IEEE 1394
Technology Brief

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BASLER VISION TECHNOLOGIES

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Introduction

IEEE-1394 Benefits

By now, most people in the machine vision field have heard a litany of pluses and minuses regarding the IEEE-1394 digital networking standard, called DV by the consumer video camera marketplace, Firewire by Apple, and iLink by Sony and others. Like most machine vision hardware technologies, it was invented without machine vision specifically in mind, so it comes as no surprise that applying IEEE-1394, or just 1394 for short, to machine vision requires ingenuity, perseverance, and digging far beyond the supplied documentation.

On the surface, it sounds just like getting any other camera technology to work in a machine vision environment! But the fact is, while 1394 is still an emerging technology, its benefits already far outweigh its limitations for use in a vast array of machine vision tasks, and we're going to see why in this discussion.

What is IEEE-1394, Really?

At the lowest level, 1394 is nothing more than a high-speed digital networking standard, much like FastEthernet. However, it differs from this familiar 100BaseT standard in two key ways:

- It is intended for short-distance communications, allowing it to achieve higher speeds (400 MBits/s today, several GBits/s in the future) over cheaper cabling ($30 for a 4.5 meter cable from www.firewirestuff.com, for example). The distance limitations can be overcome with the use of hubs and repeaters, much like in Ethernet (IEEE-802.3) technology, which already has inexpensive hubs available ($129 for a 6-port, 400 MBits/s hub).
- It provides guaranteed bandwidth. In its isochronous mode, a fixed-bandwidth channel is always available to each attached device. This allows uninterrupted live video to be transmitted without "hiccups" over the otherwise shared network.

When you are talking about using digital cameras with an industrial vision system there is another critical element to keep in mind, that is, the *1394 Trade Association Digital Camera Specification* (or D-Cam spec for short). The D-Cam spec is a camera design standard which defines features that are robust enough for industrial use. With a camera designed to the D-Cam spec, it is possible to use a standard set of messages to detect the camera on the 1394 network, and then query the camera's capabilities. These capabilities include a list of supported video modes and resolutions, and a list of programmable features such as filters, shuttering, balancing, gain, and brightness. Keep in mind that to use cameras designed to the D-Cam spec, you will need a software package on your system's host computer that is capable of controlling D-Cam compliant cameras.

One important feature of the D-Cam spec is that it defines several standard video formats and within each format, several standard modes and frame rates. For example:

Format 1, Mode 5, Frame Rate 3 = 640 x 480 / monochrome / 8 bits/pixel / 15 frames per sec.

Format 2, Mode 2, Frame Rate 2 = 1280 X 960 / monochrome / 8 bits/pixel / 7.5 frames per sec.

These standard formats are important because they make it much easier for the D-cam software in the host computer to control the camera and to process arriving images. The standard formats allow the software to change some of the basic characteristics of the camera's performance with just a few settings. They also allow the software to know the characteristics of the incoming image information thus allowing the software to process and display images correctly.

