WHITE PAPER

www.baslerweb.com

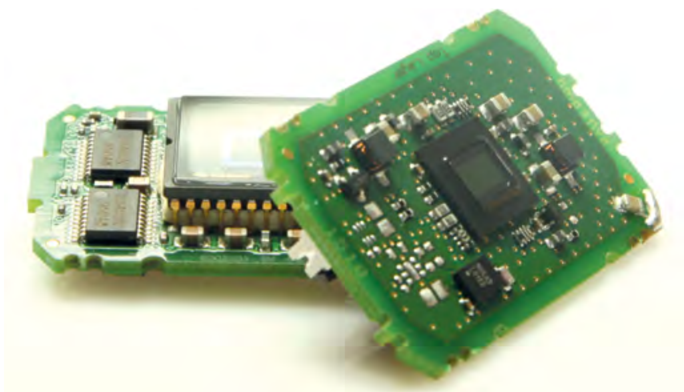
Global Shutter, Rolling Shutter - Functionality and Characteristics of Two Exposure Methods (Shutter Variants)

The process of selecting the right components for industrial machine vision applications starts with a few fundamental decisions. For starters, the camera and its interface and sensor technology must be suitable for the specifications of the overall machine vision and image processing system. Yet the choice between sensors involves more than just the question of CCD or CMOS. The shutter method must also be taken into account. This white paper describes the different functional principles behind global shutter and rolling shutter and explores how and when they are best suited for use in industrial image processing.

Contents

1. The Basic Concepts of Shutters 1
2. Exposure with Global Shutter 1
3. Exposure with Rolling Shutter 2
4. The Rolling Shutter Effect and Its Impact.............. 2
5. Does Higher Resolution Inherently Translate into Better Image Quality? 3
6. Preventing the Rolling Shutter Effect Using Flash Lighting and Exposure Times..................................... 4
7. Summary 4

CCD and CMOS sensor technologies differ in architecture and in the way they collect, prepare and process information. Parameters such as image quality and speed are directly affected by this. The shutter method is a related but distinct characteristic, and refers to the way in which image data — the photons received by the individual pixels are converted into electrons — is captured.



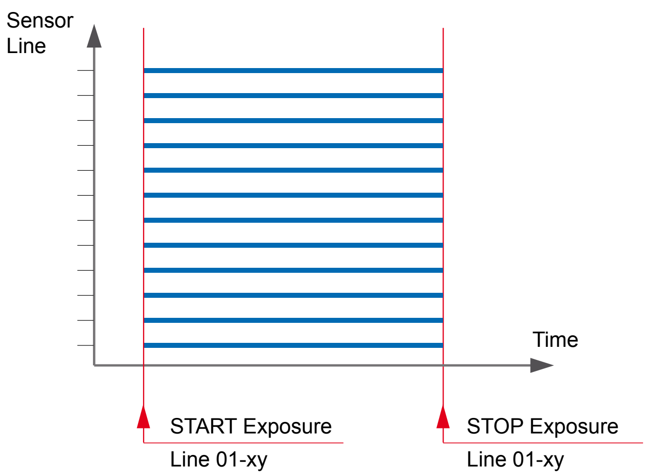
CMOS and CMOS sensors collect and process image data differently.

1. The Basic Concepts of Shutters

In traditional film cameras, the shutter protects the film inside the camera against light, opening only at the moment when the shutter release button is pressed. The shutter speed setting determines how long it remains open, ideally exposing the film to the optimal «dose» of light. If the exposure period is too short, then the images end up underexposed; if it is too long, then the photos are overexposed.

Film has largely given way to sensors nowadays, but the fundamental principles of exposure remain as true as ever. The photoelectric cells are cleared electronically at the start of exposure and then read out when the exposure period is completed. In simple terms, each image is composed of a multitude of horizontal rows. Each row in turn is composed of individual pixels. The actual pixel count depends on the resolution of the sensor. There are two fundamental methods for exposing those rows to light: global shutter or rolling shutter.

