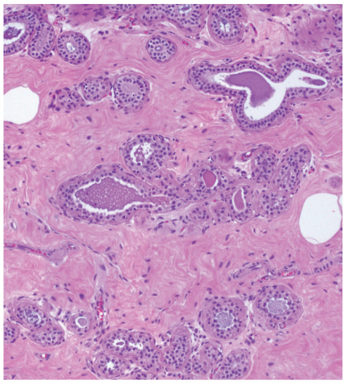
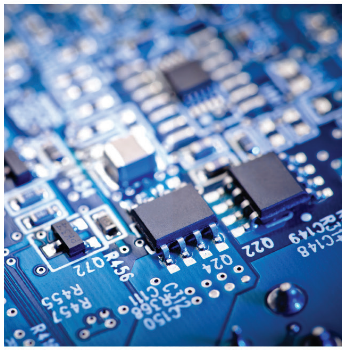
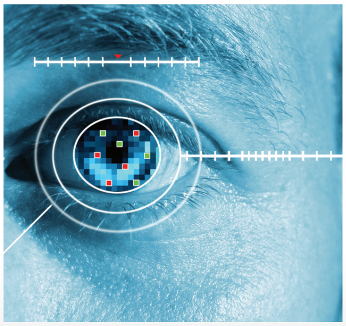
LUMENERA **WHITE PAPER SERIES**







HIGH-SPEED IMAGING

An in-depth look at USB 3.0 cameras & technical specifications

WHAT'S INSIDE

Introduction to HIGH-SPEED IMAGING

The Lt225 and Lt425 are two of the latest products released by Lumenera that excel at providing high quality, high-speed imaging for a multitude of applications. This paper provides a brief high-level overview of a few technical specifications that typically go into the development of a high-speed imaging camera.

SENSOR TECHNOLOGY: CMOS vs. CCD

There has been much debate over which sensor technology is better. Much has been written comparing CMOS and CCD sensors so little will be said here to compare them directly. Let's put the debate to rest. Frankly, it usually doesn't matter whether a sensor is CMOS or CCD. To the vast majority of camera end-users, the underlying technology of the imager isn't, and shouldn't be, of concern; it's the resulting image that's really important. In fact, the image is everything. It's true, the fidelity of the image will depend on the image sensor technology to some extent, but just as importantly on how skillful the camera designer and manufacturer are. And, regardless of the underlying technology, the image will still contain some artifacts, noise and will fall short of complete fidelity. However, as long as it contains the information you need, it's good enough.

It's also true, the differences in the technologies will influence how and how often an image can be captured or if it can be captured at all, and it will certainly influence many other aspects of image capture and camera operation. However, with the continuing evolution of sensor technology, there is so much overlap in most of the operational characteristics that can be achieved by either technology that choosing a camera based solely on whether it's CMOS or CCD is often imprudent.

Another important criterion is the ease in which images are obtained. Some cameras are so hard to use, with their poor instructions, complex interfaces or deficient software that even if they are capable of producing a suitable image, it's just too difficult to capture that image reliably.

One needs to look at the specific performance characteristics of a camera in order to make a decision as to its suitability. Let the camera manufacturer worry about the sensor technology. You, as the end user, stay focused on the image you're trying to capture. Look at the performance characteristics and select a camera with the best combination of price, performance and of course customer support. Choose a camera company with a history of providing cameras and imaging products with high quality, reliability and ease-of-use.

Need for SPEED

The frame rate of a camera will determine the shortest time between two events that can be captured. Although single frame exposures can be achieved down to fractions of a millisecond using standard cameras, their frame rate limits the shortest time between events to be on the order of 16 to 33 milliseconds at full resolution.

The reciprocal of the frame rate provides the shortest time between events that can be captured.

FOR EXAMPLE
Frame rate of 60 fps ⟶ 1/60 s = 16.666 ms between events

Correspondingly, the frame rate required to capture two events is the reciprocal of the time between the events.

FOR EXAMPLE
Time between events of 33.333 ms = 1/30 s ⟶ 30 fps frame rate

Speed is a relative concept when it comes to cameras. You might remember the early videoconferencing cameras that could only do 5 fps or less and at a low resolution. Even with new cutting edge technologies now available, many high resolution sensors are still limited to a few frame rates. Good old-fashioned analog televisions ran at 30 fps, which at the time seemed fast in comparison to other digital video solutions. Fast forward to present day and High Definition Television (HDTV) provides frame sizes of 1280 x 720 or 1920 x 180 at 60 fps - twice the speed. This speed now seems blazing fast in the eyes of viewers. At the other end of the spectrum, you have scientific and military testing and researchers utilizing frame rates greater than 100,000 fps. Technology is pushing the million frames per second barrier.

