The Elements of GigE Vision

What Is GigE Vision?

The GigE Vision standard was defined by a committee of the Automated Imaging Association (AIA). The committee included Basler AG and companies from all major product segments in the vision industry. The goal was to define a standard Gigabit Ethernet based interface tuned to applications in the machine vision industry that would allow seamless interchangeability between cameras or software.

Why GigE Vision?

Because GigE Vision is based on the Ethernet standard, it benefits from wide penetration in both the industrial and consumer markets. The appropriate components are readily available at low cost and are already installed in many PCs. Overall system cost is made even lower by eliminating the need for a frame grabber, which would be necessary with analog technology or with cameras that incorporate a Camera Link® interface.

Current interfaces have limited cable lengths. With IEEE 1394, you have a maximum total cable length of 72 meters. Normally, this maximum can only be realized by using a large number of hubs and repeaters between the camera and the PC. This increases power consumption, increases the number of individual cables needed, and increases the possibility of encountering electromagnetic interference. Camera Link and USB 2 have an even lower maximum cable length of 30 meters. GigE Vision has the great advantage of a maximum cable length of 100 meters. This can be achieved without the use of repeaters or hubs.

Until now, the bandwidth available on Ethernet (10 Mbit/s) and Fast Ethernet (100 Mbit/s) based networks was too low to transmit uncompressed images at speeds appropriate for machine vision. With the advent of Gigabit Ethernet (1000 Mbit/s), network bandwidth is high enough to transmit uncompressed images in real time, an absolute necessity for machine vision cameras. In addition, Gigabit Ethernet networks have the potential for even higher bandwidths with 10 Gigabit Ethernet projected as an option for the future.

The GigE Vision Standard

Since the GigE Vision standard builds on Ethernet technology, standard Ethernet hardware, architecture, and network structure is used with any system that incorporates GigE Vision. GigE Vision does not provide a physical description of the transport media and contains no specific implementation of a specialized, high-performance IP stack or network driver.

The standard, which is based on UDP/IP, consists of four major parts. The first part defines a mechanism that allows applications to detect and enumerate devices and defines how devices obtain a valid IP address. The second part defines a GigE Vision Control Protocol (GVCP) that allows the configuration of detected devices and guarantees transmission reliability. The third part defines a GigE Vision Streaming protocol (GVSP) that allows applications to receive information from devices. The last part defines bootstrap registers that describe the device itself (e.g., current IP address, serial number, manufacturer information, etc.).

In essence, GigE Vision is an interface standard based on Ethernet and made to meet the needs of the machine vision industry.

How Does GigE Vision Work in Detail?

Because GigE Vision is based on the Ethernet protocol, it has some similarities. A good way to describe the GigE Vision structure in comparison to the TCP/IP structure is by using the Open Systems Interconnection Reference Model (also called OSI) as shown in Figure 1.

TCP/IP was developed as a message delivery system that establishes a host-to-host connection and ensures safe and reliable delivery of the messages. It avoids network overload and automatically detects lost data and corrects it. This makes TCP/IP a good protocol for the worldwide web and for e mail, but reduces its performance for machine vision cameras.

The GigE Vision standard is based on the User Datagram Protocol (UDP). Instead of establishing a host-to-host connection as with TCP, UDP uses ports to allow pplication-to-application connections. That makes UDP less reliable than TCP. But it also increases performance and higher performance is absolutely necessary, especially for the high speed image transfers required in machine vision.

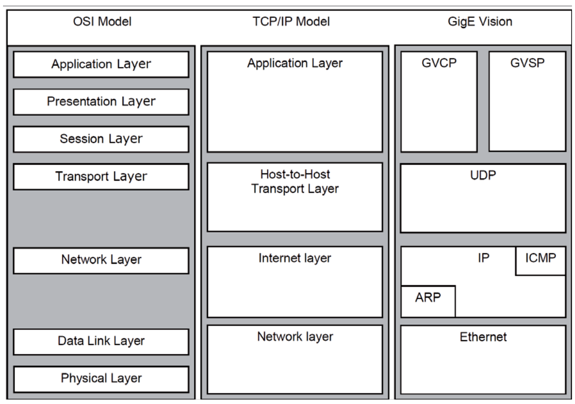


Fig. 1: OSI Reference Model

To overcome the unreliability of UDP, the GigE Vision standards committee introduced two extra protocols: the GigE Vision Control Protocol (GVCP) and the GigE Vision Streaming protocol (GVSP).