2. Exposure with Global Shutter

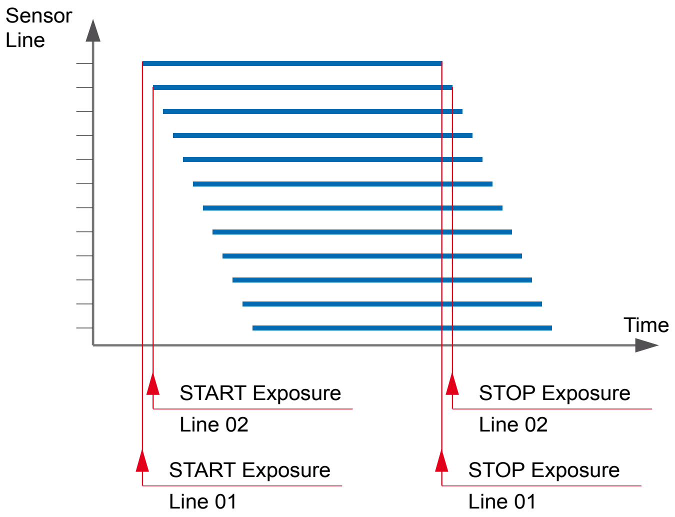


In global shutter mode, the exposure time begins and ends simultaneously for all pixels.

The global shutter methods works using the same principle as the classic aperture of film cameras. The shutter opens, light strikes the entire surface of the sensor — all of the rows at once — and then the shutter closes again. "Global" in this case refers to the simultaneous exposure of the entire surface, with the entire image area captured at once. Depending on how quickly the camera is set to record images, a moving object is thus illuminated as a rapid sequence. This shutter principle was long available only with CCD sensor technology and was considered the technology of choice for applications involving fast-moving objects passing in front of the camera. Modern CMOS sensors now also have a global shutter option, which is especially helpful for applications with high frame rates and high resolutions.

3. Exposure with Rolling Shutter

Rolling shutter is an exposure technique primarily used for CMOS sensor technology. Unlike the global shutter method, there is no "single" simultaneous exposure, but rather a series of exposures. When the shutter release is pressed, the rows are exposed in sequence, row after row. This can in some cases lead to overlapping.

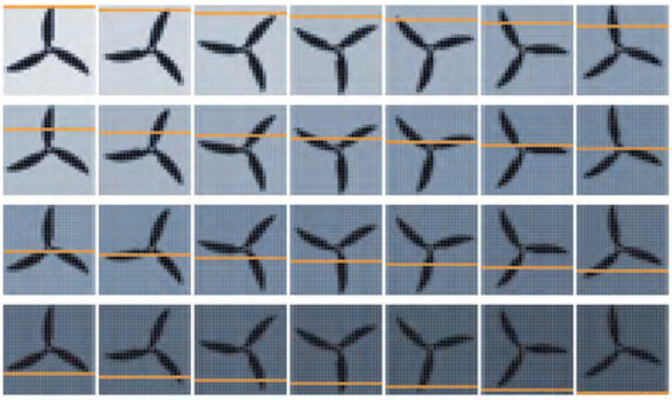


For the rolling shutter, the exposure time does not begin and end simultaneously, but rather for each individual row respectively: The graphic shows the staggered exposure of the individual rows on the photo.

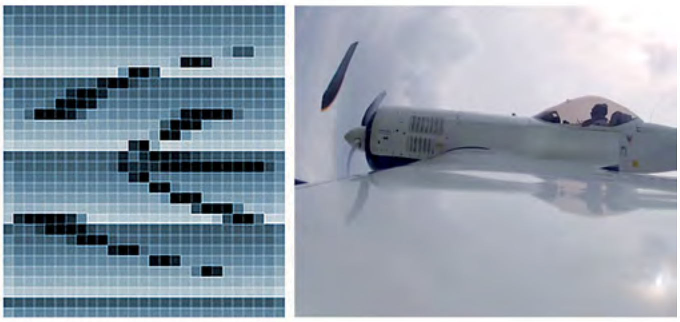
Once the last row of photo 1 has been completely exposed, the acquisition of the next image starts anew, from the first row. The rolling shutter method requires only two transistors per pixel to transport the electrons, which in turn produces less heat and significantly lower ambient noise than with the global shutter method. The 4-5 transistors required for that technique produce relatively high levels of ambient noise and heat. On the other side, especially for moving objects, the rolling shutter often creates distortions that can exceed acceptable thresholds for some applications.

4. The Rolling Shutter Effect and Its Impact

These distortions occur if the object or camera continues moving during the row-by-row exposure. As the image data is gathered, the exposed rows are reconstituted in the same sequence into a complete image. The sequential exposure of the individual rows is also visible in the way the distortions are formed in the reconstituted image. This is known as the rolling shutter effect. Another important factor beyond exposure time is the speed of the sensor. It determines how fast the rows open and close again. A fast sensor offering up to 60 frames per second (fps) suffers less from the rolling shutter effect than a slow sensor working at only 15 fps.



The yellow line shows the course of the exposure from the first image row to the last. During exposure, then propeller turns four times in total.



During the recomposition of the exposed rows into a overall image, the distortion caused by the continuous motion of the propeller is visible due to the row-by-row exposure.

