Introduction

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.

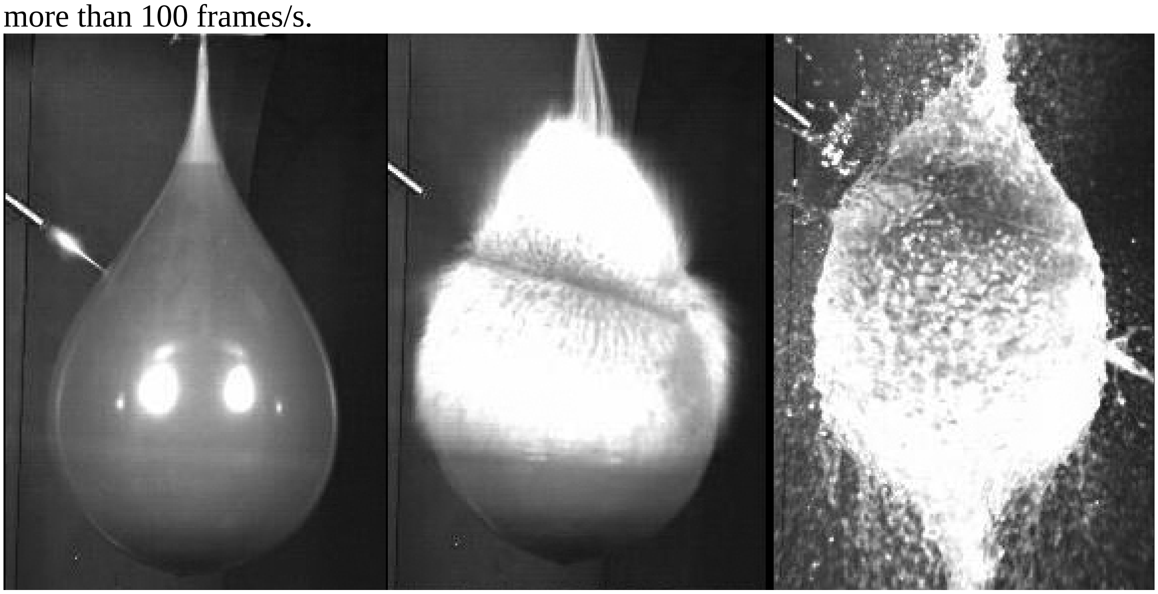
This white paper compares the five camera buses over the following eight categories on a relative scale:

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 cost of custom cables and the broad range of digital transmission formats were the driving force behind the development of the Automated Imaging Association (AIA) standard for high-speed transmission of digital video. The AIA standard is known as Camera Link, which defines the cable, connector, and signal functionality between the camera and the frame grabber. Any camera that complies with the Camera Link specification should work with any frame grabber that is also Camera Link-compliant.

Throughput: Camera Link, a high-speed serial digital bus designed specifically for machine vision cameras, offers the highest throughput of any camera bus. Camera Link provides a three-tiered bandwidth structure (base, medium, and full) to address a variety of applications. Base-configuration cameras acquire at up to 255 MB/s (3 bytes × 85 MHz), although the majority of cameras use roughly 100 MB/s or less (1 or 2 bytes × 50 MHz or less). A typical base-configuration camera might acquire 1 Mpixel images at 50 frames/s or more. Medium- and full-configuration cameras acquire at up to 510 MB/s and 680 MB/s, respectively. A typical fullconfiguration camera can acquire 1,280 × 1,024 images at 500 frames/s, or larger 4 Mpixel images at more than 100 frames/s.



