Choosing the Right Camera Bus

Machine vision acquisition architectures come in many different forms, but they all have the same end goal –to transfer image data from a physical sensor into a processing unit that can analyze the image and take an action. This goal is the same for PC-based machine vision systems, embedded compact vision systems, and smart cameras.

Of these architectures, PC-based machine vision systems are the most popular because they provide the best performance and the most flexibility for the price. With that said, all physical architectures have the same starting point and ending point. You have a camera on one end and a processing unit on the other. This white paper explores the strengths and weaknesses of the five major camera buses – analog, Camera Link, USB, IEEE 1394, and GigE Vision – and describes the decisions and trade-offs you may need to make when deciding which camera bus is right for your application.

This white paper compares the five camera buses over the following eight categories on a relative scale:

1. **Throughput –** The rate at which image data can be transferred over the bus.
2. **Effective cost –** The overall component price of a system, including the camera, cables, frame grabbers, and software.
3. **Cable length –** The maximum possible distance between the camera and the PC without repeaters.
4. **Standardized interface –** A measure of ease of use and future scalability. Plug-and-play interfaces make some camera buses easier to use and allow for future system upgrades without significant rework.
5. **Power over cable –** The ability of the camera bus to provide power to the camera over the same cable.
6. **Camera availability –** A measure of the number of different camera types available, how long the camera bus has been available, and the overall acceptance of the standard in the vision industry.
7. **CPU usage –** The amount of CPU available to process images during image acquisition.
8. **I/O synchronization –** The ease at which triggering and overall system communication is addressed and handled within the camera bus.

In this white paper, each camera bus receives a relative score from one to five for each of the eight categories above, where five is the highest score and one is the lowest. Because there is not a dominant bus for every application, the relative scores are represented in a “spider graph.” With these graphs, you can rank the camera buses yourself depending on which category is most important to you.

The initial IEEE 1394 specification was released in December 1995. Unlike USB, IEEE 1394 was never intended for basic computer peripherals – it was designed for imaging equipment. The initial speed of IEEE 1394a was 100 Mb/s compared to the 1.5 Mb/s of USB 1.1. This higher bandwidth is better suited for devices such as cameras and hard drives. Because of the initial bandwidth advantages of IEEE 1394, it is now the widespread standard for vision systems today, even though USB 2.0 has caught up in terms of throughput.

Throughput: IEEE 1394a cameras offer similar or slightly higher throughput to analog cameras but with much greater flexibility to choose between resolution and frame rate. The IIDC specification for IEEE 1394 cameras (explained below) defines several standard frame rates that range from 1,875 frames/s to 240 frames/s as well as standard resolutions from 160 × 120 to 1,600 × 1,200. The specification also provides for a scalable image format, known as Format 7, which allows for almost any arbitrary resolution and frame rate. Format 7 images are limited only by the available bandwidth on the IEEE 1394 bus and the camera manufacturer's implementation decisions. For many cameras, frame rate scales inversely with image resolution along a roughly constant curve. The http://zone.ni.com/devzone/cda/tut/p/id/5386 (6 of 10)2/1/2007 4:13:30 AM Choosing the Right Camera Bus- Developer Zone - National Instruments IEEE 1394a specification provides a maximum data rate of 400 Mb/s, which is enough for a 640 × 480 8-bit monochrome acquisition at 100 frames/s. The IEEE 1394b specification doubles the available bandwidth to 800 Mb/s and the maximum frame rate at 640 × 480 to 200 frames/s. **Score: 3**

Cost-effectiveness: IEEE 1394 cameras, which offer digital image quality, extended features, and ease of use, are only slightly more expensive that analog cameras. On top of this, they do not require special frame grabbers to acquire images into a PC. Add to this the low cost of cables, and IEEE 1394 is a very cost-effective camera bus for vision. **Score: 4**

Cable length: IEEE 1394 cameras use standard, low-cost cables that are widely available. Point-to-point connections for IEEE 1394a are limited to less than 5 m, with longer distances possible using hubs or repeaters. IEEE 1394b cameras support longer single runs up to 100 m over fiber or CAT 5 cable. Solutions are also available outside the specification that allow IEEE 1394a to be used across much longer distances over fiber-optic cable. **Score: 1**