On the consumer market, this kind of distortion is typically met with surprise and amusement, but in the industrial machine vision or IP surveillance fields it can represent a real problem. Monitoring applications can end up delivering images too distorted to serve as solid proof. Surveillance cameras are an integrated part of modern daily life: banks, public buildings, events, casinos, traffic monitoring — wherever crowds of people gather, the needs for effective security are rising. People and vehicles move at different speeds. The slower the speed, the lower the chance of a rolling shutter effect. In this case, the interplay between frame rate and exposure determines what is sufficiently slow and what is too quick to be captured effectively.

Monitoring systems in casinos for example combine high frame rates and short exposure times to create strings of images. This is useful for random sampling to detect cheating.

Examples of the rolling shutter effect (from Wikipedia)

The situation is more complicated when it comes to traffic monitoring. Depending on where the camera is positioned in relation to the object, as well as the selected frame rate and the selected exposure time, it can be difficult to limit the rolling shutter effect to tolerable levels. If for example a very short exposure time is selected (such as 1/2000s), then this produces a greater distortion within the image than for a long exposure time encompasses a larger portion of the movement. The time required by sensor and camera to capture the image row-by-row may well be insufficient here to keep up with the movement of the vehicle. If so, distortions emerge and the must be accounted for when evaluating the images.

Global shutter at standard resolution

Rolling shutter at standard resolution

5. Does Higher Resolution Inherently Translate into Better Image Quality?

By no means. Contrary to popular opinion, higher resolutions don´t necessarily produce better images. In the field of industrial machine vision, for example, this is only partially true, since all data must be individually processed and depicted. Higher resolutions are often tied to smaller pixel sizes. Small pixels have a lower saturation capacity, which in turn produces an inferior signal/noise ratio and allows for a lower dynamic range.

For applications that require neither high frame rates nor high resolutions, then CCD sensors continue to be advisable. Working with 1-2 megapixels of resolution up to 30 fps (1 MP/30 fps, 2 MP/15 fps), they deliver outstanding image quality, even with limited light. Other benefits include improved color separation, reduced noise and greater sensitivity within the visible realm. CCD sensors also still play an essential role for microscopy and astronomy applications.

CMOS sensors by contrast gain in relevance as soon as higher frame rates are required. Because of their lower load speeds and significantly higher heat development, CCD sensors can´t keep up with CMOS sensors at 60 fps at 2 megapixels

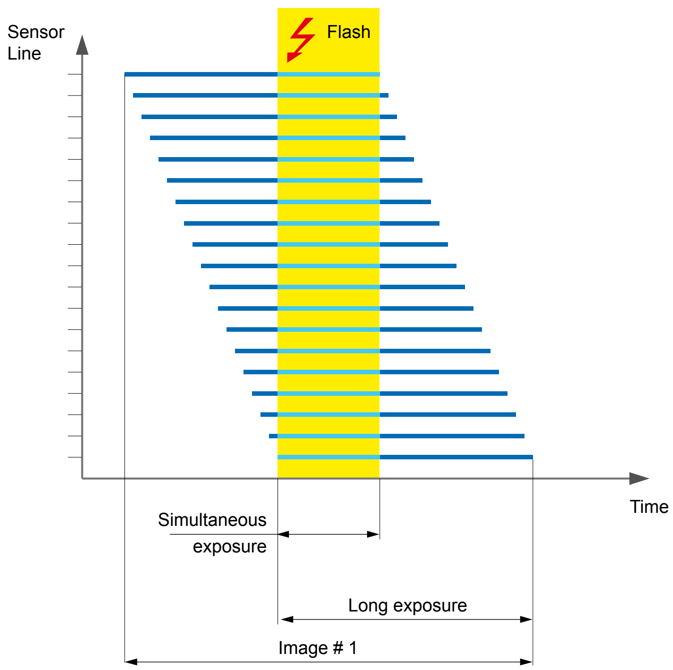
Video

The rolling shutter effect: The distortion is created by the movement of the vehicle during the exposure of the individual rows.

6. Preventing the Rolling Shutter Effect Using Flash Lighting and Exposure Times

If, during the selection of a sensor, all characteristics speak for a model using the rolling shutter method except the potential distortions, then it is possible to prevent them — presuming specific conditions can be satisfied. As with all areas of industrial machine vision and camera surveillance, light plays an important role. Light is especially crucial for exterior areas and poorly lit interior spaces. Bright daylight always allows the camera to work with shorter exposure times than at twilight or in the dark. Here industrial machine vision systems have a slight advantage: if the existing ambient light isn´t sufficient, they can be combined with flash equipment. This option is however subject to certain limitations: flash photograph is only of limited use for exterior photography, so that the costs associated with building the system is only worthwhile for interior applications in dark spaces.

