WHITE PAPER

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Comparison of the Most Common Digital Interface Technologies (Camera Link®, FireWire, GigE, USB)

The choice of a camera interface is of equal interest to both users and manufacturers of digital industrial cameras. An interface that excels in all applications and outshines all others has not yet been found. But more clearly than ever before, trends can be recognized and a possible future scenario can be discerned.

Which interface is used in each digital camera? This is an important subject in technical discussions between users and providers of digital cameras, and of course, the discussions include the advantages and disadvantages of different interface technologies. In the end, a camera with a suitable interface technology is usually found in the product portfolio.

In the following text, the four most important interfaces are compared based on data throughput, cable length, costs, and standardization. In addition, the ability to connect several cameras and the CPU load are taken into account, both central criteria when discussing the pros and cons of an interface technology.

Gigabit Ethernet

High Data Throughput, Long Cable Lengths, Low Costs

Since 2006, Gigabit Ethernet has become more and more established in industrial image processing. In terms of the number of installations, it is the fastest growing interface on digital cameras used for industrial image processing. This fast growth has resulted because Gigabit Ethernet has solved some central problems. The cable length restrictions present in earlier interfaces have been removed and the usage of several cameras with one computer has been significantly simplified. With a data rate of more than 100 MB/s and a maximum 100 meter cable length, Gigabit Ethernet is a universally applicable digital interface that, for the first time, has the potential to replace analog camera systems in almost every application.

Working in tandem with the physical interface defined by the Gigabit Ethernet standard (among others), the GigE Vision standard provides an especially clear logical implementation and supports easy integration in all image processing programs via the use of software "libraries". Also, because the exchange of GigE Vision compatible cameras can be performed without changing the application software, new investments and follow-up costs can be estimated and well-planned with cameras based on the GigE Vision Standard.

Gigabit Ethernet is already dominant in many areas of image processing, from production to intelligent traffic systems. When implementing Gigabit Ethernet, however, there are some requirements that must be met by the system manufacturer. First, the computing power needed for image acquisition must be taken into account. This is typically 5 to 10% when using appropriate drivers such as the Basler pylon driver. In addition, the user must decide what trigger interval is required. When triggered via the Gigabit Ethernet interface, GigE cameras can be triggered within approximately one millisecond. Although this is sufficient for many applications, the hardware inputs on the camera must be used in order to operate in the microsecond range.

Gigabit Ethernet

GiGE® VISION

Speed:

- 125 MB/s gross, ≈ 100 MB/s net

Cable Length:

- 100 meters

Adapter:

- Standard

Advantages:

- Standard interface on nearly every PC
- High data rates (real time in peer-to-peer connections)
- Uses existing Ethernet infrastructure
- Long cable lengths are possible

Limitations:

- CPU load must be optimized

USB 2.0 / 3.0

Ranging from Only Moderate Data Throughput and Missing Standards to a Real Alternative to GigE with an Interesting Price

In addition to Gigabit Ethernet, USB is a standard interface on all modern personal computers. It allows the easy connection of an industrial USB camera to a desktop or a laptop computer, which means that industrial cameras also compete with conventional webcams. Webcams deliver compressed data to the PC, while industrial cameras provide raw images. Most of the cameras with a USB 2.0 interface follow a simple design concept and are equipped with little or no memory, so image data loss occurs frequently. The new USB 3.0 standard, however, has higher speeds and has the potential to avoid such data loss. And connecting several cameras to one bus, which was not practical with USB 2.0, has entered the realm of possibility with USB 3.0. So we expect that the typical system layout for USB 2.0, usually one camera connected to one computer separated by a maximum distance of five meters, can soon be extended to meet more demanding applications.

The USB interface supplies connected devices with power. However, a large number of connected devices can lead to a situation where the power supplied to a camera is not ensured or only temporarily ensured. Many times USB-based cameras offer no remedy for such situations. Auxiliary power should be made available via the use of an external power supply attached to an additional connector.