The GVCP is an application layer protocol that relies on UDP. It adds mechanisms to UDP to guarantee the reliability of image transmission. In addition, it allows the configuration of a device (e.g., a machine vision camera) and the instantiation of one or more control channels. The control channels are divided into primary and secondary channels. The primary channel is created by a primary application and allows the application to read from and write to the device's registers. The secondary channel is created by a secondary application and allows the application to only read the registers.

The GVSP is an application layer protocol that relies on the UDP transport layer protocol. It allows an application to receive image data, image information, and other information from a device. Packets are always transmitted from a device to the application. GVSP provides mechanisms to guarantee the reliability of packet transmission (through GVCP) and to minimize the flow control required due to the unreliability of UDP.

How to Connect a GigE Vision Camera to a PC

Connecting a GigE Vision camera to a PC is rather easy. To start with, Ethernet cables are required and Ethernet cables are available in different categories. The most common cable category for the PC consumer market is the category 5 cable. This category is not sufficient for applications in machine vision. Basler recommends using cables with at least a category 6 rating. These cables are specified for Gigabit Ethernet and are tested for cable lengths up to 100 meters. And if system costs are not increased too much, using even higher category cables is always recommended..

Shielding is an important topic when discussing cables. The individual copper wires in an Ethernet cable should be properly shielded in order to prevent electromagnetic interference. Also, the entire cable should have an extra woven metal shield called screening as an additional interference safeguard. Cables with different combinations of shielding are available.

STP (Shielded Twisted Pair) cables have metal shielding around each copper pair, but no screening. S/UTP (Screened Unshielded Twisted Pair) cables have no metal shielding around the copper pairs, but do have screening around the entire cable. S/STP (Screened Shielded Twisted Pair) has both shielding around each pair and screening around the entire cable. We strongly recommend using S/STP cable. If the shielding in an S/STP cable is not sufficient for an application where electromagnet interference is particularly severe, special cables must be assembled.

Industrially proven connectors, including connectors with screws to prevent unintentional unplugging, are readily available.

How Do Multi-Camera Applications Work?

GigE Vision networks work in a manner similar to common Ethernet networks. Devices are plugged into a Gigabit Ethernet network interface card. To connect multiple devices, hubs, switches or a router can be used. Be aware that for the network to operate at Gigabit speed, every device in the network must be Gigabit compliant. If one device is only Fast Ethernet compliant, for example, the bandwidth of the entire network will be reduced to only Fast Ethernet speed (100 Mbit/s).

All devices in a network share the available bandwidth. On a Gigabit network, 1000 Mbit/s of bandwidth is available and is shared by all of the connected devices, regardless of whether two, four, or more devices are connected. For cameras, this typically means that as you attach more cameras, the maximum frame rate at which you can operate each camera will decrease.

Device recognition in a GigE Vision network also works in a fashion similar to Ethernet networks. Each device in the network must have an assigned IP address and subnet mask. For the devices to communicate properly within the network, all devices must be on the same subnet and each device must have a unique IP address. There are three possible methods for assigning IP addresses to devices on the network: static IP Addressing, Dynamic Host Configuration Protocol (DHCP) addressing, and Link Local Addressing (LLA - also known as AutoIP).

When a device is attached to the network, the network first checks the device to see if it has beenassigned a static IP address. If no static address is available or if the network can't accept the address(e.g., there is an IP address conflict), the device will automatically try to find a DHCP server on thenetwork and will attempt to obtain an IP address from the server. If no DHCP server is available, thedevice automatically defaults to LLA and will assign itself an IP address. If the network detects an IPconflict, the device will be assigned an IP address of 0.0.0.0. At that point, the device can only becontacted via special broadcast requests, and it will remain in that state until a valid IP address isassigned and a proper network connection is established.

This automated procedure guarantees that no two devices share the same IP address. It alsosimplifies the connection of multiple cameras to a network.

