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Tutorial

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Review of up-to date digital cameras interfaces

Abstract: Over the past 15 years, various interfaces on digital industrial cameras have been available on the market. This tutorial will give an overview of interfaces such as LVDS (RS644), Channel Link and Camera Link. In addition, other interfaces such as FireWire, Gigabit Ethernet, and now USB 3.0 have become more popular. Owing to their ease of use, these interfaces cover most of the market. Nevertheless, for certain applications and especially for higher bandwidths, Camera Link and CoaXPress are very useful. This tutorial will give a description of the advantages and disadvantages, comment on bandwidths, and provide recommendations on when to use which interface.

Keywords: Camera Link; Gigabit Ethernet; USB 3.0; USB3 Vision.

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1 Frame grabber interfaces

1.1 RS644

In the beginning, digital industrial cameras were equipped with an RS644 or RS442 interface, a purely parallel interface, based on LVDS (low voltage differential signal). This means that every signal from the camera to the frame grabber provides every single bit from or to the camera as a twisted pair of wires. On an 8-bit camera signal further signals have to be provided: the master clock, video sync data such as line valid (LVAL), frame valid (FVAL), data valid (DVAL), or trigger and more. There are at least 24 connections on the cable. When going to higher bit-depths and to color cameras providing an RGB signal, the number of connections on this parallel interface was hard to handle.

1.2 Channel Link

The next interface was Channel Link, a mix between a parallel and a serial interface. Based on National Semiconductor chipsets, the number of connectors were reduced, and oversampled to achieve the required data rate of up to approximately 300 MB/s. But still, the transmitted signal was an LVDS signal. The connection to the camera was the Channel Link cable, including the various image signals, an additional cable, a standard RS232 cable to set the different parameters to the camera, and the power connection. Finally, the performance was really good, but the number of cables (three cables: one for power cable, one for setting parameters, and the Channel Link cable for data streaming) was not accepted.

1.3 Camera Link

With Camera Link (Figure 1), the data stream is more or less the same as with Channel Link, whereas the parameter data are transmitted through a virtual RS232 connection that is provided from the frame grabber. This is realized through the clser***.dll library. An additional power connection is necessary. Today, with Power over Camera Link (PoCL), even the power cable can be integrated into the Camera Link interface. The entire specification of Camera Link is available from the Automated Imaging Association (AIA) [1].

Camera Link is separated into four different classes: the base configuration with a maximum of 24 bits per clock, resulting in 255 MB/s at three taps. Only one Camera Link cable is needed. A medium configuration with a maximum of 48 bits per clock is six taps with 510 MB/s, but already requires two Camera Link cables. The full configuration has 64 bits per clock, eight taps with max 680 MB/s. Just imagine this data volume: This is one CD-ROM per second full of data. In addition to these, the 10-tap mode was invented, still using the two Camera Link cables, with a maximum data stream of 850 MB/s. This is the limit for Camera Link with a maximum clock of 85 MHz. The maximum cable length depends on the clock frequency, with 5 m being the minimum. With 85 MHz, 7 m should still be fine, whereas 10 m or sharp bending radii could be critical, especially in an industrial environment.

Figure 1 Camera Link cameras.

Today's FPGAs (field programmable gate arrays) are able to simulate the Channel Link National Semiconductor chipsets. This allows for designing and building smaller cameras. In this case, it is important to get the required impedance of 100 Ω. Although the pure data stream is rather high, the bandwidth for setting parameters is slow. The minimum bandwidth is 9600 baud, but can be set up to 115 000 baud in many cases. For fast changing parameters, such as a change of the area-of-interest (AOI), this can be too slow. In some cases, preloaded parameter sets can be changed inside the camera, but AOI tracking is usually not possible. Camera Link is a well-established interface in machine vision. Its strengths are high data rates and real-time capability. A disadvantage is the cost: a frame grabber and special cables with a limited length are required. In addition, the installation of a frame grabber takes some time.

1.4 CoaXPress

If data streams are higher than 10-tap Camera Link, CoaXPress (CXP) is the standard high-speed interface. As a peer-to-peer connection with a single coaxial, cable lengths of 100 m are achievable to provide data with up to 6.25 Gb/s (according to 780 MB/s). Furthermore, with 20 Mb/s (2.5 MB/s), isochronous data for communication and control are accessible. When using four cables in parallel, a data stream of 25 Gb/s (3.125 GB/s) can be transmitted. Specifications can be downloaded from the Japan Industrial Imaging Association (www.jiia.org).

