



WHITEPAPER

The Networked Operating Room

Real-Time, High-Resolution Imaging in Diagnostic
and Surgical Environments

This whitepaper examines the use of GigE Vision® interfaces in medical technology, highlights their unique advantages through application examples, and considers future developments in the medical field.

Pleora Technologies Inc.
www.pleora.com

WHITEPAPER

Table of Contents

Executive Summary1

Introduction2

Seeing is Believing2

Real-Time Video Networking3

Medical Imaging Applications4

Case Study – Dexela Limited6

Developments in Image-Guided Surgery7

Conclusions7

References8

About Pleora8

Appendices:

 A. Comparison of Medical Imaging System Interfaces. .9

 B. High-Speed Image Transmission and Storage12

Executive Summary

Today's operating and diagnostic rooms are vastly different from those of the past. Physicians often rely on live, high-resolution imaging of patients using intraoperative, robotic, and radiological systems to enhance the precision of operations such as implant positioning, tumor removal, and angioplasty. The state-of-the-art sensors employed in these kinds of procedures serve to enhance a surgeon's effectiveness while also minimizing the level of invasiveness for the patient.



In diagnostic systems, real-time imaging is improving clinical assessments, and in some instances reducing the need for surgical intervention in the first place. The latest digital radiography systems, for example, are equipped with flat panel detectors (FPDs) that deliver uniform high-resolution images across the entire rectangular field of view. The images are streamed live to PCs for on-the-spot capture, display and storage. More importantly, the images may be analyzed in real time. Fast, reliable data transfer eliminates the wait times, cost, and waste associated with X-ray film, which significantly improves patient diagnosis and throughput.

Other diagnostic applications that require digital imaging include dental and veterinary practices, where generally more compact systems with flexible and simpler cabling are required—a defining feature of Ethernet connections. Beyond enabling exceptionally reliable image transmission, the use of Gigabit Ethernet (GigE) networks and the adoption of GigE Vision® interfaces in a wide range of medical devices have enabled the cost-effective distribution and installation of digital systems worldwide. Ethernet is the only transmission medium that offers long cable reaches in addition to providing multi-sensor aggregation and image/video distribution capabilities using standard switches and other network equipment, and is so widely deployed that equipment and support are readily available anywhere on the globe. More recently, USB3 Vision™ standardized the transportation of high-speed imaging and video data to computers over the widely available USB 3.0 bus.

As the resolution and frame rate of medical imaging devices grow, networks will need to accommodate the increased data throughput. With the introduction of GigE Vision over 10 GigE, the necessary capacity is available for high-speed imaging, as well as multi-sensor aggregation of increasingly sophisticated medical devices.

Introduction

In many of today's digital imaging systems, real-time functionality is achieved using point-to-point connections between a vision sensor or detector and a PC. Images often need to be viewed on multiple displays in different areas, necessitating additional

Within three to five years the average oncology department will experience exponential growth in the size, complexity, and volume of medical images.

point-to-point connections using more PCs, frame grabber boards, display controllers, and other pieces of specialized hardware, adding complexity and cost.

The introduction in 2006 of GigE Vision, an open standard for the reliable transport of video and control data over Ethernet networks, offered medical system designers and integrators a

flexible and inexpensive alternative to existing interfaces. Its rapid adoption for high-performance video applications is a reflection not only of the growing field of image-guided surgery but also of Ethernet's widespread use in nearly every medical domain.