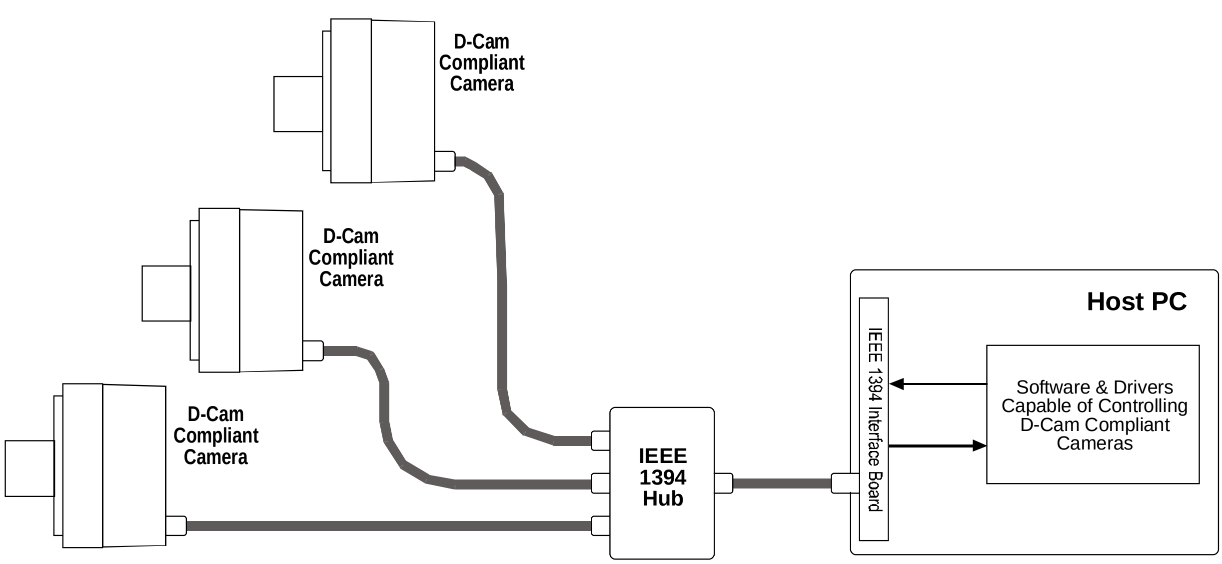
The D-Cam specification also includes an open image format called Format 7. This format provides general guidelines about how an image should be structured but allows enough flexibility so that camera designers can use it in unique ways. For example, Format 7 has been used to implement Area of Interest (AOI) scanning. With AOI, the camera user can designate an area of the cameras sensor and only image information from the designated area will be transmitted from the camera.

The 1394 Dream

Here's a machine vision dream that I would not have dared to dream a year ago: I'm sitting at my desk, watching video pour into three windows on my computer. One window is receiving 20 frames per second (FPS) video in full-color from a 780 x 580 camera. Another window is receiving 30 FPS video from a 640 x 480 camera. The third window is receiving a 1300 x 1030 image at up to 10 FPS based on an external trigger signal being delivered directly to the camera.

All of these video formats are running over a single network, with a $50 cable connecting each camera to a $200 hub. Another $50 cable connects the hub to a $1,700 Dell computer. (Dell now offers a standard "Digital Movie" package that adds a 1394 interface board to many of their systems for $99. But keep in mind that to control the cameras, you will need to add a software package capable of controlling cameras compliant with the D-cam spec.)

Since the 1394 video data is deposited directly into host memory (similar to the operation of memory-less frame grabbers), the video data is ready for processing as it arrives. Typically, the camera control software will include modes that will allow you to process and display images. They also frequently include the capability to change camera settings on the fly.



2 Technology

Comparison between IEEE-1394 and other digital interfaces

Since there are many different interfaces available, for example, RS 422, RS 644, and USB, vision system integrators are very likely to be confused when choosing the right interface for their application. For the ideal design of a vision system, it is vital to have the right bus/interface. To make things even more complex, there is no easy answer such as “IEEE-1394 is the best choice.” Furthermore, the new CameraLink standard, promoted by companies such as Pulnix, Basler AG, and many frame grabber companies, seems to be the state of the art interface. So why should IEEE-1394 be an alternative?

These questions are as complex as most vision applications and there is no simple guideline. Each of these interfaces offers many benefits and each of them has its individual drawbacks and restrictions. In the table below, we try to give a brief comparison of the most popular interface systems.

	RS 644 [1]	CameraLink	IEEE-1394	USB 2
Topology	Link	Link	Bus	Bus
Adapter	Frame Grabber	Frame Grabber	Standard Adapter	Standard Adapter
Windows Driver	Proprietary	Proprietary	Native (Win 200, Win 98)	Native (support delayed)
“Guaranteed” Bandwidth	~ 20 to 40 MBytes/s	~ 255 MBytes/s	~ 32 MBytes/s [2]	~ 38 MBytes/s [2]
Cable Length	~ 10 m @ 40 MHz ~ 20 m @ 20 MHz	~ 10 meters	4.5 meters	5 meters
Wires Needed for 8 Data Bits	22 [3]	10	4	2
Parameter Port	No	≥ 1 KByte/s	~ 8 MBytes/s [2]	~ 9 MBytes/s [2]

[1] These specs are for a typical 8-bit camera application operating at 20 MHz or at 40 MHz.