There are many applications in science and industry that require frame rates higher than those provided by standard video (traffic, human kinetics, sports replay analysis to name but a few), but not the high speeds described above; a high-speed zone, if you will, where frame rates are on the order of a few hundred fps.

In reality, there is not a singular definition of what constitutes high-speed imaging. Simply put though, high-speed imaging allows your application to run quickly and achieve the resolution you're looking for, regardless of barriers you're facing such as lighting. Most cameras, Lumenera's included, allow for subwindowing of the image where a smaller portion of the frame is output resulting in higher frame rates. Frame rates in the thousands of fps are achievable, but the resolution of the frame would only be a few pixels which makes it practically useless except for detecting an object's presence or absence. No details about the object would be distinguishable with such low resolution.

However, with the introduction of the Lt225 and its big brother the Lt445, high resolution high-speed imaging is achievable. The Lt225 has a resolution of 2048 x 1024 and outputs 170 frames per second. Halving the resolution to 1024 x 1024 (still an impressive 1 megapixel) doubles to the frame rate to 340 frames per second. The Lt425 starts with a 2048 x 2048 frame size and 90 fps at full resolution with the same proportional increase in frame rate when subwindowed.

These high frame rates are achieved using an onboard memory buffer coupled with adaptive dataflow management logic in a high-speed FPGA providing the reliable delivery of images with no lost frames in any environment.

> “**With** the introduction of the Lt225 and its big brother the Lt445, high resolution high-speed imaging is achievable.”

USB 3.0 = EASY HIGH PERFORMANCE

Supercars bring an exhilarating level of performance leaving many of us in awe. The high speed, acceleration and handling are all powerful sensations that come to mind. But if you've ever driven a supercar, you also quickly notice the lack of visibility, how awkward it can be just getting into the car, or the unforgiving controls that translate even the slightest driver input into a mad rush of power. For these reasons you may be quite happy leaving the supercar at home for your daily commute to work and jumping into your reliable, comfortable, compact car that is user friendly, provides a smoother ride and that gives you the benefit of greater fuel efficiency. Wouldn't it be amazing if you could enjoy the best of both worlds?

In machine vision, this is what USB 3.0 is all about; the performance of a supercar with the ease-of-use of your compact car. USB 3.0 provides a high-speed data interface (even superspeed), with the ease-of-use of a consumer oriented technology. No need for specialized framegrabbers, exotic cabling or tedious software installation.

USB 3.0 is an evolution of USB 2.0, one of the most popular data interfaces available today. One of USB 3.0's most compelling features for machine vision systems is its high bandwidth providing a transfer speed of approximately 5 Gb/s, which is ten times faster than USB 2.0 and five times faster than the widely deployed GigE interface. Not all of this is usable speed as USB 3.0 relies on 8b/10b data encoding to embed bus timing information within the data, but even taking this into consideration the effective payload data rate still stands at 4 Gb/s. USB 3.0's data transfer speed is effectively approaching the speed of specialized machine vision interfaces such as CameraLink and CoaXPress,

however, unlike these two interfaces USB 3.0 does not require any special interface cards or framegrabbers in the host computer. USB 3.0 delivers a true plug-and-play experience, largely due to it now being native on today's computers, as well as finding its way into embedded computers and even tablets. Going hand-in-hand with computing hardware, all major software operating systems have built-in support for USB 3.0.

One advantage offered by USB 3.0 over the specialized machine vision bus technologies is it is so much easier to use. Also, the ubiquity of USB 3.0 ensures the standard has matured to a solid, reliable computer peripheral bus with access to a vast selection of devices. With a wide selection of computer platforms and operating systems, USB 3.0 offers a wide choice of options for system designers, simplifying the implementation of complex machine vision systems.

Lumenera was the pioneer of USB 2.0 megapixel industrial imaging, introducing it more than a decade ago and now fully supports USB 3.0 with the introduction of the Lt series of cameras. The high frame rates and large resolutions of the Lt225 and Lt425 dictate the need for a high-speed interface like USB 3.0. These cameras output image data at rates greater than 3 Gb/s.

Comparing Electronic Shutter:

GLOBAL VS. ROLLING

An electronic shutter regulates how light is exposed on an image sensor. It controls how much light reaches the photosensitive sites in the image sensor and at what moment in time the exposure will occur.