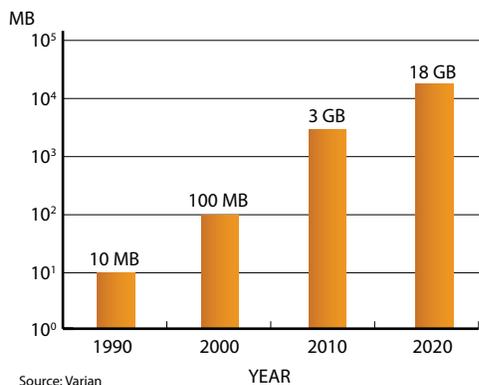


Figure 1: Projected image storage per patient

Similarly, radiation oncology is also undergoing a dramatic workflow transformation. Within three to five years the average oncology department will experience exponential growth in the size, complexity, and volume of medical images – see **Figure 1**. The increase is due, in part, to the success of image-guided oncology programs, which generate new images at each step in the treatment process— diagnosis, staging, planning, verification, setup, response, and follow-up. Storing, managing, and providing access to these images in the long-term will become critical as the giga- and terabyte needs of today expand to the petabyte requirements of tomorrow.

Learn more...

Interested in learning more about the GigE Vision standard in other industries? Download the *All About GigE Vision* eBook! [Click here to download now.](#)

Seeing is Believing

Precision surgery without real-time imaging is practically unimaginable. However, real-time video and high-quality images that are essential to the surgeon can only be achieved with network interfaces that are reliable, easily configurable, and low maintenance. Both GigE Vision over Ethernet and USB3 Vision over USB 3.0 achieve these objectives.

By having all devices connected to a local network and using a common interface topology, multiple image streams from different sensors or detectors can be transmitted to any combination of PCs, processing units, and displays. This approach simplifies the implementation of advanced multi-stream applications, and substantially reduces the need for costly specialized equipment and custom cabling.

While GigE networks can handle the throughput of the majority of applications, 10 GigE provides the extra capacity needed for increasingly higher data volumes.

In a medical environment, this means bringing together all the elements into a common framework that complements Picture Archiving and Communications Systems (PACS) based on the Digital Imaging and Communications in Medicine (DICOM) standard. Further still, rich application toolkits provided by some manufacturers permit the enhancement of X-ray images before displaying them or storing them to a PACS archive.

In the pre-operative planning stage, surgeons use computed tomography (CT) and other scans of the patient's body to determine the best surgical approach. Standard 8-bit images are being superseded by very high resolution images with greater pixel depth of up to 16 bits per component that closely match the capabilities of the human eye, and provide surgeons with an unprecedented level of detail. When such images are combined or overlaid with those obtained during surgery, a network infrastructure that scales seamlessly to accommodate the increasing bandwidth requirements, without sacrificing legacy equipment, is vital. While GigE and USB 3.0 can handle the throughput of the majority of applications, 10 GigE provides the extra capacity needed for increasingly higher data volumes. Appendix A analyzes the primary interfaces in use today and compares the maximum achievable data rates.

Real-Time Video Networking

Video compression adds significant latency and can affect detail, which is why uncompressed images are required in medical environments. In fact, medical research shows that a surgeon's ability to accurately perform surgical tasks begins to decrease when video latency (glass-to-glass) exceeds the range of 300 to 500 milliseconds (ms). Consequently, most system designers aim for an end-to-end latency of 200 ms or less, a figure achieved by careful selection of the interface and networking technology.



Especially in robotic surgery, where the image feed is guiding the surgeon's tools, the low latency of image transfer becomes very important. In these circumstances, latency must be reduced to a point where movement on the display is practically indistinguishable from that of the direct visual perception of the surgeon at the operating table.

Therefore the use of real-time communication technology and real-time operating systems are vital in high-performance clinical applications, where latency and jitter must be ultra-low and deterministic.

For this reason, GigE Vision interfaces employ a low overhead network protocol, and vendor-optimized software uses filter drivers that significantly lower CPU usage. Also, by increasing Ethernet data packet payload through the use of jumbo frames, rather than standard frames, higher throughput can be realized.

Medical Imaging Applications

The medical field has been converting from earlier analog to more powerful digital systems for some time. As digital technology evolves and exceeds the capability of analog devices, so too does the expansion in the range of applications for image-guided surgical and diagnostic systems.