Cost-effectiveness: Because Camera Link is designed for medium- to high-performance image acquisition, the cameras are generally more expensive than lower-performance cameras. Also, Camera Link requires a frame grabber that can handle the high data rates described above, which are often more expensive than analog frame grabbers. **Score: 1**

Cable length: The Camera Link standard replaces expensive, custom cables with a single, low-cost standard cable with fewer
wires. Special components on the camera are used to serialize 28 parallel TTL signals into four high-speed differential pairs, which
are transmitted across the cable. A similar component is used on the frame grabber to deserialize the data stream into parallel TTL
signals. This reduces cable size and cost and increases noise immunity and maximum cable length.
The Camera Link specification defines a maximum cable length of 10 m. Camera Link uses a standardized cable that is relatively
inexpensive and works with any Camera Link-compliant camera and acquisition device. Base-configuration cameras only require one
cable. Medium- and full-configuration cameras require two cables. **Score: 3**

Standardized interface: The Camera Link specification defines a standard cable, connector, signal format, and serial
communication API for configuring cameras. However, unlike IEEE 1394 and GigE Vision, the communication between the camera
and PC is not defined by the standard. This means that every Camera Link camera requires a special camera configuration file to
explain to the software how to acquire images from the camera, how to communicate with the camera, and which features can be

modified. You can compare cameras and download camera files at **ni.com/cameras**.
Score: 3

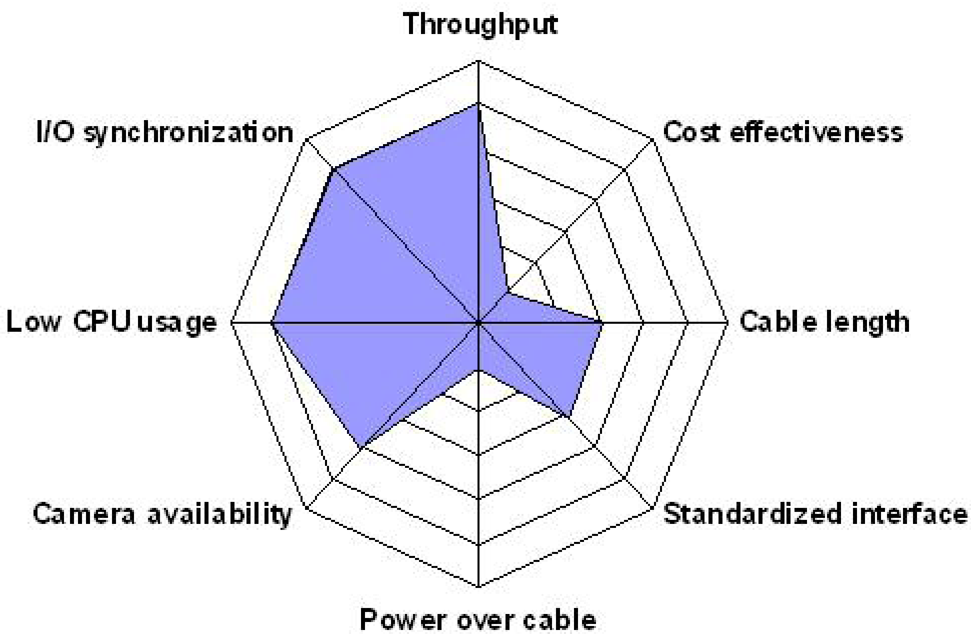
Power over cable: As of 2006, Camera Link does not provide power over the cable. The standardization committee is working to
add this feature. **Score: 1**

Camera availability: Almost every major machine vision camera maker provides Camera Link cameras, and most high-resolution,
high-speed, and linescan cameras are based on Camera Link. While not as prolific as analog, Camera Link is the preferred standard
for high-performance imaging. **Score: 4**

CPU usage: Camera Link cameras require the use of frame grabbers, which transfer the image data to memory using DMA
channels that do not burden the computer's CPU. Because of this, Camera Link image acquisition uses very little of the system CPU.
Score: 5

I/O synchronization: Although serial signals are defined on the cable pinout, the specific serial commands for setting exposure,
gain, and offset, for example, are not defined by the specification. The frame grabber driver software must be configured to
accommodate a particular camera's serial commands. Control signals are also provided on the Camera Link cable for triggering and
timing, but many manufacturers provide separate connectors for advanced triggering capabilities. Although the limited scope of the
Camera Link specification does not provide plug-and-play compatibility, it gives camera and frame grabber companies an
opportunity to differentiate their products be adding features or enhancing functionality. Overall, Camera Link provides the most I/O
flexibility and capability. Because of their more demanding synchronization requirements, most linescan cameras use Camera Link.

Camera Link


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