There are two basic types of electronic shutter; Global and Rolling. In a sensor with a global shutter, all its pixels are exposed simultaneously for a period of time called the “exposure time”.

In a sensor with a rolling shutter, the sensor’s pixels are exposed sequentially one by one left to right, row by row. Each pixel is exposed for the “exposure time” but there is a lag between the first pixel of the first line starting its exposure and the last pixel of the last line starting its exposure. This lag is equal to the frame period, which we saw earlier is the reciprocal of the frame rate of the imager. The key point to understand is that even though each pixel is exposed for the same length of time, resulting in a uniformly exposed image, the pixels are not exposed at the same point in time. The pixels at the top of the sensor are exposed earlier than those at the bottom of the sensor with the lag progressively increasing from the top of the image to the bottom.

If the target is relatively static a rolling shutter works very well. However, when it comes to high-speed imaging, the target is usually not relatively static and in fact is usually moving quite rapidly, hence the need for high frame rates.

When using a global shutter on moving targets, as long as the exposure is short enough, the image can be captured with no significant blur. The use of high speed strobe lighting can further reduce blur by effectively “freezing” the target in place.

When using a rolling shutter with its sequential exposure on moving targets, not only do you have the same susceptibility to blur, but in addition there are three more image artifacts that can manifest under the right conditions. These artifacts are skew, wobble and banding.

The first two will only occur when there is significant relative motion between the camera and object being imaged and the latter when light levels change suddenly during image capture. The conditions that result in these artifacts are common when doing mid to high-speed imaging.

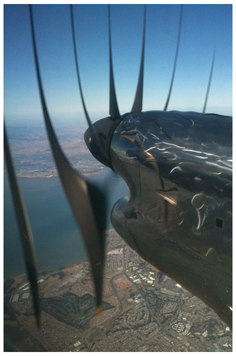
SKEW is described as the apparent leaning of moving objects in a scene. It appears when the motion is horizontal with respect to the camera field of view. A simple way to understand skew is to imagine imaging a vertical tower while panning the camera horizontally. As described above, the image of the tower is exposed line by line from top to bottom over a small time interval.

As the camera pans left to right over that time interval, the top of the tower will appear further to the right in the image compared to the bottom of the tower which will appear further to the left. The tower will actually appear to be leaning in the same direction as the camera is panning. It’s the relative motion between camera and object that’s important, so if the camera were held steady and the tower was moving, the same effect would occur. The tower would appear to be leaning in a direction opposite to its actual motion. The greater the speed, the more pronounced the effect.

GLOBAL VS. ROLLING SHUTTER

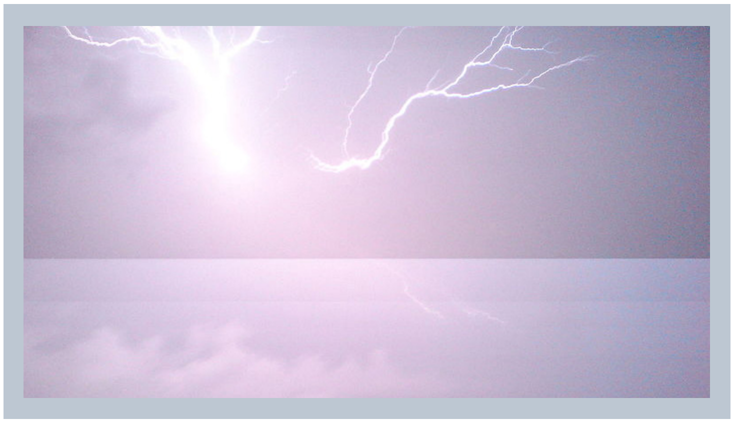
Continued from previous page

WOBBLE is the apparent shrinking or stretching of objects in a scene. Whereas skew occurs when motion is horizontal to the field of view, wobble, occurs when the motion is vertical. Imagine imaging a high-speed model rocket being launched vertically upwards. In each frame, the top of the rocket is exposed earlier than the bottom of the rocket. The position of the rocket has changed getting higher in the frame during the time between exposing the top and bottom. This leads to the rocket appearing to shrink in length. The faster the rocket moves, the more the apparent shrinking. When imaging an object moving in the opposite direction, such as a ball falling straight down, rather than shrinking, the object appears to be stretched.



Again, as with skew, it's the relative motion that's important, so, tilting the camera while viewing a stationary object has the same shrink/stretch effect. As an aside, this artifact can be used to one's benefit by carefully synchronizing the movement with the scanning rate of the sensor. This is the basis for time delay integration (TDI) sensors, a topic which is beyond the scope of this paper.