Typical applications include:

- Computed tomography (CT scan)
- Image-guided or robotic surgery
- Digital radiography
- Fluoroscopy
- Dental imaging
- Veterinary radiology

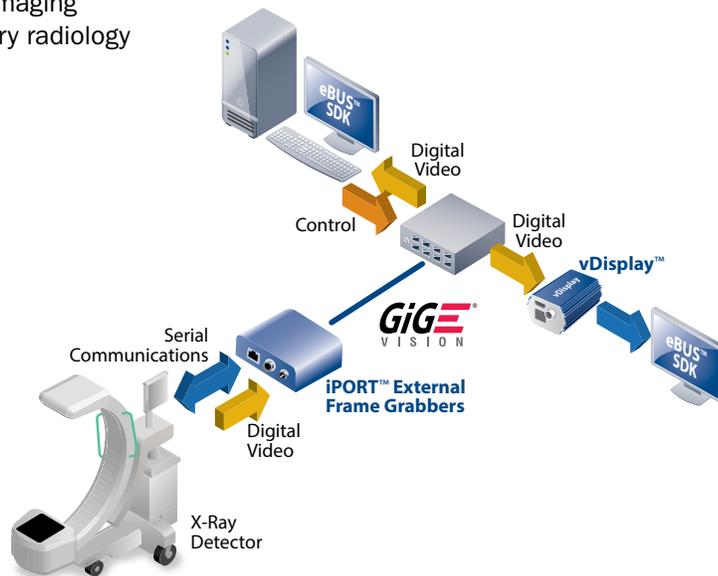


Figure 2: Real-time digital imaging in hospital operating rooms

In all of these areas, advances in the sensitivity of X-ray imaging devices—with the advent of image intensifiers and flat-panel digital detectors—have resulted in a reduction of the radiation dose to which patients are exposed. This is especially important in fluoroscopy, an X-ray imaging technique that provides physicians with real-time images of a patient's anatomy by using radiation exposure over time, which results in a greater cumulative absorption. **Figure 2** shows how real-time imaging can be realized in today's operating rooms in a three-step process.

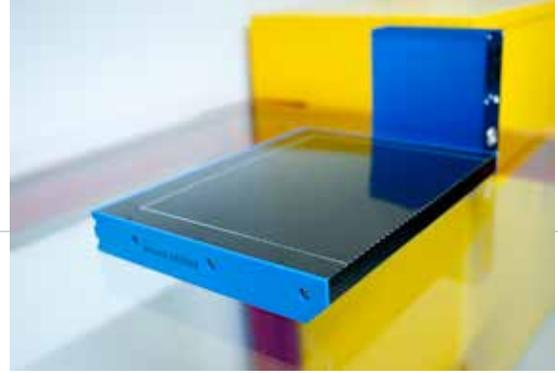
1. A GigE Vision-compliant external frame grabber in the C-arm formats X-ray images into IP packets for reliable, real-time transport over a local, standard GigE network.
2. A GigE network switch multicasts the imaging data to:
 - a PC for storage;
 - a software-based video processing PC for image correction; and
 - a display in the control room.
3. The processing PC sends the enhanced image back through the network to the display in the control room for multi-window viewing, as well as to the monitors in the operating room—all in real time with low, consistent latency.

Enhanced imaging includes image-corrected video from the C-arm, as well as one or more of:

- Highlights by analysis software to show blockages;
- Pre-operative images of the patient's heart; and/or
- Patient vital signs.

All displays are equipped with external frame grabbers, which are compact video receiver boards that convert the GigE Vision image stream to HDMI/DVI signals for viewing on high-definition monitors. The software runs on the GigE network interface cards (NICs) built into most PCs. Economies are also realized in the affordable Cat 5/6 cabling or, where regulatory requirements call for electrical isolation, in cost-effective GigE fiber connections. The GigE Vision-compliant infrastructure already in place in healthcare facilities represents an important first step in the rollout of advanced network solutions for image-guided surgery systems. Furthermore, the long-distance reach of Ethernet allows each network element to be located in the appropriate department, giving hospitals and healthcare facilities more flexibility in system design. Appendix B provides more detail on high-speed image transfer and storage.