2 Interfaces without frame grabber

2.1 IEEE 1394

To make life easier and to direct users from analog to digital cameras, machine vision people looked for a plug and play solution. Owing to the established interface on digital camcorders, the choice was to use IEEE 1394, also known as FireWire (from Apple) or iLink (from Sony). The specifications are hosted by the 1394 Trade Association (www.1394ta.org). IEEE 1394 is a fast serial bus, using peer-to-peer connections. This interface allows hot plugging and unplugging. Newly plugged devices are identified automatically by the bus and are controlled by the master device (usually the PC). There are different bandwidths available: 1394a provides three bandwidths of S100, S200, and S400, according to 100, 200, and 400 Mbit/s, respectively. The 1394b allows for an additional bandwidth of 800 Mbit/s. IEEE 1394 offers higher bandwidths, but for machine vision S800 is the maximum. Usually 1394a has 400 Mbit/s, according to 50 MB/s. The bandwidth is separated into an asynchronous part to set parameters, which has a minimum of 20% of the total bandwidth. Thus, parameters can be changed very quickly, and AOI tracking is feasible. The isochronous channel receives up to 80% of the bandwidth and is used for the image transfer. The total net rate is 37.5 MB/s, whereas a single camera – due to its architecture – can only transmit 32 MB/s. Every 125 ms, a new package is transmitted on the bus. A single camera can only send 2×2048 bytes per block. For 1394b, the package size is 2×4096 block, resulting in 64 MB/s for a single camera. The total maximum net bandwidth for more than one camera is 75 MB/s. IEEE 1394 has a very low CPU consumption. The cable length is specified as 4.5 m, but with a well-shielded cable 10 m is achievable.

2.2 Gigabit Ethernet

The next step for interfaces in machine vision was Gigabit Ethernet (GigE; Figure 2). This happened for several reasons. First, the cable length of GigE is 100 m. This will cover nearly all applications. Secondly, a GigE interface is (or will be) available on every motherboard due to network access. The more common an interface, the higher the cost advantage. Thirdly, the general acceptance for a new interface of digital cameras is higher if this is already known beforehand. This is important, because the market for analog cameras has

Figure 2 GigE cameras.

well-established Hirose connectors and BNC coaxial cables. The most widely used cable for consumers is a category 5 cable. As this category does not fulfill the GigE requirements, at least a category 6 cable is recommended. To achieve a clear signal over 100 m, the shielding of the system, and especially of the cables, is important. The longer the cables, the more important the shielding. It is recommended to use S/STP (Screened Shielded Twisted Pair) cables.

The standard for GigE vision [2], which is hosted by the AIA (www.visiononline.org), is based on UDP/IP, a standard internet protocol, but is optimized for the requirements of the machine vision industry. Together with the GigE Vision Control Protocol (GVCP) and the GigE Vision Streaming Protocol (GVSP), certain improvements are added to the UDP, to increase the reliability of the protocol. The most important issue is the control of each and every single package that is transmitted. If one package is missed, it will be resent to get the full and correct image.

If a device such as a camera, a hub, or a switch is plugged into the GigE Vision network, it works in the same way as on the known Ethernet network. An assigned IP address and subnet mask is necessary. When all devices are mounted to the system, the weakest member in the community determines the total bandwidth, meaning that if among all other GigE (1000 Mbit/s) components just one device is only Fast Ethernet (100 Mbit/s), the maximum bandwidth is only 100 Mbit/s. Switches might work with 10 GigE, but all connections and components of the network have to be taken into account. As a further step, 10 GigE will increase the bandwidth by a factor of 10.

When GigE Vision was launched, the concern was the CPU load on the used host PC, because Camera Link and IEEE 1394 have CPU-independent incoming data management. Nevertheless, the CPU load is within acceptable limits. Even the customer himself can decide how much CPU load can be accepted, because there are two options: either using a standard GigE card inside the host PC, the filter driver, or – with a lower CPU load – together with an Intel Pro 1000 GT network card and the optimized performance driver. The advantage of a lower CPU load when using the performance driver together with the Intel card depends on the package size, preferred are jumbo frames (6 kB packet size). A typical CPU load for an application based on GigE interface is approximately 5%. With higher CPU performance the relative load will decrease.