BANDING is the appearance of horizontal bands in the image that appear brighter than the rest of the image. The common cause is when using strobe lighting (e.g. a camera flash) during exposure. When doing higher speed imaging where the exposures are necessarily very short, external lighting is often required in order to enable image capture by brightening the scene. If the duration of the strobe is shorter than the frame rate, or if the strobe starts or stops during the exposure of the frame, this artifact may occur. It's easy to see why. The rows of pixels in the image are exposed at different points in time. If a strobe occurs for a short duration, only the rows of pixels being exposed during that time will see it. Similar effects occur with some types of fluorescent lighting which are strobing faster than our eyes can see, but not too fast for the image sensor to detect.



CMOS GLOBAL SHUTTER: Until recently, CMOS sensors only offered rolling shutters, but technology has evolved in recent years making it possible to now also implement quality global shutters.

Not all global shutters are created equal. An important qualifier for global shutter performance is its efficiency; which measures how much parasitic light reaches the photosensitive area even when it should not. Of course sensor manufacturers go to great lengths to develop new techniques and innovations to minimize such problems. Sensor manufacturer CMOSIS claims parasitic light sensitivity of 1/50,000 for its CMV4000 sensor, which means that there will be only one single parasitic photon for each 50,000 photons! This is the sensor chosen for use in Lumenera's Lt425 USB 3.0 camera.

There are reasons why global shutters are not perfect, making a case for both rolling shutter and global shutter technologies to co-exist. Global shutter technology tends to have higher read and dark current noise than a rolling shutter. If an application is less interested in capturing a moving target and more interested in low noise performance, a rolling shutter might be a better solution. The simpler design of a rolling shutter also makes it less expensive. However, motion is often a fact of life in many vision applications, and for those that require high-speed imaging, the benefits of CMOS global shutter technology are now available.

What you need to know about:

COLOR FIDELITY

We live in a world of color. We gather a lot of information from our surroundings based on color, react differently to each one, and have our own favorites and preferences. Colors may be soothing, some may motivate, while others warn us of danger. With color offering so much, why are so many machine vision systems limited to monochrome? Color is opening doors to a world of new possibilities for an increasing number of machine vision applications.

The camera in your system is the gateway to the color wonders of the world. A camera delivering accurate color is no small feat, much less doing so in a reliable and repeatable manner. Cameras from various manufacturers often rely on comparable sensors but this is where the similarities end. Unless purposely designed, cameras will deliver varying color quality even when using the same image sensors. Color quality may even vary between units of the same camera model.

Capturing accurate color at high speed only adds to the challenge. Operating at high frame rates results in a much shorter exposure time, which means there is less light reaching the sensor. It's a lot easier to obtain accurate color when light is plentiful than under minimal light conditions. When choosing a camera for such an application the camera needs to fast, but also has to offer outstanding light sensitivity to be able to deliver accurate color.

At Lumenera we go to great lengths to design and manufacture our cameras so as to deliver accurate color, and ensure that a camera model will always deliver color in the same manner from unit to unit, no matter when it was manufactured.

Some of the ways in which Lumenera accomplishes this task include:

- Camera electronics are designed with proven, high performance components using the tightest tolerances, giving performance and repeatability to the design.
- Individual cameras are calibrated in the manufacturing process to compensate for individual variations.
- Final quality inspection by a team of trained specialists ensures excellent color performance.

Our dedication and success to color accuracy and repeatability is demonstrated by our strong presence in microscopy and life sciences applications. Color imaging applications are plentiful, one obvious example being paint quality and color accuracy in a manufactured product such as automobiles. As a consumer buying produce at the supermarket your choice will often be guided by the color of the fruit or vegetable. Producers know this and will employ a vision system to automatically select the most appealing fruits and vegetables to ship to consumers, while the remaining are turned into processed foods. An application with more profound consequences is the interpretation of color in a life science or medical imaging application where tissue samples are analyzed. All of these applications, and more to come in the future, rely on cameras that deliver accurate color in a repeatable manner even at a high frame rate.

