Technical Paper

The Emergence of Camera Link

About six months ago, a camera manufacturer inquired whether Alacron (Nashua, NH: www.alacron.com) had the hardware to interface to a new model of high-speed camera interconnection technology called Camera Link. Intrigued, Alacron arranged to borrow a new 200-500 Mbytes/s multi-tap Camera Link camera to test its interfacing and other capabilities. Close evaluation revealed that this new image sensor and interconnection technology rapidly would create enormous improvements in machine-vision performance, as well as enormous challenges to the machine vision-industry. Not only is the physical interface to the camera vastly superior to current commercially available native PC technology, but also its transmission rate meets or exceeds the storage and processing capabilities of current technology. Channel Link technology is spreading and probably will become the primary camera interconnection technology in the near future. To do this, the primary historical factors influencing the choices of manufacturers and consumers of machine-vision technology must be understood and how the recent history of PC, data transmission, and image-sensor technology has influenced these factors.

Driving factors

Users buy cameras to meet specific needs and speed requirements and consider system price and ease of integration as primary factors in making their choices. Similar factors influence systems integrators, who have to provide application solutions at competitive prices. Thus, the kind of interface implemented is not usually as important to the camera user as is the price, the availability of many vendors, the available suitable technology, and the ease of integration. Camera manufacturers design cameras with a view to keeping the cost, power, and size to a minimum for a required performance range. Additionally, they consider the availability of frame grabbers for their camera, if one is needed, and either adapt their designs of their camera interfaces to a commonly available one, or promote a specific frame-grabber manufacturer who supplies a compatible interface. Frame-grabber manufacturers are similarly interested in the lowest cost and broadest supported camera solutions possible for a particular design.

Brief background

Prior to the mid-to-late 1980s, most machine-vision systems were custom products produced as an integrated package that was sold to a systems integrator or end user. Beginning with the widespread adoption of the PC, manufacturers began to take advantage of the widespread PC/AT-based computers and operating systems to make modular merchant cameras and frame grabbers. In the mid 1990s, the technological basis for the PC-based machine-vision industry accelerated with the introduction of the PCI bus standard, making available for the first time a native PC-based real-time imaging system using widely available and multi-sourced cameras and frame grabbers.

Until recently, analog cameras provided the standard interface. This allowed customers, camera vendors, and frame-grabber vendors to design products that met most everyone's needs. Competition was based mostly on price and features. With analog cameras as the standard interface, the main differentiator was whether processing was done real-time on the frame grabber or the data were transferred in non-real-time to the PC via the AT bus for storage or future processing. Here, competition was at the frame-grabber level.

Concurrently with the introduction of PCI technology, digital cameras based on TTL, PECL, and LVDS emerged. These cameras yielded higher performance for the camera manufacturers who could take

advantage of the digital revolution to support faster and larger formats. Camera manufacturers were able to meet the higher frame and data rates, but now have to worry about compatibility with as many framer grabbers as possible. Frame-grabber vendors now have to design for the numerous, slightly different, digital interfaces that camera vendors are providing, as well as to convince integrators and consumers of their claim to the most ease of integration while charging the lowest prices. Therefore, frame-grabber manufacturers further differentiated themselves into supporters of native PC (for example, Bitflow, Imagenation, Integral Technologies, etc.) versus co-processor groups (for example, Alacron, Coreco, Datacube, Matrox, etc.), even further complicating the commercial market. These common or classic camera interfaces and frame-grabber formats are summarized in Table 1.

Table 1. Common camera and frame-grabber characteristics

Technique	*Data rate*	*Availability*	*Standard interface*	*Transmitter cost (camera)*	*Receiver cost (frame grabber)*
Analog Color NTSC, PAL	**4-6 MHz**	**Largest**	**Yes**	**$1.00**	**$12.00**
Analog BW RS-170	**4-6 MHz**	**Large**	**Yes**	**$1.00**	**$7.00**
Parallel (RS-422)	**1-100 Mbytes/s**	**Medium**	**No**	**$20.00**	**$20.00**
Parallel (LVDS)	**40-320 Mbytes/s**	**Medium**	**No**	**$20.00**	**$20.00**

Since 2000, further standardization of peripheral buses (spurred by OEM PC manufacturers to enable the public to easily add peripherals--or even cameras--to their PCs without expert assistance) has had an invigorating effect on the choice of camera interfaces. This has been further accelerated by the rapidly increasing CPU and memory data rates commercially available at competitive prices, which present an increasing option of native PC-based real or near real time processing at speeds only recently possible (see Table 2)