2.3 USB 3.0

In addition to the GigE connection on today's PCs, USB (Universal Serial Bus) is the standard interface for nearly all additional devices to the PC. Whereas USB 2.0 offers a moderate bandwidth and no real standardization, the upgrade to USB 3.0 (Figure 3) [3] makes this consumer interface equally popular as the well-established GigE interface. However, USB 3.0 will not replace GigE, because GigE already provides a good bandwidth together with a cable length of 100 m, whereas USB 3.0 has a high data rate of 625 MB/s (gross) with approximately 350 MB/s net rate, but is limited to only 5 m cable length. Even with high-quality cables or repeaters, it cannot achieve the same data volumes as GigE. The standard, driven by many camera manufacturers, is hosted again by the AIA (www.visiononline.org).

When upgrading from USB 2.0 to USB 3.0, one focus was to keep the CPU load as low as possible. This was achieved through a zero copy (Direct Memory Access, DMA is available). The CPU load of USB 3.0 is in the same range as the CPU-independent interface such as IEEE 1394. Furthermore, latency and jitter are minimized due to the bidirectional communication possibilities. Finally, uniform definitions of cables and other accessories will prevent potential malfunction of data transmission.

The development of USB3 Vision is a huge step for machine vision. The setup and integration of a machine vision system will become easier and more cost effective, because USB 3.0 will become one of the most popular and accepted interfaces on PCs. This will drive costs down and multiplicity and reliability up. With regard to bandwidth, USB3 Vision will fill the gap between GigE Vision and Camera Link and is poised to replace older USB 2.0 and IEEE 1394 interfaces. This new vision standard will push the change from older interfaces or even analog cameras to digital.

Figure 3 USB 3.0 camera.

Table 1 Short overview of current interfaces for industrial digital cameras.

	IEEE 1394 a/b	GigE Vision	USB 3.0 Vision	Camera Link	CoaXPress
Bandwidth	37.5 MB/s or 75 MB/s	≈100 MB/s	≈350 MB/s	850 MB/s	3125 MB/s
Standards	IEEE 1394 TA DCAM Standard	GigE Vision Standard	USB 3.0 Vision Standard	AIA Camera Link Standard	CoaXPress Standard
Cable length	4.5 m	100 m	5 m	5 m	25 m

2.4 GenICam

Besides all these interfaces with different standards with various protocols, registers, ranges, and variables, the main task is the connection between the camera and the PC. Controlling or reading out the camera does not depend solely on the interface, as long as the bandwidth or cable length is sufficient. Therefore, a generic program for an interface-independent software platform was created, which permits accessing all necessary parameters to the camera and stream image data, independent of the interface. Different manufacturers can also be used. Each camera has an individual xml-file, describing the properties of the camera. Today, interfaces such as Camera Link, IEEE 1394, GigE, and USB 3.0 are already covered by GenICam. It is possible to use the different interfaces simultaneously on one host PC. This standard is hosted by the European Machine Vision Association (EMVA) (www.emva.org) [4].

3 Summary

Today's interfaces are very reliable for industrial purposes. A lot of expertise has been put into the standards, but a 'one size fits all' interface for industrial cameras does not exist, because there are some specifications needed for high data throughput and persistent requests to keep costs down. Nevertheless, clear trends are visible. There are further interfaces on the market [5–8]. A list of currently used interfaces for industrial digital cameras is shown in Table 1.

For very high data streaming (>850 MB/s) CoaXPress will be the standard. For up to 850 MB/s Camera Link with mid-, full-, and 10-tap configuration will remain in use for a longer time. The base configuration will probably be replaced by USB 3.0, because it covers the bandwidth and can work with the cable length. USB 3.0 is much more cost effective than Camera Link base configuration. GigE and possibly 10 GigE will coexist in parallel to this class of bandwidth, because both cover a cable length of 100 m. For standard connections with lower data volumes, USB 3.0 will be the preferred interface, mainly for cost reasons. Nevertheless, with all the different interfaces, one key factor to handle all the various technologies is a reliable and powerful API (Application Programming Interface), based on GenICam, that allows creation of long-lasting machine vision solutions now and in the future.

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