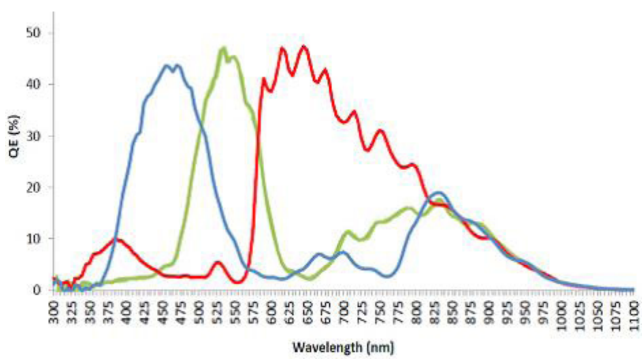
High-Speed Imaging:
PUTTING IT ALL TOGETHER

In order to develop a camera, suitable for high-speed imaging, we had to select a sensor with global shutter that had suitable resolution and frame rate. In order to keep the price of the camera reasonable, this meant using CMOS imager technology, specifically the sensors developed by CMOSIS. In order to satisfy the image data rates, for ease of use and to keep the end user's system costs to a minimum we selected USB 3.0 as the data interface avoiding the need for complex software or a framegrabber. This was all combined with our design expertise, proprietary processing algorithms and manufacturing capabilities resulting in the Lt series of cameras.

The Lt225 and Lt425 are high-speed cameras ideally suited for applications that include traffic monitoring, automatic license plate recognition (ALPR), high-speed inspection and motion analysis and control. These cameras can be customized to suit Original Equipment Manufacturer (OEM) designs with specific form factor or enclosure requirements and are available in monochrome, color or enhanced near IR sensitivity models. Scientific-grade versions are also available and suitable for life science applications such as digital pathology and slide scanning. Their high resolution and relative low noise is suitable for capturing enough detail to do all sorts of data analysis.

Camera Characteristics	
Resolution	2048 x 1024 or 2048 x 2048
Dynamic Range	60 dB
Full Well Capacity	13,500 e-
Quantum Efficiency	45% peak color, 64% peak monochrome
Read Noise	13 e-
Dark Current Noise	125 e-/s (@25 °C die temp)

Color Quantum Efficiency Curve



Monochrome Quantum Efficiency Curve

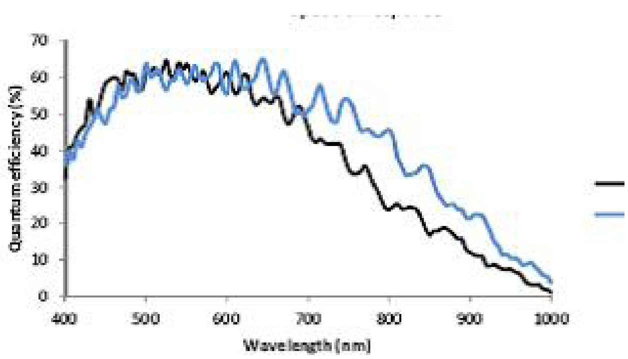


Image capture can be synchronized using either a hardware or software trigger and is complemented by 128 MB of onboard memory that is used for frame buffering to ensure full image delivery with no loss of data.

The compact, light weight design of these cameras, which measure 40 x 40 x 53 mm, and the multitude of threaded mounting holes, ensure easy, flexible integration into tight spaces and enclosures. The fully locking USB 3.0 connector provides a simple and secure single cable plug-and-play installation. For additional functionality, simplified I/O cabling can be connected to the locking Hirose connector to support external power input as well as 1 optically isolated output, 1 optically isolated input and 2 configurable I/Os.

PUTTING IT ALL TOGETHER

Continued from previous page

The Lumenera camera Software Development Kit (SDK) provides a full suite of features, functions and source code samples that allow you to maximize the camera's performance within your own vision application. The SDK is compatible with all of our USB and GigE-based cameras. Microsoft DirectX/DirectShow, Windows API and .NET API interfaces are provided, allowing you the choice of application development environments from C/C++ to VB.NET or C#.NET.

All Lumenera cameras come with a 1 year warranty and are supported by an experienced team of technical support and imaging experts. We understand your imaging needs and are here to help you get the most out of your camera whatever the imaging application.

About The Company:

LUMENERA CORPORATION

Lumenera Corporation, a division of Roper Technologies, headquartered in Ottawa, Canada, is a leading developer and manufacturer of high performance digital cameras and custom imaging solutions. Lumenera cameras are used worldwide in a diverse range of industrial, scientific and security applications. Lumenera solutions provide unique combinations of speed, resolution and sensitivity in order to satisfy the most demanding digital imaging requirements. Lumenera customers achieve the benefit of superior price to performance ratios and faster time to market with the company's commitment to high quality, cost effective product solutions.

Lumenera Corporation
7 Capella Court
Ottawa, ON
Canada, K2E 8A7

613-736-4077
info@lumenera.com
www.lumenera.com