Table 2. Latest camera and frame-grabber characteristics

Technique	Data rate	Availability	Standard interface	Cost to camera	Cost to frame grabber
Serial USB 1.0	**1.5 Mbytes/s**	**Widespread**	**Yes**	**$10.00**	**Not needed**
Serial FireWire	**50 Mbytes/s**	**Limited**	**Yes**	**$20.00**	**Not needed**
Serial USB 2.0	**60 Mbytes/s**	**Limited**	**Yes**	**$10.00**	**Not needed**
Camera Link	**10 – 297 Mbytes /per channel**	**Medium**	**Yes**	**$4.00**	**$4.00**

The ubiquitous USB 1.0 interface is now used for low-speed, low-resolution cameras connected directly to the PC, therefore eliminating the need for a frame grabber. However, the limited distances, speeds, and resolutions of USB 1.0-cameras severely limit their applications in a serious machine-vision environment. The high-technology industry expects that USB 2.0 interface will supplant the USB 1.0 platforms as PCs evolve their USB designs, but USB 2.0 may take time to become widespread in the motherboard market.

The IEEE 1394 (FireWire) and newer USB 2.0 standards are fast enough for the original analog camera signal in digital formats as well as for low-to-medium speed, existing, digital cameras. Impeding IEEE 1394's utility, however, is the lack of widespread OEM PC support for it in the industrial PC market (as opposed to the consumer portable/Apple environment). The USB 2.0 interface can provide higher data rates, but the same difficulty applies with the additional problem that IEEE 1394 has wider current acceptance. Even with the newest PCI, CPU, and memory technology, the standard PC may have significant problems doing near real-time processing without adding extra processors. After two processors, the cost and shared memory contention potentially make a co-processor (accelerated) frame-grabber substantially cheaper and more efficient than the native PC solution. The advantage of using shrink-wrapped software packages is also lost.

Camera Link emerges

The Camera Link standard is based on National Semiconductor's inexpensive Channel Link technology, which boasts superior transmission rates of up to 2.38 Gbits/s (297.5 Mbytes/s) per channel. With a standard connector and pin-outs, Camera Link, as currently defined, uses one to three channels (Base, Medium, or Full configurations, with a recent extension proposed by Basler Vision Technologies), depending on video data format and rate. The Full configuration delivers impressive transmission rates of up to 680 Mbytes/s at 66 MHz or 850 Mbytes/s at 85 MHz. Moreover, this technology is highly scalable and limited only by the number of chipsets that frame-grabber makers put on a laminate or the number of frame grabbers an integrator or end user is willing to put in a chassis. For low- and medium-end cameras, frame-grabber manufacturers and end users are back in the same competitive environment as they occupied during the analog era. Camera vendors like the ease of implementing Camera Link, and the low power and low cost of the Channel Link chipsets. Frame-grabber vendors like the new standard because they don't have to do a lot of hardware design, and the interface is easy to implement. Therefore, IEEE 1394 and USB 2.0 boards, and even single Camera Link boards costing less than $50, will satisfy most native PC processing needs. Customers like the ease of systems integration and the low cost. So, it's pretty much an all-around win.

In the last year, however, semiconductor performance improvements have begun to expand beyond microprocessors and memory to CCD and CMOS sensors. This trend will continue. For example, the performance of high-end CMOS imagers such as Micron Imaging's (formerly Photobit) MV13 (10 bits x 10 taps x 66 MHz) is 833 Mbytes/s and the MV40 (10 bits x16 taps x 66 MHz) is 1333 Mbytes/s. All this data need a scheme for storage or processing that will tax the most powerful current multiprocessor and envisioned uni-processor system in the near future. This also includes accelerated frame-grabber manufacturers who bypass the 64-bit/66-MHz PCI bus, as well as CPU memory performance issues.

At present, camera manufacturers are acceding to the high-speed data acquisition markets and customers (for example, military, semiconductor, and PCB inspection areas--which constitute a non-trivial segment of the vision market) and are beginning to manufacture cameras using the near 1-Gbyte/s rates. However, such manufacturers will have to convince frame-grabber manufacturers to support their cameras, and the frame grabbers will require acceleration for use in anything approaching real-time in the machine-vision market. Otherwise, such camera manufacturers would quickly have to become makers of "intelligent" cameras, which can perform significant processing and data reduction before leaving the camera. Such an undertaking would require significant digital hardware design and manufacturing experience and a significant software effort, all of which most manufacturers have been unwilling to undertake in the past.

For the foreseeable future, Camera Link will remain the only standard digital camera interface with the potential high performance and scalability needed by medium- and high-end cameras, and the low cost needed by the low end, of the industrial digital camera market. Given the past reluctance of most camera manufacturers to expand to processing cameras (and the required extensive software suites), the frame-grabber vendors, systems integrators, and end-users will split into two groups: a native PC, low-cost group, keeping pace with the changes in standard PC technology and boxed software, and the remaining users, who will require accelerated frame grabbers or high-end multiprocessor servers with sophisticated data I/O channels. With respect to either group, the continued adoption and enhancement of the Camera Link standard is assured.

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