WHITE PAPER

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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. When it comes to selecting a sensor, what matters is not just the required resolution but also the shutter technique. 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

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. You can find a detailed comparison of the two technologies and their advantages in our White Paper "*Modern CMOS Cameras as Replacements for CCD Cameras*".

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.

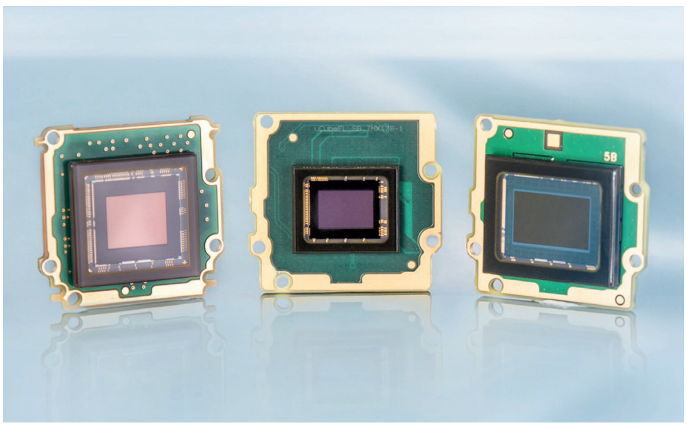

Fig. 1: A comparison of rolling and global shutter sensors

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, hopefully 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.

Fig. 2: Image overexposed and underexposed

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

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. Until a few years ago, this type of shutter was reserved exclusively for CCD sensor technology. It is especially suitable for applications in which the camera has to capture and record fast-moving objects or is itself moving quickly. By now modern CMOS sensors, such as Sony's Pregius series or the PYTHON series from ON Semiconductor, are available with global shutters, which make them an excellent replacement for older CCD systems.

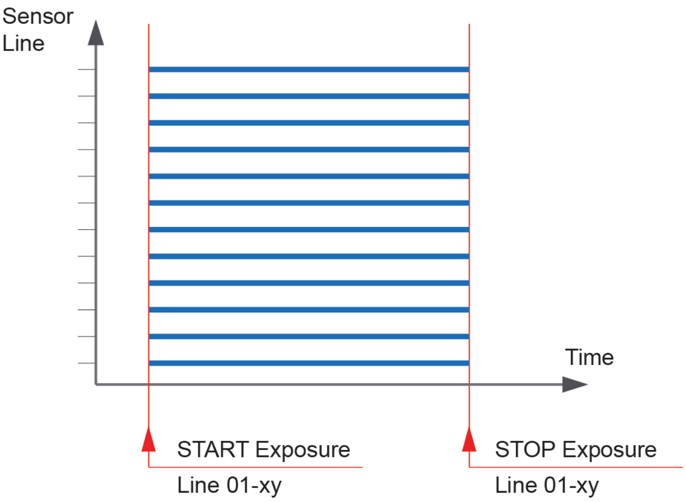

Fig. 3: In global shutter mode, the exposure time begins and ends simultaneously for all pixels.

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 and the camera is triggered, the lines are exposed in succession, line after line. This can in some cases lead to overlapping.

Once the last row of photo 1 has been completely exposed, the acquisition of the next image starts anew, from the first line. The rolling shutter method requires only two transistors per pixel to transport the electrons.This creates less heat and generates much less background noise than with global shutters, whose 4–5 transistors tend to produce comparatively high background noise and a lot of heat. On the other side, especially for moving objects, the rolling shutter often creates distortions that can exceed acceptable thresholds for some applications.

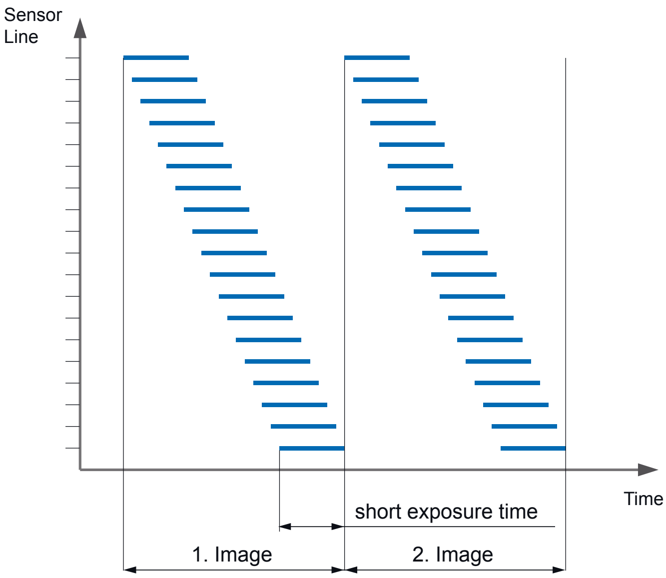

Fig. 4: For the rolling shutter, the exposure time does not begin and end simultaneously, but rather for each individual row respectively: The graphic shows the staggered exposure of the individual rows on the photo.

The sensor's readout times for the individual lines is particularly important to consider here. Modern CMOS sensors with a rolling shutter, such as Sony's STARVIS line, sometimes achieve lower values here than older rolling shutter sensors, which means there is less delay between the lines and, consequently, less of a rolling shutter effect.

	MT9J (older sensor by ON Semiconductor)	IMX226 (newer sensor from the STARVIS line by Sony)
Resolution	14 MP	12 MP
Lines	3288	3036
Readout time	~ 31 µs	~ 10 µs
Maximum delay 1st – last line	~ 100 ms	~ 30 ms

Tab. 1: Comparison of two rolling shutter sensors

With this reduction – by roughly a factor of 3– a few applications that were previously reserved for global shutters are now also feasible for rolling shutter sensors. Here it is important to check to what degree the movement in the image – whether from the camera or object – is reflected as a distortion on the sensor.

