

Choosing the right interface?

With the addition of GigE Vision standard to the already popular Firewire (IEEE 1394) and CameraLink interfaces, machine vision customers have a wider choice of data interfaces. Though the expanded choice is always welcome, thorough understanding of benefits and limitations of each interface is required to select the most appropriate one that fits the application. This document is intended to serve as an overview to guide the users through selecting the interface.

The choice of interface must be considered in the context of overall requirements for the machine vision application. So the first step is to define the intended goals for the imaging system. This ultimately determines all the components in the vision system including the sensor type, camera performance, interface and post processing software and hardware.

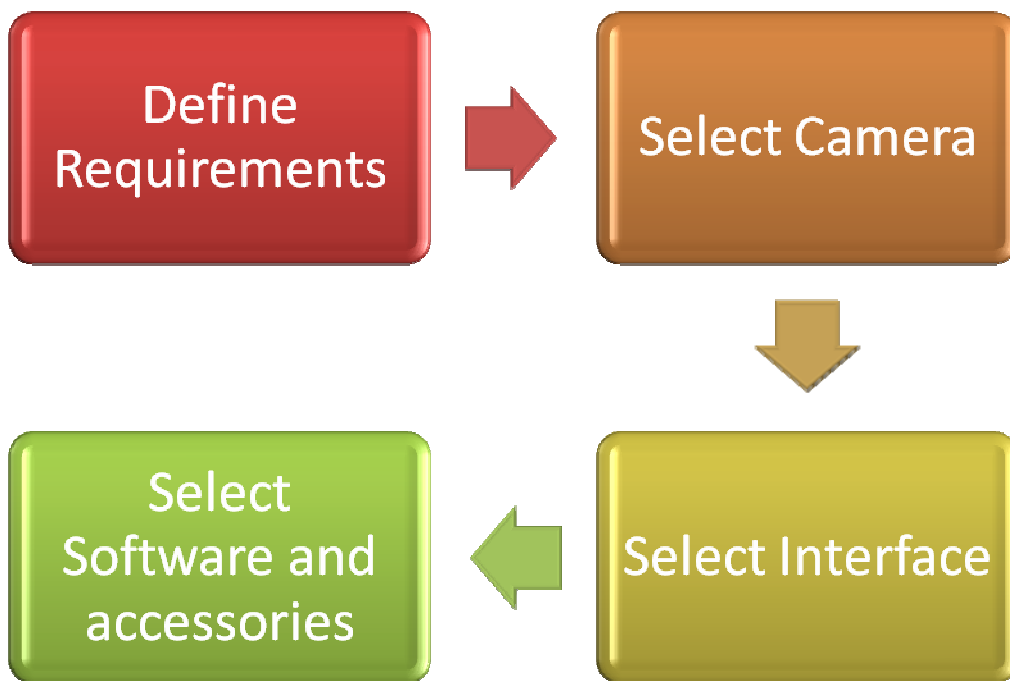


Figure 1. Careful attention must be paid while defining the application requirements as they drive the choice of camera, interface and software

I. Start with the camera.

Before jumping into the benefits and limitations of each data interface, it is important to select the right image sensor/camera that fits your application. Often high performance machine vision applications impose strict requirements on several key attributes such as spatial resolution, frame rate, noise and form factor. Some of the key questions to ask at this juncture are

- What spatial resolution is required?*
- Is the application time-critical? What frame rate is required?*
- Is image fidelity or low noise important?*
- Are there any special requirements for form factor of the camera?*

Resolution

Number of pixels in a sensor determines the spatial resolution of the camera. If you add the pixel size and the magnification factor, it will also determine the field of view of the sensor.

The table below provides a list of MegaPlus camera models and available sensor resolutions. Sensor resolution and frame rate together determine the data bandwidth required for the operation. For example, an 11 megapixel EP11000 camera produces a full frame 12-bit image which is 22 MBytes. This coupled with the frame rate (see below) of 4.6-6 fps sets the requirement for minimum bandwidth.