[2] 80% of the bus bandwidth is used for image data and 20% is used for parameter data.

[6] 16 wires are used for data bit transfer and two wires each are used for the separate Line Valid, Frame Valid, and Pixel Clock signals required with RS-644 transmission.

A careful comparison of the specifications shown in the table should be your first selection guide for the interface. For example, for an integrator who needs very high speed, USB 2 and IEEE-1394 are not the first choice. On the other hand, these buses are the ones to select in cases where multiple cameras are needed or cost is a critical issue. Also, the user needs to be aware that the D-Cam specification currently does not specifically support Line Scan cameras. However, the specification is open and line scan support could be achieved via Format 7. As for USB 2, it is still in its infancy in machine vision and we are not aware of any kind of machine vision support.

Flexibility and Cost Reduction

Many image processing application engineers face a familiar group of problems when designing and building a system. The end user requires system flexibility, simple adaptation, fast delivery times, and most importantly a reasonable price. With conventional systems, whether analog or digital, engineers must confine themselves to certain combinations of the existing cameras, frame grabbers, and software. The product choice for this system configuration is limited. Unless the decision is made to use a high cost frame grabber that supports multiple cameras, sometimes known as multi-norm, it is usually not possible to operate cameras with different resolutions from the same frame grabber.

For many applications, the introduction of digital cameras is hindered by the cost specified by the end customer, however technically effective digital cameras may be. With the increased use of IEEE-1394 in the industrial image processing business, many of these problems are solvable in a sure, safe, and cost effective way.

Hardware Cost Example

This example compares two similar vision systems. Each system uses four Megapixel resolution digital cameras. The traditional solution consists of one frame grabber per camera, one parallel digital data cable per camera, and one power supply per camera.

The 1394 solution requires one hub and one interface card to connect the four cameras, along with five inexpensive 1394 cables. The 1394 cables carry power to the cameras directly from the computer's internal power supply. (Note that not all computers are capable of supplying enough power for the cameras. In some cases a separate power supply may be required.)

Traditional Solution with multiple frame grabbers	Price	1394 Solution	Price
Four Cameras	18,000	Four 1394 Cameras	18,000
Four Frame Grabbers	4,400	One 1394 Interface Card	100
Four Cables	400	One 1394 Hub	120
Four Power Supplies	320	Five Cables	150
Total	$23,120	Total	$18,370

Multiple Camera Support

In some applications, for example the inspection of complex objects, cameras with different resolutions and different frame rates are required. A classic example is the use of a high frame rate CCIR resolution camera such as the Basler A302f camera (768 x 582 pixels) in combination with a lower frame rate, higher resolution camera such as the Basler A101f (1300 x 1030 pixels). Thanks to the capabilities of IEEE-1394 to control multiple cameras in a simple and standardized way, the image processing engineer can now work without an expensive and difficult to program multi-norm frame grabber. The IEEE-1394 bus allows different cameras to operate together with ease.

3D measurement technology is a typical industry application area for multiple cameras. At least two cameras are needed for applications of this type. With IEEE-1394, it is theoretically possible to connect up to 64 devices (63 cameras and an interface board) to one bus interface. In practice, the bandwidth sets the limit for the number of cameras to be used. The current version of the IEEE-1394 standard supports transfer rates of up to 400 MBits/s. Currently, between two and four cameras with a total image data rate of up to 256 MBits/s can be operated with simultaneous image capture.

The bi-directional design of the bus makes configuration of the camera and return confirmation to the PC very simple. This simple connection makes significant cost reductions possible. For the first time, digital image capturing with all of it's advantages, such as better image quality and reduced susceptibility to interference due to the cable, is cost effective and has become a real alternative.