GigE Vision Camera Setups in Comparison to Other Interfaces

GigE Vision vs. Camera Link

Over the past five years, the Camera Link interface has been dominant in the marketplace for higher bandwidth cameras. The IEEE 1394 camera interface (known as FireWire®) has also been widely used. But FireWire can't provide sufficient bandwidth capacity to adequately service state-of-the-art CCD sensors from Kodak and has thus never been a viable alternative to Camera Link. This all changed with the establishment of the GigE Vision standard.

GigE Vision mirrors the clear advantages of FireWire in that it eliminates the need for frame grabbers in machine vision applications and it uses standard cabling and network cards. GigE Vision has enabled the development of new camera designs that are more cost-effective and that are stateof -the-art from a technical perspective. The new GigE Vision cameras are more user friendly, are easier to configure and integrate, and because GigE Vision implements dedicated bandwidth for camera control, they allow parameter changes on the fly.

	GigE Vision		Camera Link	
Camera	Basler piA1600-35gm Kodak KAI-2020 CCD-Sensor 1600 x 1200 resolution 35 frames/s	3,799 €	Camera A Kodak KAI-2020 CCD sensor 1600 x 1200 resolution 35 frames/s	4,200 €
Power Supply	Basler pilot power supply	35 €	Standard Camera Link power supply	78 €
Cable	Ethernet CAT6, S/STP 10 meter shielded cable	25 €	Camera Link 10 meter cable	230 €
Interface Card	Intel Pro 1000 GT	45 €	Standard frame grabber	990 €
TOTAL		3,904 €		5,498 €

Table 1: Comparison of System Elements and Costs (GigE Vision vs. Camera Link)

GigE Vision vs. Analog Cameras

Because cameras using digital interface technology have not been competitive, analog cameras still capture the biggest portion of the machine vision market. Analog setups with multiple cameras represent a large portion of the market and for various technical reasons, these camera setups can't be directly replaced with FireWire devices. With the introduction of Gigabit Ethernet cameras that don't require frame grabbers, new possibilities for cost-effectively replacing analog camera setups arise. Multi-camera analog systems are now prime targets for replacement with GigE Vision cameras and Gigabit Ethernet components.

Scenario I: One Camera Connected to One PC

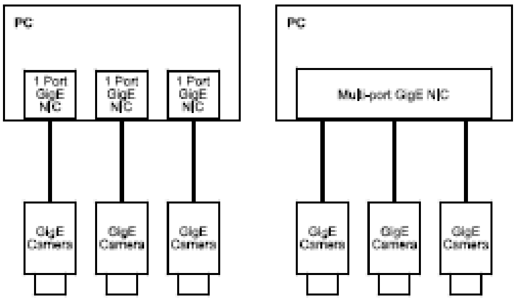
In this scenario, one camera is connected to one PC. This can be accomplished for GigE Vision cameras by either using one single-port network interface card in the PC.

	GigE Vision		Analog	
Camera	Basler scA640-70gm VGA, progressive scan GigE Vision	699 €	Standard analog camera Quality brand Interlaced, NTSC	495 €
Power Supply	Basler scout power supply	35 €	Standard analog power supply	78 €
Cable	Ethernet CAT6, S/STP 10 meter shielded cable	25 €	Standard 10 meter analog cable	70 €
Interface Card	Intel Pro 1000 GT	45 €	Analog frame grabber 2 inputs Quality brand	325 €
TOTAL		804 €		968 €

Table 2: Comparison of System Elements and Costs (GigE Vision vs. Analog, Scenario 1)

Scenario II: Multiple Cameras Connected to One PC (Simultaneous Grab)

In this scenario, multiple cameras are connected to one PC. This can be accomplished for GigE Vision cameras by either using one single-port network interface card per camera or by connecting several cameras to a multi-port interface card. This scenario mirrors a similar analog scenario with a grabber that supports simultaneous grabbing by multiple cameras.