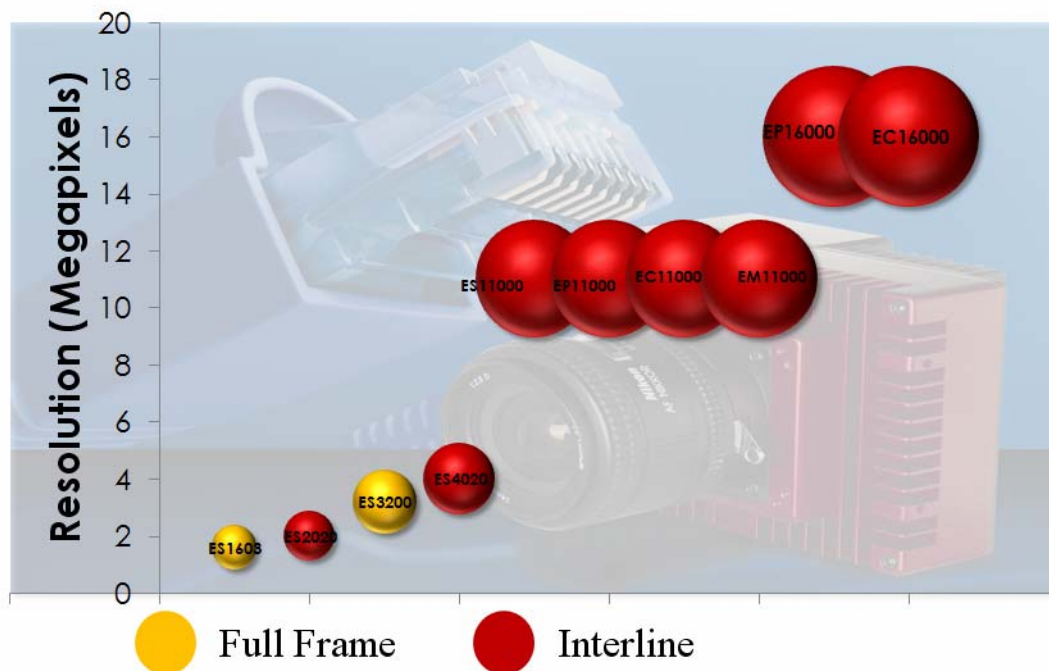


Figure 2. Advanced cameras such as MegaPlus provide a choice of sensor resolutions from 1.6 to 16 megapixels

Frame Rate

In a continuous production or QA/QC environment, the time to image or data has a direct impact on the speed of operation. For example, a flat panel display inspection requires fast frame rate to optimize the speed of inspection while an application that requires just one frame may not require such a frame rate.

Camera manufacturers often specify maximum frame rate achievable for a given camera. However, it must be noted that the image from cameras that do not provide on-board (in-camera) image processing capabilities, must further undergo image corrections such as defect concealment, flat field normalization and color reproduction. This adds to the total capture time by as much as several hundred milliseconds.

A chart is provided below for different MegaPlus camera models. The required bandwidth is calculated by

$$\text{Bandwidth in MBytes/sec} = \frac{X \times Y \times 2 \text{ Bytes per pixel} \times \text{Frames per second}}{10^6}$$

Where X and Y are the number of pixels in horizontal and vertical dimensions. The equation assumes that data is stored in 16 bits or 2 Bytes per pixel. From the above equation, it can be seen that the bandwidth requirement can be reduced with partial readout of the sensor or transferring pixel data as 8 bits per pixel, an acceptable compromise for certain low resolution, low speed applications.