When using a USB 2.0-based camera, it is important to determine whether occasional image data loss caused by the small amount of memory or the basic level of the components in the camera can be accepted or compensated for. What's more, you must understand that the physical length of the system is limited by the maximum cable lengths defined in the USB 2.0 and USB 3.0 standards. As opposed to the DCAM/IIDC standard for FireWire and GigE Vision standard for Gigabit Ethernet, USB 2.0 cameras do not follow a defined, logical interface standard for industrial cameras. Thus for USB 2.0, you must decide whether you are ready to select one specific supplier and to design your application according to the specifications adhered to by this particular supplier. But because it will support a real standard based on GenICam, USB 3.0 will overcome this disadvantage. GenICam provides a universal programming (configuration) interface across a wide range of standard physical interfaces such as USB 3.0, GigE Vision, Camera Link, and IEEE 1394, regardless of the camera type and image format. This approach makes it easy to connect GenICam compliant cameras without the need for camera specific configurations. With GenICam, the interface underlying the data transfer becomes much less important. So in many cases it will be advantageous to longer rely on an established USB 2.0 interface and to adopt a USB 3.0 interface that adheres to a standard and promises to become far more suited to industrial applications.

USB 2.0

Speed:

- 60 MB/s gross, 24 MB/s net (could be extended to 48 MB/s net)

Cable Length:

- 5 meters or more

Adapter:

- Standard

Advantages:

- Common interface on nearly every PC (great interface for consumer market)
- Very low costs

Limitations:

- CPU load must be optimized
- Non-standard drivers
- USB connectors can be hard to find

USB 3.0

Speed:

- Up to 625 MB/s gross, 400 - 500 MB/s net

Cable Length:

- 5 meters

Adapter:

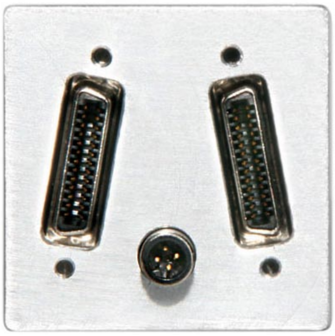
- Standard

Advantages:

- USB 3.0 support can be added to existing computers (even laptops via Express cards)
- Backwards compatibility (USB 2.0 included in the new standard)
- All USB-certified devices must be approved by the USB Implementers Forum (USB-IF).
- Legacy drivers are still usable (but not optimal)
- Extension of the standard to include fiber optic cables is planned

Camera Link

Very High Data Throughput, Established and Secure Standard, High Costs



Camera Link is and will remain an extremely robust and powerful interface for industrial cameras in all performance categories. Today, most kinds of cameras are available in a version that can be connected to a computer via Camera Link. The bandwidth available with Camera Link can accommodate very small cameras with the size of a sugar cube up to cameras with several megapixel resolution and often several hundred frames per second speed. Camera Link has become the standard interface for line scan cameras based on the high line rates and the large amount of data that these cameras can generate.

Since it was designed especially for industrial cameras, Camera Link has clear advantages such as extremely high bandwidth, relative ease of use, and high data security. All components in a Camera Link solution must adhere to the Camera Link Standard. Cables, connectors, and frame grabber cards that adhere to this standard are not typically used in applications other than image processing. These components, and therefore the whole Camera Link solution, are relatively expensive. Also, each component must be certified by the manufacturer and compatible with the other components in the system. Only this will guarantee completely smooth interaction.

Except for Asia, cameras with a FireWire or a Gigabit Ethernet interface have supplanted Camera Link as the default for many applications. This is true because the FireWire and GigE interfaces can offer a more cost effective and in many cases a more flexible solution than Camera Link.