Case Study – Dexela Limited



Based in London, U.K., Dexela Limited (Perkin Elmer) is a developer of innovative medical technologies for fast, low-dose X-ray imaging. In 2009, Dexela launched a family of flat panel CMOS X-ray detectors ideally suited to breast tomosynthesis (3D imaging) and a range of other applications including mammography, fluoroscopy, dentistry, cardiology, angiography, and bone densitometry. Key to the product design was understanding the data-intensive challenges that radiologists face when moving to digital mammography, and the need to review digital mammograms even more efficiently than reading films on motorized light boxes.

Dexela strives for a rapid time-to-market of typically six to nine months, and by partnering with Pleora to supply a fully integrated GigE Vision interface, they were able to attain their goal.

With growing customer demand for an Ethernet interface to replace the more costly and cumbersome Camera Link® interface, Dexela quickly realized that in-house development would take too long and decided to source the technology from an experienced industry supplier. Dexela strives for a rapid time-to-market of typically six to nine months, and by partnering with Pleora to supply a fully integrated GigE Vision interface, they were able to attain their goal.

Figure 3 illustrates a typical Dexela digital X-ray system used for advanced mammography analysis in which breast tissue is irradiated from seven to twelve incremental angles in a matter of seconds. This large volume of data is rapidly transmitted via the GigE connection to a PC that processes the information practically in real time, and generates 3D images on the display. Not only is the overall radiation dose lower than that of a standard X-ray, but the images obtained reveal far better qualitative information leading to a more reliable patient diagnosis.

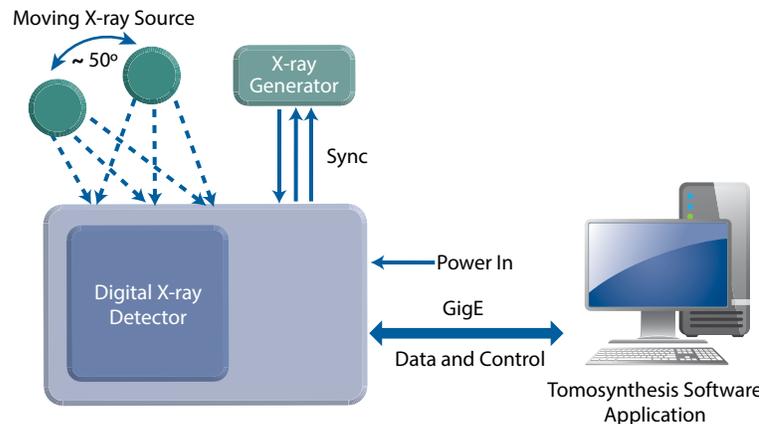


Figure 3: A digital X-ray system with a flat panel detector

Developments in Image-Guided Surgery

As Dexela continues to develop higher resolution systems, the company sees huge potential in 10 GigE connectivity. As earlier analog-based fluoroscopy systems are being replaced by newer digital flat panels, the throughput required will exceed the capabilities of GigE. The use of GigE Vision over 10 GigE will not only provide the necessary throughput but also enable more devices to be connected via single, long-reach links – see Appendix A.

Ultra-high resolution will bring other benefits too. Surgical precision is calculated by very accurate detection algorithms using custom calibration of the camera or other visual sensors. As a result, the identification of X-points, virtual reference markers in the patient's body in the x-y plane, has an outstanding accuracy of one to two percent of a pixel.

One of the advantages of networked equipment is the improved flexibility it provides—the instrument can be taken to the patient rather than the other way around. As digital X-ray machines increase in performance and decrease in size, they can be wheeled into operating rooms, which is especially important with certain conditions, such as neurological or spinal injuries, where patients must be kept immobile.