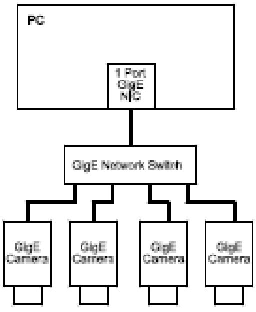
	GigE Vision		Analog	
Camera	4 Basler scA640-70gm cameras VGA, progres-sive scan GigE Vision	2,796 € (699 €/ camera)	4 standard analog cameras Quality brand VGA, progressive Scan	2,464 € (616 €/ camera)
Power Supply	4 Basler scout power supplies	140 € (35 €/ pc)	4 standard analog power supplies	312 € (78 €/pc)
Cable	4 Ethernet CAT6, S/STP 10 meter shielded cables	100 € (25 €/ pc)	4 standard 10 meter analog cables	280 € (70 €/pc)
Interface Card	Quad port Intel Pro 1000 PT	280 €	1 analog frame grabber 4 inputs Simultaneous grab Quality brand	500 €
TOTAL		3,316 €		3,556 €

Table 3: Comparison of System Elements and Costs (GigE Vision vs. Analog, Scenario II)

Scenario III: Multiple Cameras Connected to One PC (Non-Simultaneous Grab)

In this scenario, multiple cameras are connected to one PC by using one single-port GigE network adaptor. The cameras are connected to the network interface card via a standard Gigabit

Ethernet network switch. This scenario mirrors a similar analog scenario with a grabber that does not support simultaneous grabbing by multiple cameras



	GigE Vision		Analog	
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Power Supply	4 Basler scout power supplies	140 € (35 €/ pc)	4 standard analog power supplies	312 € (78 €/pc)
Cable	4 Ethernet CAT6, S/STP 10 meter shielded cables	100 € (25 €/ pc)	4 standard 10 meter analog cables	280 € (70 €/pc)
Inter-face Card	Quad port Intel Pro 1000 PT	280 €	1 analog frame grabber 4 inputs Simultaneous grab Quality brand	500 €
TOTAL		3,316 €		3,556 €

Table 4: Comparison of System Elements and Costs (GigE Vision vs. Analog, Scenario III)

Comparison of GigE Vision, IEEE1394, Camera Link, and Analog Interfaces

	GigE Vision	IEEE 1394a	IEEE 1394b	Camera Link	Analog
Cable Length	100 meters	4.5 meters (up to 72 meters with repeaters)	4.5 meters (up to 72 meters with repeaters)	Up to 15 meters (depending on the bandwidth)	Up to 100 meters (depending on the video signal and quality loss)
Bandwidth	100 MBytes/s	32 MBytes/s	64 MBytes/s	255 Mbytes/s (base configuration) 680 Mbytes/s (full configuration)	-
Bit Rate	1000 Mb/s	400 Mb/s	800 Mb/s	>2000 Mb/s	-
Standards	GigE Vision Standard	IEEE1394 Trade Association DCAM Standard	IEEE1394 Trade Association DCAM Standard	AIA Camera Link Standard	Various standards for video signal timing. No standards for software or configuration.
Interface Board	Common gigabit Ethernet Board	Common IEEE 1394a Board	Common IEEE 1394b Board	Special frame grabber	Special frame grabber
Maximum Number of Cameras	Unlimited	16 (DCAM)	16 (DCAM)	2 (per frame grabber)	6 (depending on the frame grabber)
Plug & Play Ability	Yes	Yes	Yes	No	No
Cables	Industrial and consumer	Industrial and consumer	Industrial and consumer	Industrial	Industrial and consumer

Table 5: Short Overview of Different Interface Technologies and Their Technical Specifications

Drivers

Basler offers the new pylon driver package for use with Gigabit Ethernet cameras. In addition to camera and network drivers, the pylon package includes: an advanced viewer, extensive documentation, the camera API, and many sample programs.

When Basler's engineers developed the pylon package, they benefited from more than six years of FireWire driver development experience. The way that pylon's drivers are designed show that this deep knowledge, along with key customer feedback, was at the core of the development process. The most challenging task for Gigabit Ethernet driver development was to make the implementation machine vision specific. This was accomplished by making sure that the package was robust enough to pass the GigE Vision certification process.