Camera Link

Speed:

- Base (max 24 bits per clock) –
  e.g., 255 MB/s using 3 taps at 8 bit depth
- Medium (max 48 bits per clock) -
  e.g., 510 MB/s using 6 taps at 8 bit depth
- Full (max 64 bits per clock) –
  e.g., 680 MB/s using 8 taps
- Basler 10 Tap Mode: 850 MB/s

Cable Length:

- Up to 10 meters for 85 MHz, longer for lower frequencies

Adapter:

- Special adapter needed

Advantages:

- Standard for high data streams
- Cables are industry standard

Limitations:

- Needs special frame grabber
- Expensive cabling

FireWire

Moderate Data Throughput, Established and Secure Standard, Moderate Costs

Up to now, FireWire (also known as IEEE 1394) has been the most successful digital interface for industrial cameras. Cameras with a FireWire interface have been on the market for years and are implemented and running in thousands of applications. Initially, the cameras adhered to the FireWire-a standard. This meant that they had a bandwidth limitation of 32 MB/s and that only about 30 frames per second at about one megapixel resolution could be transmitted smoothly. Today's FireWire-b interface provides twice this bandwidth, and more data from one or from several cameras can be transmitted.

One main advantage of FireWire lies within the FireWire standard itself. The standard defines a very stable method for exchanging data between the cameras and the computer. This ensures a reliable transmission sequence, as well as a reliable receive sequence and a predictable data transfer duration. This is especially important in very fast applications where a high level of precision is important. This explains why many applications still use FireWire cameras despite the boom in Gigabit Ethernet cameras. In addition, FireWire cameras receive power via the interface in most cases.

For FireWire cameras compliant with the DCAM/IIDC standard, a logical interface for industrial cameras is well defined. This facilitates easy integration into image processing software as well as simultaneous operation of cameras from different manufacturers or even an exchange of cameras.

According to the standard, FireWire allows a maximum cable length of 4.5 meters. But tests with special cables up to 8 meters have been very successful, so in reality, such cable lengths can definitely be realized. The flexibility of a FireWire cabling is limited, however. All of the cameras in the system must typically be attached directly to the computer, although some cameras do have daisy chain functionality (which does not increase the allowed overall cable length). Multi-camera systems can be implemented, but they quickly come up against bandwidth limitations when delivering image data simultaneously. The main reason for this is that all connected cameras must share the bandwidth made available by the interface. Scaling by use of active network components such as switches or adapter cards with two or more FireWire buses is possible, but typically not very feasible. This limited ability to handle multiple cameras is a small drawback when a high number of connected cameras must transmit data at the same time.

In terms of cost, FireWire cameras are very attractive. The accessories are a bit more expensive than those for Gigabit Ethernet cameras and considerably less than the peripherals for Camera Link cameras.

FireWire

FireWire

Speed:

- IEEE 1394a: 50 MB/s gross, 37.5 MB/s net, max 32 MB/s per device
- IEEE 1394b: 100 MB/s gross, 75 MB/s net, max 64 MB/s per device

Cable Length:

- 4.5 meters maximum

Adapter:

- Inexpensive adapter cards available

Advantages:

- A comprehensive digital camera standard including: trigger ready signaling, integration enabled signaling, and change on the fly optimization
- Very low CPU load
- Real time capability

Limitations:

- Is not on every mother board

Conclusion and Outlook

A "one size fits all" interface for digital industrial cameras does not exist, but there are clear favorites for the future.

Because the Gigabit Ethernet interface has the most technological flexibility with regard to bandwidth, cable length, and multi camera functionality, it will play a particularly important role. In addition, there are bright future prospects for 10 Gigabit Ethernet, which will increase the bandwidth by a factor 10 and still have the advantages mentioned for the current standard. In brief, today's GigE Vision based solutions offer high technical and financial security for the future.

Just as now true for GigE, USB 3.0 will become a standard interface on every personal computer in the near future. If USB 3.0 is combined with the GenICam standard, it has the potential to provide a standardized, cost-effective, easy-to-use interface for digital cameras. With USB 2.0, different manufacturers provide different drivers that are not compatible in most cases. In contrast, the USB 3.0 standard promises to become a universal, industrial-suited standard with a high speed and a reasonable price.

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