Conclusions

Manufacturers of medical imaging systems choose GigE-based networked video for image transport and archiving in order to:

- Improve clinical workflow by increasing patient throughput;
- Drive down system costs by using commonly available components and cabling;
- Isolate PCs and other processing equipment from sterile environments;
- Extend the life of legacy equipment by adapting it to be GigE Vision compliant; and
- Future-proof their systems to accommodate the addition of multi-vendor sensors, displays, and processors.

As medical imaging systems evolve, real-time video networks will be important technology elements for the medical community as it expands into new areas of image-guided surgery and diagnostics. Real-time display, and the processing and storage of patient scans is redefining how physicians perform complex surgeries and diagnose life-threatening diseases, greatly improving the quality of patient care.

By leveraging the mainstream Ethernet networking platform and the GigE Vision standard, hospitals and healthcare facilities will be positioned to find new efficiencies in the way these advanced procedures are delivered, and broaden access for all.

References

George Chamberlain, Pleora Technologies; *Real Time Arrives*. Imaging Economics; April 2010.

John Phillips, Pleora Technologies: *Overcoming the design challenges of image-guided surgery systems*. EE Times; October 2010.

Pleora Technologies: *Customer Conversations — Dexela*; 2011.

Medical Design Briefs: *GigE-Vision®-Compliant Receivers for the Networked Operating Room*. www.medicaldesignbriefs.com; January 2011.

Varian Medical Systems: *OncoView™ Image Management and Storage Solution: An Oncology-Specific Approach to Image Management and Storage*. Whitepaper; November 2008.

About Pleora

Pleora Technologies Inc. pioneered the use of Gigabit Ethernet for real-time networked video connectivity and revolutionized industrial imaging. With this spirit of innovation, Pleora engineers networked video connectivity solutions for mission-critical applications. Working with its rich portfolio of video networking elements, Pleora partners with customers to tailor solutions to their individual needs, from definition to deployment, with full integration support.

To find out why more military, medical, and manufacturing integrators and OEMs choose—and stay with—Pleora, visit <http://www.pleora.com>.

Pleora Technologies Inc.
340 Terry Fox Dr, Suite 300
Kanata, Ontario
Canada, K2K 3A2

Tel: +1.613.270.0625
Fax: +1.613.270.1425
Email: info@pleora.com
www.pleora.com

© 2013 Pleora Technologies Inc. iPORT, vDisplay, eBUS, AutoGEV, and NetCommand are trademarks of Pleora Technologies Inc. Information in this document is provided in connection with Pleora Technologies products. No license, express or implied, by estoppels or otherwise, to any intellectual property rights is granted by this document. Pleora may make changes to specifications and product descriptions at any time, without notice. Other names and brands may be claimed as the property of others.

Appendix A – Comparison of Medical Imaging System Interfaces

The main non-vendor specific interfaces typically used in medical imaging systems are Camera Link, CoaXPress, GigE Vision, HDMI, and USB3 Vision. Other interfaces used in the machine vision industry generally have low adoption rates or no application in operating and diagnostic environments.

Attribute	Camera Link	Camera Link HS	CoaXPress	HDMI	USB	GigE Vision	GigE Vision over 10 GigE
Cable Type	Camera Link	Copper or Optical	Coaxial	Copper	USB 3.0	CAT 5/6 or Optical	Copper or Optical
Power over Cable	13 W	Possible	4 W	0.25 W	4.5 W	13 W	15.4 W
Industry Adoption	Broad	Low	Limited	Moderate	Broad	Broad	Emerging
Relative System Cost	High	Medium	Medium	Medium	Low	Low	Medium
Max Payload Throughput on Single Cable	2.08 Gb/s	16.8 Gb/s	6.25 Gb/s	10.2 Gb/s	2.8 Gb/s	980 Mbps	9.0 Gb/s
Requires Non-standard Hardware	Yes	Yes	Yes	No	No	No	No
Max Distance	10 m	15 m (copper, 2.4 Gb/s) 100 m (optical, 16.8 Gb/s)	130 m @ 1.25 Gb/s 40 m @ 6.25 Gb/s	15 m	3 m	100 m (Cat 5) 40 km (optical) Unlimited with switches	7 m (Direct Attach Copper) 100 m (Cat 6a) 40 km (optical) Unlimited with switches
Network Topology	Point-to-point	Point-to-point	Point-to-point	Point-to-Point	Star	Distributed	Distributed
Native OS Support	No	No	No	Yes	Yes	Yes	Yes
Guaranteed Delivery	No	Yes	No	No	Yes	Yes	Yes
Standard Ratification	2000	2012	2009	High	2013	2006	2006