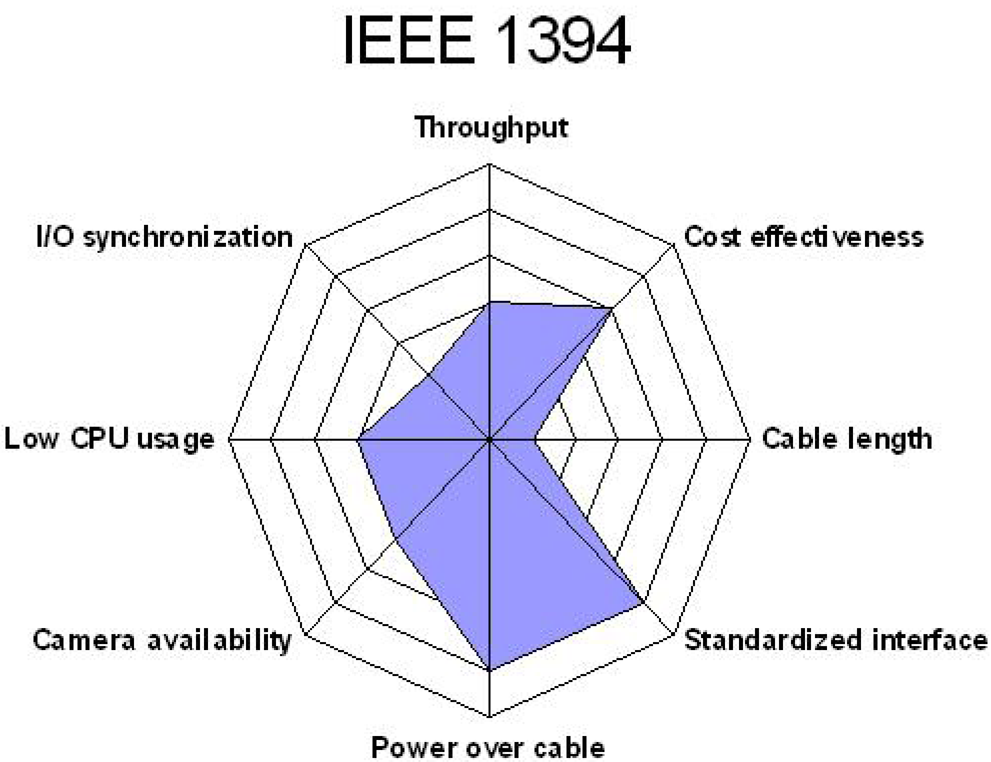
Standardized interface: Several years ago, the 1394 Trade Association formed a working group to define an industrial camera specification. The resulting 1394 Trade Association Industrial and Instrumentation specification for Digital Cameras (IIDC) defines a vendor-agnostic hardware register map that allows basic query and control of the camera. Several video and external triggering modes are supported. The vendor-agnostic nature of the specification promotes interoperability between different hardware and software. This hardware, software, and cabling standard makes IEEE 1394 the easiest camera bus to use and maintain. **Score: 5**

Power over cable: IEEE 1394 has power on the cable. Most cameras can draw power off the IEEE 1394 bus without the need for an external power source. High-power devices still require an external power source. **Score: 5**

Camera availability: IEEE 1394 has been an industry standard for more than five years, and, over this time, hundreds of different IEEE 1394 cameras have been introduced. Today, you can find infrared, linescan, megapixel, and high-speed IEEE 1394 cameras. However, because of bandwidth and I/O synchronization limitations, you can still find higher-performance and more flexible Camera Link cameras, especially for linescan. **Score: 4**

CPU usage: IEEE 1394 does not require a frame grabber, which means it relies on the CPU to transfer images to system memory. CPU rates differ among software providers, but, in general, the overall usage is higher than that of frame grabbers. **Score: 3**

I/O synchronization: Just like USB and GigE Vision, I/O synchronization is inherently more challenging without a frame grabber to broker communication signals and triggers. With that said, many IEEE 1394 cameras provide direct trigger input and output lines. Also, there are a few IEEE 1394 plug-in boards that provide isolated digital I/O and triggering, which greatly simplify system synchronization. **Score: 2**



Gigabit Ethernet is a new camera bus technology for machine vision systems. With relatively high bandwidth, long cable lengths, and wide usage in the consumer and industrial applications, Gigabit Ethernet shows promise for security and long-distance vision applications. Unlike USB and IEEE 1394, Ethernet was not originally intended to connect peripherals. Ethernet does not offer plug-and playnotification. Device discovery requires additional protocols or user intervention. These shortcomings are addressed in the new GigE Vision standard from the Automated Imaging Association (explained below).