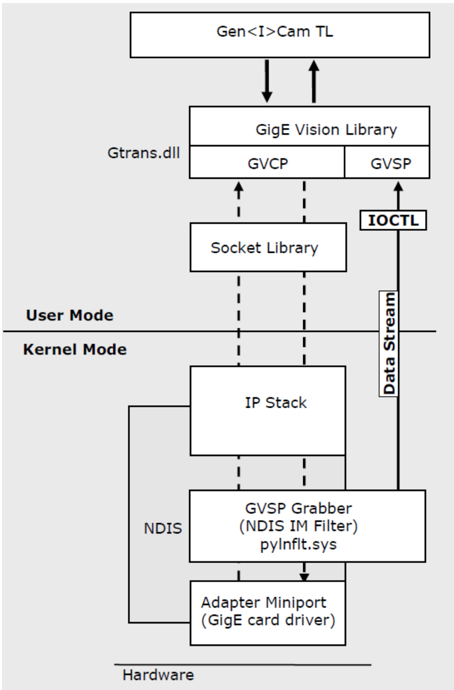
Whenever Gigabit Ethernet is discussed in connection with machine vision, CPU usage in the host PC is one of the most interesting topics. Each player in the machine vision industry must convince potential customers that the CPU load generated by the use of a GigE transmission mechanism is within acceptable limits. The main difference between GigE and FireWire or Camera Link is that with GigE there is no CPU independent incoming data management. This means that every incoming packet must be inspected when arriving in the PC and copied afterwards. This process always requires CPU involvement. To keep the CPU load as low as possible, Basler offers two different GigE Vision drivers: a filter driver and a performance driver.

The Basler Filter Driver

The Basler filter driver quickly separates incoming packets and transfers these packets directly to the application. The filter driver can be used with all network interface cards available on the market. The CPU load associated with the filter driver is generally attributable to the fact that packets must normally be copied two times.

The Basler filter driver is located below the Windows IP Stack. It detects any incoming GVSP packets and passes them directly to the Basler GigE Vision library (Gtrans.dll) in the User Mode. This reduces the CPU load significantly.

GVCP packets take the standard route across the IP stack and the WinSock socket library.

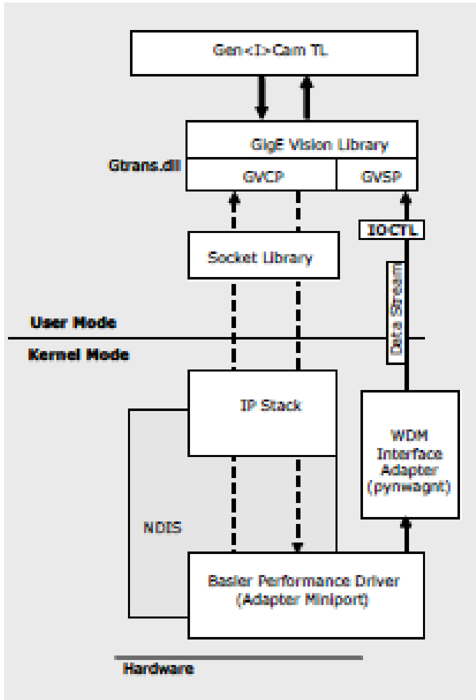


The Basler Performance Driver

This Basler performance driver separates incoming packets and transfers these packets directly to the application. The CPU load associated with the performance driver is generally due to the need to make at least one copy of the incoming data.

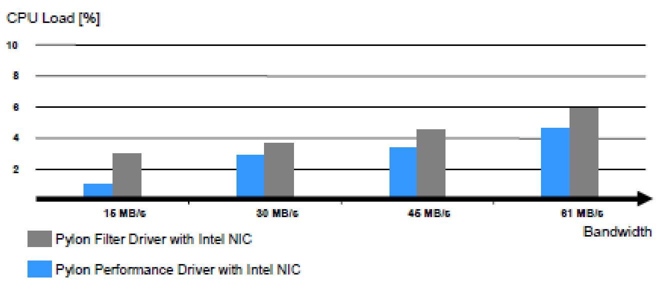
The Basler performance driver is a hardware specific GigE Vision network driver and is compatible with network interface cards that use specific Intel chipsets.

The main advantage of the performance driver is that it lowers the CPU load needed to service the network traffic between the PC and the camera(s) even more significantly than the filter driver.



Filter and Performance Driver CPU Load Comparison

As described above, the filter driver and the performance driver use the CPU with different intensities. The following graph reflects typical results for a medium performance PC and a bandwidth situation comparable to IEEE 1394b. The PC is equipped with a Pentium D 2.7 GHz processor, an Intel Pro 1000 GT network card, and has the Basler pylon SDK installed.



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