticated multi-camera capabilities of FireWire devices (with minimal CPU loading), and because of the guaranteed bandwidth allocate when devices are plugged in, FireWire cameras are ideally-suited for such applications.

Questions and Answers

Q1: Why go digital? Aren't analog cameras less expensive than digital cameras?

A1: While an analog camera may appear less expensive than a comparable digital camera at first glance, remember that the analog camera must be supplemented with a framegrabber A-to-D converter, which typically closes the price gap. And with digital cameras now competitive with analog in terms of price, FireWire digital solutions have the added advantage of standard accessories and software compatibility, which further drive economies of scale in both price and availability. And that has the added advantage that communities of practitioners have emerged around FireWire, so there are manufacturers, distributors, consultants, and documentation that will help to support your work.

Furthermore, many FireWire cameras, especially most offered by Allied Vision Technologies, Inc., have additional technical advantages. These include features such as:

- LookUp Tables
- Shading correction
- Digital inputs and outputs
- Color correction and enhancement

These get some of the smarts out of the CPU and into the camera frequently resulting in faster and/or qualitatively better solutions. Additional features include programmable trigger and strobe functions, enabling exposures that support optimal imaging.

Q2: To build a solution for my application, will we have to develop extensive custom software entirely from scratch?

A2: Unless your circumstances are extremely unusual or demanding, more than likely you can build your solution largely by making parameterized calls on industry-standard software packages for such tasks as edge-detection, pattern matching, 3D calibration, blob analysis, etc. All of the leading software packages (named elsewhere in this paper) support the FireWire standard. Using this approach you need only write the control software that coordinates the function calls and evaluates the results relative to your particular image processing requirements. This solution is economical in terms of development time, ease of maintenance, and draws upon proven best-practices.

Q3: What if cable distances between devices exceed 10 meters?

A3: Using copper, with repeaters, FireWire (both IEEE 1394a and 1394b) can support 70 meter distances. With Glass Optical Fibre (GOF), 1394a and 1394b can reliably communicate over distances up to 500 meters!!

Q4: My application requires that every image in a sequence be captured, with no lost frames permitted. How can I make sure that happens?

A4: First, be sure to verify that the candidate camera(s) and communications bus and protocol are matched to the frame rate and resolution you desire. As long as you scope your requirements within the capacities of the camera and either IEEE 1394a or 1394b, you can be confident you've got the building blocks on which to build an effective solution.

Q5: There are temperature extremes, vibration issues, and cable-stresses in my target application. How robust are FireWire solutions?

A5: Many FireWire cameras can operate in a wide range of operating environments, and are specifically designed to absorb shock and vibration. And because of the accessories industry that has evolved around FireWire, locking industrial-caliber cables are readily available to insure reliable uptime for your application.

Summary

For industrial, medical, and scientific image processing applications, FireWire provides one of the most comprehensive, high-performance, cost-effective solutions platforms. There are tens of thousands of FireWire cameras in use around the world, and a large body of user expertise and standards that help to drive and sustain economies of scale.

Except for extraordinarily high-speed applications requiring expensive Camera Link solutions, FireWire offers very impressive throughput at very affordable prices.

In fact, there are additional benefits for FireWire beyond the ones mentioned in this paper, but we've emphasized just some of the main points in order to keep the paper brief. For additional information, or to set up an appointment to evaluate your particular application requirements, please contact:



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This Whitepaper was issued in March 2006, and will remain topical and current throughout at least the Summer of 2006. Please check with AVT for any updates for Fall 2006 or later.