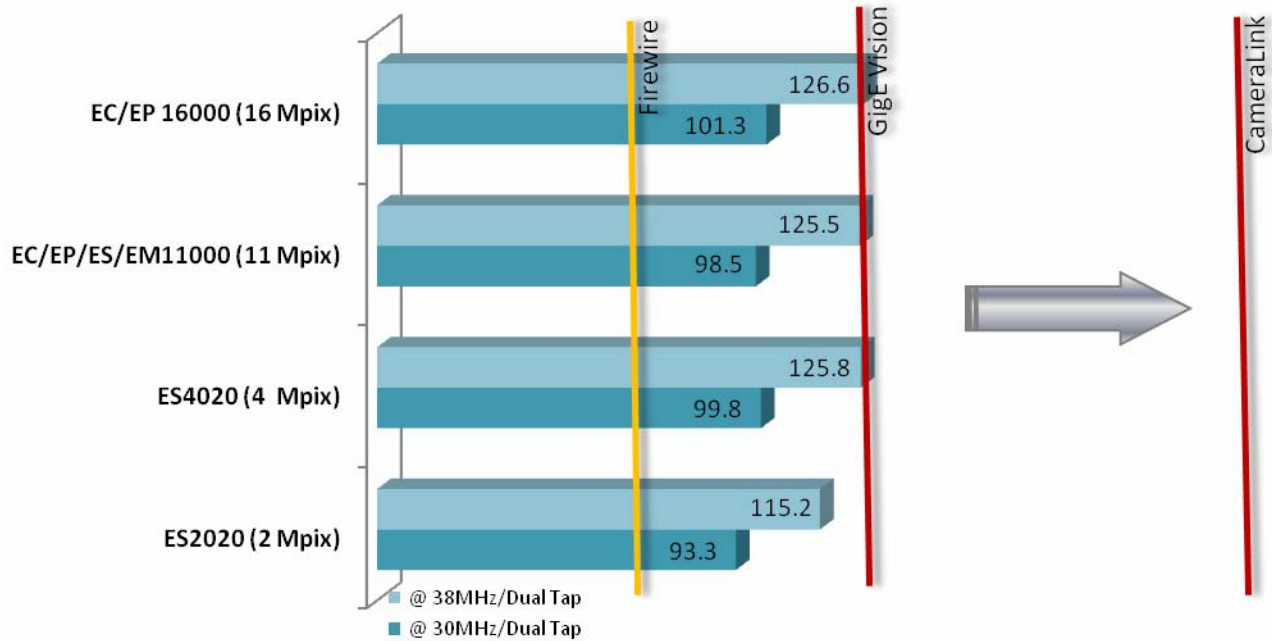


Figure 3. Bandwidth (in MBytes/sec) required to operate select MegaPlus cameras at full resolution and frame rate. Theoretical bandwidth limits of GigE Vision (125MBytes/sec), Firewire (60 MBytes/sec) and CameraLink (680 MBytes/sec off the chart) is shown for comparison.

Image fidelity or Low noise

Image fidelity refers to camera's ability to reproduce a given scene. It is a sweeping term that encompasses several measurable performance attributes -such as camera read noise, dynamic range and number of defective pixels. Often, sub-optimal camera makes a compromise between frame rate and the noise. However, a carefully designed camera makes the most out of the sensor performance.

For example, MegaPlus cameras employ thermal isolation techniques to place heat generating components such as FPGAs away from the sensor. Some of the models such as EC11000 also use active Peltier-based cooling to reduce the dark noise and number of "hot" pixels by as much as 100 times.

Special requirements

Machine Vision applications often require custom form factor or modifications to an existing camera. So, the camera design must be flexible to handle varying degrees of customization and form factor. For example, an aerial imaging application requires a compact camera that can be mounted in tight spaces. It will also require flexible cables oriented in a specific direction. This should be done without compromising the overall quality of the image.