Individual Parameter Setting Before Each Image Capture

Since it is possible to individually configure each camera before each image capture, an image processing system using IEEE-1394 is particularly flexible and fast. The flexibility makes it very easy to configure the system for situations such as different reflective behaviors of test pieces or parts. Through the use of the "Area of Interest" (AOI), which is just one of the parameters that can be controlled with IEEE-1394, the given bandwidth can be used even more effectively. The AOI feature allows the camera user to specify a portion of the camera’s sensor array and when an image is captured, only the pixel information from the specified portion of the array will be transmitted out of the camera. This is a particularly interesting option, because cameras which offer a continuously adjustable AOI, can avoid the transfer of unnecessary pixel data. Digital cameras from Basler Vision Technologies offer IEEE-1394 capability with this feature.

Application Examples

Today, there are already applications realizing the benefits of IEEE-1394 technology. For example, at one of our customer sites, Basler was faced with a vision system which has the following specifications:

The machine is a high-speed assembly system. Two independent robots take different parts (different in size, shape, and reflection) from a support unit and mount these parts on a mounting plate. Timing is crucial, and in the worst case, a part must be taken from the tray every 100 ms. Accuracy of parts mounting is also critical (0.5 mm). To have a vision system inspecting these operations, 4 cameras (2 on each of the robots) are needed:

- 2 low resolution Basler A302f cameras (640 x 480) for checking if the mounting plate is in place
- 2 high-resolution Basler A101f cameras (1300 x 1030) for checking the components to be mounted.

Since most of the parts are different, the two A101f cameras must be reconfigured before almost every image acquisition. In the worst case, the AOI, shutter, and sometimes gain need to be adjusted.

Solution used before Basler's Intervention

The customer used analog cameras with CCIR resolution (768 x 582) only. This drastically restricted the number of parts which could be mounted using the robots. Since these cameras had no communication port for configuration, adjusting the AOI was not possible and differences in reflection of the parts needed to be adjusted for by driving a flash circuit. All cameras were interfaced into one frame grabber (one PC).

Possible solution with digital cameras using RS 644 or CameraLink

Using RS 644 or CameraLink based cameras, the customer would need one frame grabber for each camera. It is very likely that the user would need two PCs (one for each robot). Changing the camera-configuration "on the fly" would require advanced grabber cards since simple grabbers are not capable of easily changing their registers for different AOIs.

IEEE-1394 solution

All cameras are attached to a single interface card in the PC. The Basler A302f is only used when a new mounting plate is positioned by the handler. In normal operation, only the two Basler A101f cameras will be sending data at the same time and they will be operating at about 10 FPS. This results in a data rate of about 27 MBytes/s, which is well within the specification for IEEE-1394.

Since IEEE-1394 supports bi-directional communication between the camera and the PC, before each frame capture, the PC can easily change resolution, gain, offset, shutter speed, or whatever is required.

The IEEE-1394 solution results in these clear advantages for the customer:

- Only one PC,
- Only one interface card (very inexpensive compared with frame grabber cards),
- Easy and inexpensive cabling,
- The system meets the expectations for speed and accuracy,
- The range of inspectable parts is much bigger than with the old system.

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Frequently Asked Questions

Q: Can I get a consistent frame rate from IEEE-1394?

A: With the IEEE-1394 bus, image data is transmitted using something known as isochronous transfer. With isochronous transfer, data transmission takes place in a sequence of 125 microsecond time slots. In each time slot, you can have a 4 KByte image data payload. Thus, the maximum image data rate is 4 KByte per 125 microseconds or 32,000,000 Bytes per second.

Now, let's take a look at the Basler A101f and consider how much image data it needs to transfer when it is operating at its maximum of 11.75 frames per second. The CCD array in the A101f contains 1,339,000 pixels and 1 Byte of data is used to represent the image data for each pixel. So, each captured frame on the A101f contains 1,339,000 Bytes of data. If we multiply this by a frame rate of 11.75 per second, we find that 15,733,250 Bytes of data must be transferred each second. As you can see, this is well below the 32,000,000 Byte per second capacity of the IEEE-1394 bus. So, the bus can transfer the data from an A101f operating at full frame rate with ease and can easily maintain this transfer rate from second to second.