Throughput: The theoretical maximum bandwidth of Gigabit Ethernet is 125 MB/s. With hardware limitations and software overhead, the practical maximum bandwidth is closer to 100 MB/s. This bandwidth is the same as IEEE 1394b and is second only to Camera Link. **Score: 3**

Cost-effectiveness: The overall system cost of GigE Vision is very similar to IEEE 1394. The cameras may be slightly more expensive, but the cabling is cheaper. Neither requires a frame grabber. **Score: 4**

Cable length: Cable length is truly where GigE Vision excels. With cable lengths reaching 100 m, GigE Vision is the first camera bus to rival analog in terms of cable length. This characteristic has helped GigE Vision replace analog in security and monitoring applications. **Score: 5**

Standardized interface: Recently, the Automated Imaging Association along with several member companies defined an in-depth industrial camera standard built on top of Gigabit Ethernet called GigE Vision. The GigE Vision standard overcomes some of the shortcomings of Gigabit Ethernet by providing plug-and-play behavior, device discovery, error handling, and secure image transfer.

The GigE Vision standard provides a level of standardization that is on the same level as IEEE 1394 in terms of ease of use and hardware scalability. **Score: 5**

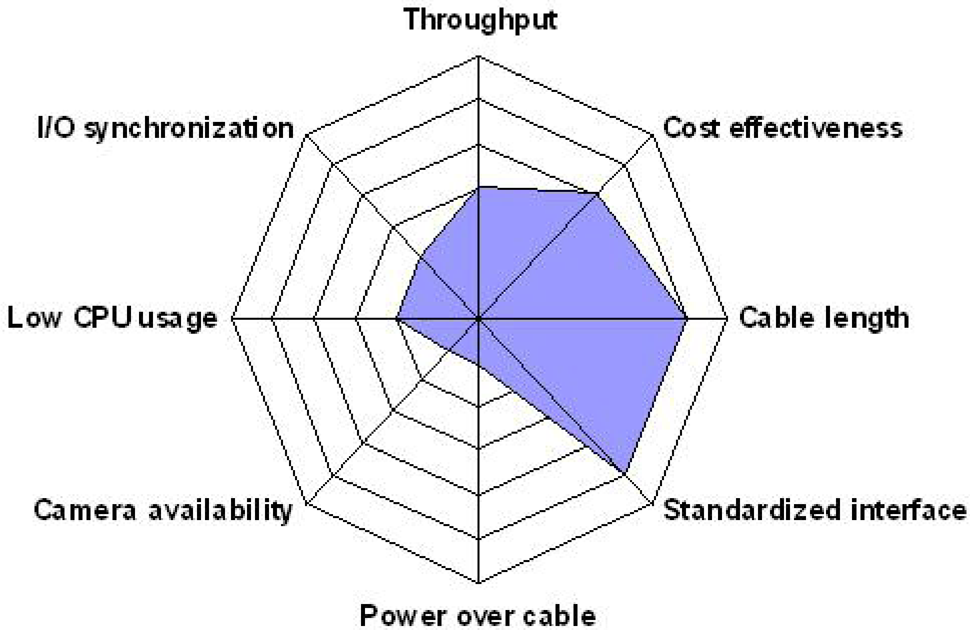
Power over cable: One major drawback of GigE Vision is the inability to power the camera over the Ethernet cable. This means that every GigE Vision camera requires its own, separate power supply. **Score: 1**

Camera availability: The GigE Vision standard, completed in April 2006, is currently gaining acceptance in the industry. It may take several years before the breadth and availability of cameras reaches that of IEEE 1394. **Score: 2**

CPU usage: Different software implementations of the GigE Vision standard yield very different CPU loads. In general, there are two types of drivers for acquiring images from GigE Vision cameras: filtered and optimized. Filter drivers separate incoming image data packets from other traffic on the network at a high level. They are easier to create and use but make heavy use of the system CPU. Optimized drivers written specifically for a dedicated network interface card (NIC) work at a much lower level. For instance, by writing an optimized driver for an Intel NIC, packets containing image data can be separated at the NIC instead of the CPU. These optimized drivers use very little of the CPU and are essential for image processing applications that are processor-intensive. Score: 2

I/O synchronization: Because GigE Vision applications often make use of the long distances between the PC and the camera, triggering and communication are a little more challenging than with IEEE 1394. Oftentimes with IEEE 1394, a proximity sensor is connected to the PC that then triggers the camera with a known pulse. However, with Ethernet distances up to 100 m, it is more difficult to use the PC to condition a trigger signal between a proximity sensor and the GigE Vision camera. Score: 2

GigE Vision



Throughput
Cost effectiveness
Cable length
Standardized interface
Power over cable
Camera availability
Low CPU usage
I/O synchronization