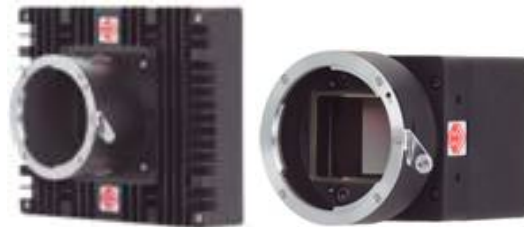


Figure 4. Applications might require small form factor to fit the camera into smaller spaces. For example, MegaPlus EP11000 (left) and EM 11000 camera (right) use the same 11 megapixel sensor, but EM is ¼ the size of EP camera

Choose the right Interface

Once a camera/sensor choice is made based on the above requirements, it is relatively easy to decide on the data interface. However, since this decision can have far reaching implications on the data throughput, software integration and future upgradeability, it is important to pay attention to the relative merits of each data interface. Though all the cameras to look the same in view of a given interface standard, it is important to consider the fullness of the solution. For example, a camera design must allow future upgradeability without requiring entirely new cameras to be purchased. Below is a typical set of questions to ask before selecting the right interface

What is the maximum data rate required?

Where is the camera with respect to the location of the PC?

Does the interface of choice compromise imaging performance?

Can the camera be upgraded if a newer interface is available?



GigE Vision is the newest of the data interface standards. It is developed as a common data interface standard based on more commonly available gigabit ethernet (GigE) protocol and cabling. It attempts to standardize camera control and image acquisition so that cameras and software from multiple vendors may inter-operate seamlessly.

GigE Vision Pros

- High bandwidth (125MBytes/sec or 1000 Mbps) for real time image transmission
- Image transfer of up to 100 meters in length
- Standard gigabit Ethernet hardware allows single/multiple camera connection to single/multiple computers
- Low cost cables (CAT5e or CAT6) and standard connectors
- Scalable to future 10GigE standard

GigE Vision Cons

- Lower bandwidth compared to CameraLink's maximum 680MBytes/sec.
- Increased CPU load - As GigE communication relies on the host PC to pack/unpack the stream, it puts added load on the CPU. This is in addition to any other image processing tasks that CPU may have to accomplish. This load is lessened if the camera, such as MegaPlus camera with on-board FPGA, performs some of the image processing functions such as image corrections and color processing right in the camera.

- Trigger latency: There can be increased latency with triggering over GigE Vision. But, if the camera hardware supports hardware triggering, it is a non-issue.



CameraLink is an established interface for industrial imaging applications. It offers the highest data throughput (over 680MBytes/sec) and lowest latency of all interfaces. It offers more deterministic image transfer through a dedicated frame grabber, which may cost over \$1,000. This is much higher than a typical high performance NIC card. The distance between the camera and PC/Frame grabber is limited to 10 meters compared to 100 meters for GigE. This can be extended, of course at an added cost, to over 10 meters by use of extenders and fiber optic adapters.

CameraLink Pros

- Highest bandwidth available
- Reliable, low latency data transfer
- Minimal increase in CPU load due to dedicated frame grabber
- Well established for machine vision cameras
- Wide availability

CameraLink Cons

- Expensive frame grabber might be required
- Limited cable lengths



FireWire

Firewire was originally developed as a consumer interface with ease of use in mind. It is also known as IEEE1394 standard. It uses a plug-n-play architecture to deliver theoretical maximum of 60 MB/sec (IEEE 1394a or S400) to 100 MB/sec (IEEE 1394b). In practice, over 60MB/sec throughput is rarely achieved due to added overhead.

Firewire Pros

- Ease of use
- Widely available on PCs

Firewire Cons

- Low bandwidth
- Limited cable lengths

A comparison of interfaces

The following table provides a summary comparison between GigE Vision, Firewire (IEEE1394) and CameraLink standards.

	GigE Vision	CameraLink	Firewire (IEEE 1394a/b)
Bandwidth[†]	Up to 125 MB/sec	Over 680 MB/sec	Up to 50 – 100 MB/sec
Cable Length (Max^{††})	100m	10m	5m
Frame Grabber	No	Yes	No
Cost	Low	High	Low
Real time data/trigging	++	+++	+
CPU load^{†††}	High	Low	High
Availability	+	+++	++

[†] Practical bandwidth is typically lower than theoretical maximum due to overhead.

^{††} Cable length can be extended by using repeaters or fiber optic extenders.