Flash photography also doesn´t work where external light is present, such as daylight. IR light and IR pass are only valuable tools for preventing these problems in nighttime applications.



Compensation for the rolling shutter effect through timely use of flash. The flash must cease at exactly the moment when the exposure of the last row commences and the first row closes.

Another option for avoiding the effect is extending the exposure time. This gives the sensor more time to expose the rows. The higher the frame rate, the faster the rows are processed and hence the weaker the distortion.

A combination of flash and longer exposure times is also possible. The exposure time is corresponding extended so that the exposure of the individual parts overlaps with the duration of the flash. The flash is set to cover precisely this overlap. Some cameras also feature a digital output that can send a signal to an external flash.

It´s worth noting that these measures are not always feasible for all applications. If for example an overly long exposure time is selected, then the rolling shutter effect is reduced, but the photos will have blurred movement. The limits of attainable improvement are thus somewhat narrow and cannot always be achieved.

In some cases, software solutions featuring special tools for repairing rolling shutter distortions can serve as a sensible compliment to the correction and countermeasure plan for the camera instruments.

7. Summary

The market for industrial machine vision is also of increasing interest to sensor makers. CMOS technology in particular has seen massive technological leaps in recent years, and has made significant strides to catching up to CCD sensors in their traditional strength, image quality. The classic problem areas for CMOS sensors, including limits on extended exposure times, short product life cycles and rolling shutter distortions, have largely disappeared or are now so minor as to be of minimal relevance for normal use.

The mass production for the high-end consumer market, where CMOS sensors with rolling shutter now come pre-installed on smartphones, is constantly pushing development forward. Some manufacturers are even delivering sensors with four shutter modes, capable of switching between them on the fly to fit the respective application. The area of use can be expanded to an entire range of application areas, from industrial machine vision to surveillance, barcode scanning and other imaging processes. Increased quantum efficiency, the ratio between the number of electronics and the number of photons gleaned from them, and an optimized signal/noise ratio delivers outstanding image quality even for moving objects in poor lighting conditions. And the technological progress is almost certainly not yet done.

Customers can look forward to a continued stream of improvements on the technical side, as well as constantly improving pricing. This comes not least courtesy of the design and architecture of the sensors (since two transistors are cheaper than five), as well as the economies of scale as these sensors increasingly dominate the landscape.

Basler Industrial and Network Cameras

About Basler

Basler is a leading global manufacturer of digital cameras for industrial and video surveillance applications, medical devices, and traffic systems. Product designs are driven by industry requirements and offer easy integration, compact size, excellent image quality, and a very strong price/performance ratio. Founded in 1988, Basler has 25 years of experience in vision technologies and has designed and manufactured high quality digital cameras for 15 years. The company employs more than 400 people at its headquarters in Ahrensburg, Germany, as well as at international subsidiaries and offices in the U.S., Singapore, Taiwan, China, and Korea.

Authors

Dr. Joachim Linkemann
Senior Product Manager

Dr. Joachim Linkemann started out with Basler in Ahrensburg as an optics designer in 1997. The physicist has developed illumination concepts and calculated optics which were manufactured according to his plans. As product manager he has been conducting the complete lifecycles of a number of products for more than ten years now. He is focusing on customizations in order to develop optimal solutions in close cooperation with customers. Optics is still an important field of activity.

Björn Weber
Product Manager

Björn Weber joined Basler in 2005. He holds a degree in electrical engineering and until 2008 was responsible for industrial cameras. Thereafter he switched to Basler's IP team, where he initially was in charge of product support, and since 2011, of product management for IP cameras. In his current position, he is responsible for the strategic product management of Basler's high-end cameras.

Contact

Dr. Joachim Linkemann
Tel.: +49 4102 463 236
Fax: +49 4102 463 46236
E-mail: joachim.linkemann@baslerweb.com

Basler AG
An der Strusbek 60-62
22926 Ahrensburg
Germany

Contact

Björn Weber
Tel. +49 4102 463 448
Fax +49 4102 463 46448
E-mail: bjoern.weber@baslerweb.com

Basler AG
Germany, Headquarters
Tel. +49 4102 463 500
Fax +49 4102 463 599
sales.europe@baslerweb.com
www.baslerweb.com

USA
Tel. +1 610 280 0171
Fax +1 610 280 7608
sales.usa@baslerweb.com

Asia
Tel. +65 6367 1355
Fax +65 6367 1255
sales.asia@baslerweb.com

BASLER the power of sight