But what happens if we are running two cameras? Well, let's consider what would happen if we were running two A101f cameras on the same bus at full frame rate. In this case, each camera would need to transmit 15,733,250 Bytes of image data per second for a total of 31,466,500 Bytes per second. As you will notice, this total is below the 32,000,000 Byte capacity of the bus.

But how would the system handle this situation so that each camera is able to transmit data on a timely basis? The answer is easy, in each 125 microsecond time slot, the system allocates 2 KBytes of the 4 KByte data payload to one camera and 2 KBytes to the other. The system "guarantees" that each camera can transmit 2 KBytes of data during each time slot. This guaranteed bandwidth lets each camera transmit data in a timely manner and ensures that each camera will be able to maintain its frame rate from second to second.

The system's ability to divide its available bandwidth between devices and to guarantee transmission time to each device holds true with up to 64 devices attached to the system. The limiting factor is that the total data transmission rate of all of the attached devices must not exceed the 32,000,000 Byte capacity of the system. Although in theory a single IEEE-1394 bus can handle up to 63 cameras (plus an interface board), in practice you will seldom see more than 3 or 4 industrial grade cameras attached to a bus. Industrial grade cameras with their large pixel arrays and high frame rates generate large amounts of image data and this means that 3 or 4 cameras will usually consume the entire image data capacity of the bus.

One final thing to keep in mind is that the standard frame rates defined in the D-Cam spec are approximate. For example, if you set the camera to operate at 15 FPS, the actual frame rate may be 15.1 or 15.2 FPS.

Q: If the motherboard on my computer comes with an IEEE-1394 port built in, must I still use an interface board on my computer?

A: There are motherboards with an IEEE-1394 port built in and with these boards, you do not need an interface card. However, you still need to install a software package that is capable of controlling a camera that is compliant with the 1394 Trade Association Digital Camera Specification (D-Cam spec) along with the appropriate drivers.

Keep in mind that there is a type of software used to control “V-Cam” compliant cameras. This software **will not** work with cameras compliant to the D-Cam spec. (V-Cam cameras are very simple devices such as web cameras.)

Q: What are the differences between the commonly available IEEE-1394 video cameras (such as the Sony Handicam) and the IEEE-1394, D-Cam compliant cameras such as the Basler A101f?

A: The main difference is the data format. The image compression used in multimedia cameras made for the consumer market is “lossy.” This means that some data is discarded during the image compression process so that the images will be smaller and can be transmitted faster.

In industrial image processing applications, loss of data is unacceptable. So D-Cam compliant cameras use an image format which causes no data loss.

Q: Since IEEE-1394 is a standard, why can’t I just buy an IEEE-1394 interface board for my PC from the shop around the corner and have it work with my Basler camera?

A: The cards themselves can operate on an IEEE-1394 bus just fine. But the software and drivers included with the card are meant for consumer market cameras and can not control industrial type cameras (such as Basler cameras) that are complaint with the D-Cam spec.

Q: Matrox and National Instruments have announced that they will have software available for controlling D-Cam compliant cameras. Can you tell me which camera functions these software packages will be able to control on Basler cameras?

A: These packages should be able to control all of the standard features, formats, and modes that are defined in the D-Cam spec and are implemented in Basler cameras, for example, gain, brightness, and shutter time. (Keep in mind that not every feature, function, and mode defined in the standard has been implemented in Basler cameras.)

Basler cameras also include several features that fall under a D-Cam spec category called “Advanced Features.” These include, test images, shading correction, and binning. The Matrox and National Instruments software may not support these advanced features.

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Summary

Although the IEEE-1394 bus system technology is not yet established in every area of industrial image processing, the overall concept clearly shows the direction in which development will proceed. The flexibility of the bus system allows image processing system designers to make their choice of a digital camera without considering a frame grabber. The price reduction made possible through the introduction of IEEE-1394 technology opens many new markets for system designers where image processing solutions were either too expensive or time consuming. Today, high performance IEEE-1394 camera systems with excellent image quality and demonstrated superiority in industrial image processing are already available.

Sources:

Advanced Imaging Magazine, October 2000

Basler Vision Technologies, Vision Components Development Group