^{†††} CPU load using “non-real time” camera. However, it is reduced in GigE Vision cameras with on-board processing such as MegaPlus

After considering the application requirements, camera performance, data throughput and ease of integration, one can arrive at a choice for the right interface. In general, the following guidelines can be followed. However, a discussion with the camera or software vendor is recommended before making a final decision.

Select	If your requirements are
GigE Vision	-Low cost -High frame rate (below 125 MBytes/sec) -Inter-operability -Long cable lengths
CameraLink	-Highest frame rate (above 125 MBytes/sec) -Real time data transmission/Low latency
Firewire (IEEE 1394)	-Ease of use -Low frame rate (e.g., single frame capture)

MegaPlus cameras from Princeton Instruments

High performance is central to the design of MegaPlus cameras. As a result, they are being used in some of the most demanding applications at the world's leading manufacturing facilities. By following the "block" design approach, MegaPlus cameras deliver the best resolution, low noise performance and advanced data interfaces.

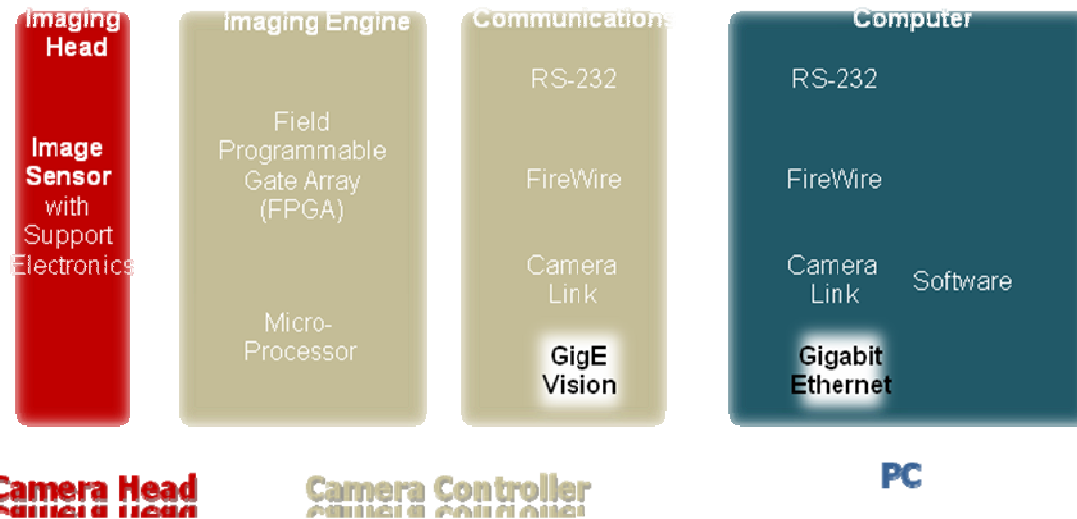


Figure 5. MegaPlus cameras deliver the best performance and a wide choice of interfaces including the latest GigE Vision interface

MegaPlus Feature	Application Benefits
1.6 to 16 megapixel resolution	Wide choice of sensor for your applications
High frame rate	Reduce time from capture to image
Cooled sensor	Thermal isolation and active cooling for low dark noise and hot pixels
FPGA based imaging engine	No additional overhead to perform Defect correction Flat field normalization Color RGB interpolation Customizable
GigE Vision, CameraLink or Firewire interfaces	Select the right interface independent of the camera/sensor choice. No need to change the camera if you decide to change interface.
Customized form factors	Ability to use the cameras in space constrained
World class clean room and production facilities	Consistent, dust-free, quality across thousands of cameras
Worldwide support Network	Local support to get the best out of the cameras

References

1. GigE Vision Information on Advanced Imaging Association (AIA) website
<http://www.machinevisiononline.org/public/articles/articles.cfm?cat=167>
2. “Acquiring from GigE Vision” white paper from National Instruments
<http://zone.ni.com/devzone/cda/tut/p/id/5651>
3. “Troubleshooting GigE Vision cameras” from National Instruments
<http://zone.ni.com/devzone/cda/tut/p/id/5846>