Figure 4: A comparison of video interfacing technologies, employed in medical imaging systems.

The following is a brief introduction to these interfaces:

- **Camera Link:** Introduced in 2000 and has a large installed base, mainly because of its high speed and low latency. Additionally, a recent improvement on the standard is the ability to power the camera over the data cable. However, its cumbersome 26-wire connection cables and limited point-to-point networking capabilities add installation complexity and expense.
- **Camera Link HS:** Released in 2012 to overcome the speed limitations of Camera Link for line scan cameras; however the short cable reach of up to 15 meters is a limitation.

- **CoaXPress:** Has some advantages in its speed, reach, and straightforward coaxial cabling, but like the other non-Ethernet based standards, has no networking capability. Introduced in 2010, it was designed to address some large existing coax installations, and as a consequence, has gained only narrow industry acceptance. Speeds comparable with 10 GigE are only attainable using more expensive multi-core and active cables, and over significantly shorter distances.
- **GigE Vision:** Ethernet has been in use since 1980 and is a mature and well-recognized standard. Cat 5/6 cables are widely available and have 8-strand, full-duplex cores. Power over Ethernet—where a camera can receive power over the data cable—has wide acceptance, and provides plenty of power. GigE Vision was introduced in 2006 and is based upon the 802.3 Ethernet standard. Version 2.0, released in November 2011, introduced support for 10 GigE, link aggregation, image compression (JPEG, JPEG 2000 and H.264), and the enhanced synchronization of vision system elements using IEEE 1588. Backward compatibility of all Ethernet equipment is assured. While standard Ethernet has some inherent latency, application of the GigE Vision standard, coupled with powerful software tools, has reduced it to minimum levels.
- **10 GigE Vision:** GigE Vision Version 2.0 Version 2.0, released in November 2011, introduced support for 10 GigE. Where GigE Vision over 10 GigE ensures backwards compatibility of existing GigE Vision devices, the same will not be true of next generation Camera Link devices.
- **HDMI:** The High-Definition Multimedia Interface is a compact audio/video interface for transmitting uncompressed digital data, developed in 2002. While it has wide adoption outside the vision industry and boasts an impressive data rate (up to 10 Gbps), it is limited to point-to-point architectures and cables cannot be run further than 15 meters. Additionally, the standard does not allow for cameras to be powered over the data cable.
- **USB3 Vision:** A global standard for transporting high-speed imaging and video data to computers over the widely available USB 3.0 bus at throughputs approaching 3 Gb/s. The USB3 Vision standard, ratified in February 2013, helps reduce the design, deployment, and maintenance costs of high-speed video applications by making it simpler to leverage the native performance attributes of the USB 3.0 platform, such as its high bandwidth, power over cable, and plug-and-play usability.

As demand for increased throughput grows, so does the need for higher capacity connections. Equally as important will be the distances that can be reached without the need for costly extenders, switches, and special cabling. GigE Vision's reach of 100 meters over copper is a distinct advantage, and fulfills the need for the majority of medical applications. In addition, the ubiquitous nature of Ethernet makes it ideal for sharing images and data across larger medical campuses.

Ethernet is a standards-compliant solution based on widely available off-the-shelf components. Together with GigE Vision's processing and distribution capabilities, imaging system manufacturers have the opportunity to expand their product lines beyond traditional digital imaging solutions. Interfaces that are compliant with the global, open GigE Vision and GenICam standards, ensure seamless interoperability between equipment designed by different manufacturers.

Similarly, the USB3 Vision standard helps reduce the design, deployment, and maintenance costs of high-speed medical imaging applications based on the USB 3.0. USB3 Vision makes it simpler to implement applications using the affordable and widely available USB 3.0 ports, while leveraging the native performance attributes of the USB 3.0 platform, such as its high bandwidth, power over cable, and plug-and-play usability. In addition, USB 3.0 cameras and other imaging products from various vendors can interoperate seamlessly, without time-consuming integration issues.

Of all the interfaces, only GigE Vision and USB3 Vision have multi-channel aggregation capability (not to be confused with link aggregation) in which a number of cameras can be received via a single port. Channel aggregation, achieved with standard Ethernet switches and USB 3.0 hubs, illustrates the versatility of these standards.

Appendix B – High-Speed Image Transmission and Storage

The data-intensive challenges of digital radiology are growing with the development of higher resolution, higher frame rate devices. Consequently, faster connections with greater throughput will be required.

It is important to note that, mainly for reasons of packet overhead, the real amount of useful data transferred over the link is always lower than the theoretical bandwidth.

Throughputs of typical cameras and sensors

Figure 5 shows the throughput values for typical image sensors where:
Effective throughput (bp/s) = No. pixels/image x No. bits/pixel x frame rate

Sensor	Pixels	Bits per Pixel	Frame Rate	Throughput	Connectivity Required
VGA	640 x 480	8	30 fps	74 Mb/s	GigE
Digital Camera	1600 x 1200	8	30 fps	461 Mb/s	GigE
Digital Camera	5120 x 5120	10*	25 fps	7.9 Gb/s	10 GigE
Flat Panel Detector	3088 x 3072	16	3 fps	398 Mb/s	GigE
Flat Panel Detector	3088 x 3072 (with 4x4 pixel binning**)	16	46 fps	382 Mb/s	GigE

*packed into 1.5 bytes per pixel **combining 16 pixels into one

Figure 5: Effective throughput of typical video sensors

The packet overhead for the GigE Vision streaming protocol is:

- ~5% with standard frames (1464 bits of raw data)
- ~1% with jumbo frames (8964 bits of raw data)

However, other transmit and receive factors in the network will determine the maximum throughput, which is around 700 Mb/s for a GigE connection using standard frames and 960 Mb/s using jumbo frames.

Therefore, from the chart, images from each of the sensors can be transmitted over a GigE link, except for the 16-bit camera, which would require a 10 GigE connection.

Higher bandwidth also brings other advantages. For example, multiple cables can be replaced with a single connection (channel aggregation) or a number of sensors can be connected over the same link. A well-designed implementation of GigE Vision over 10 GigE can easily transmit video of four 2.0 Gb/s sensors or even five 1.6 Gb/s sensors, allowing for protocol overhead. This is particularly valuable for systems that have limited space for routing cables and connectors.

Storage Requirements

Using the example of the flat panel detector at full resolution, the storage required per image will be:

$$\text{Storage (MB)} = 3088 \times 3072 \text{ pixels} \times 16 \text{ bits} \div (1024 \times 1024) = 144.75 \text{ MB}$$

And for a typical tomosynthesis series of seven images equals a total of 1013.25 MB.

Optional image compression, using JPEG compression for example, permits users to significantly reduce storage volumes. Images stored for later viewing, such as post-operative progress reports for example, can generally be slightly compromised depending on the level of detail required. Compression ratios may vary from 2:1 for full original image retention, up to 50:1 with some loss of finer detail. Using the latter, the tomosynthesis series would require only 20.3 MB of storage.