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. With a fast sensor that has a frame rate of no more than 60 frames per second, the effect tends to be lower than with a slow sensor that has, for example, a maximum of 15 frames per second.

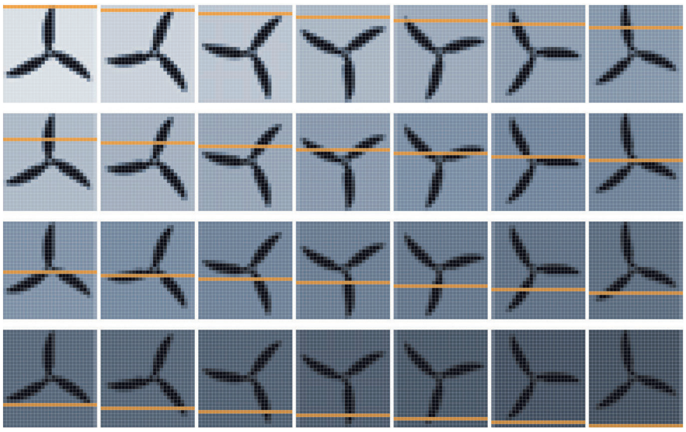

Fig. 5: The yellow line shows the course of the exposure from the first image row to the last. During exposure, then propeller turns four times in total.

However, a direct conclusion of frame rate on distortion cannot be drawn. The decisive factor is actually the readout speed of the individual lines, since this defines the delay from line to line:

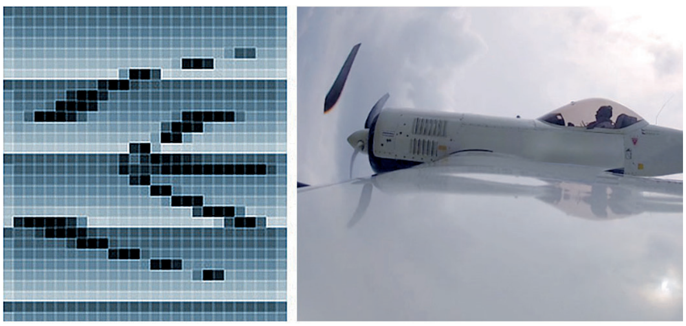

Fig. 6: During the recomposition of the exposed rows into a overall image, the distortion caused by the continuous motion of the propeller is visible due to the line-by-line exposure.

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 various speeds. The slower they move, the smaller the likelihood and extent of a rolling shutter effect. The interaction of the readout rate and exposure time determines what is slow enough versus what is too fast to be recorded correctly.

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

Fig. 7: 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 they must be accounted for when evaluating the images.

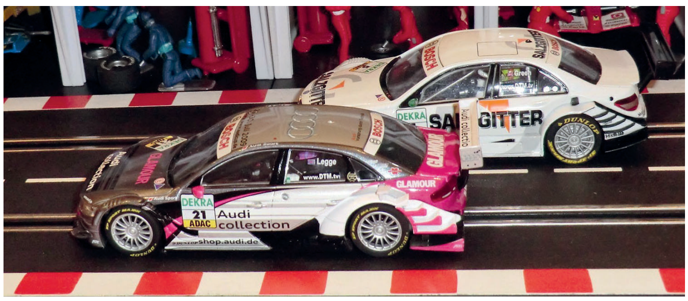

Fig. 8: Global shutter at standard resolution

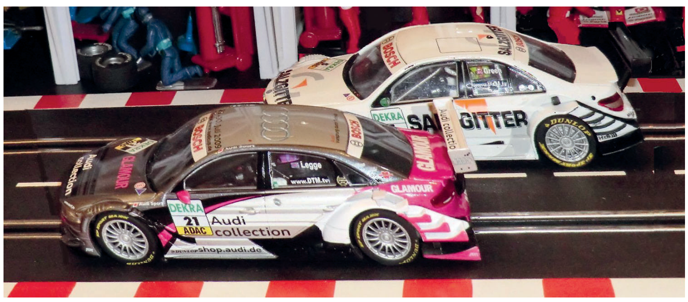

Fig. 9: Rolling shutter at standard resolution

5. Motion Blur

The rolling shutter effect should not be confused with a motion blur. Motion blur is created if the exposure time for moving objects is too long. If a scene is exposed with a long exposure time such as 500 ms, for example, this will blur subjects that move more than one pixel value during this time.

For a hypothetical sensor with 1000 lines, a read-out time of 50µs and an exposure time of 1000µs, it takes 50950µs until the last line is fully exposed. This means that in addition to the rolling shutter effect, a larger amount of motion blur also covers the image diagonally, even if not in the individual lines.

But this effect also occurs with global shutter sensors and therefore should not affect the decision for or against a particular shutter technology. Only the minimum exposure time might play a role for high-speed applications. However, sensors with rolling shutters as well as global shutters are available which can be exposed for an extremely short time (up to a few microseconds).

6. 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.

In industrial image processing, there is now also a trend towards higher resolutions; sensors with 2 to 5 MP have become the standard and even higher resolutions of more than 5 MP are used more frequently. The sensor manufacturers recognized this customer demand and implemented it with high-quality CMOS sensors with excellent image properties for rolling shutters (back-illuminated) as well as global shutter technologies.

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

7. 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: A flash has very limited applications for outside areas; its use and the associated effort will only be worthwhile for interior applications in a dark room or with low ambient and scattered light.

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.

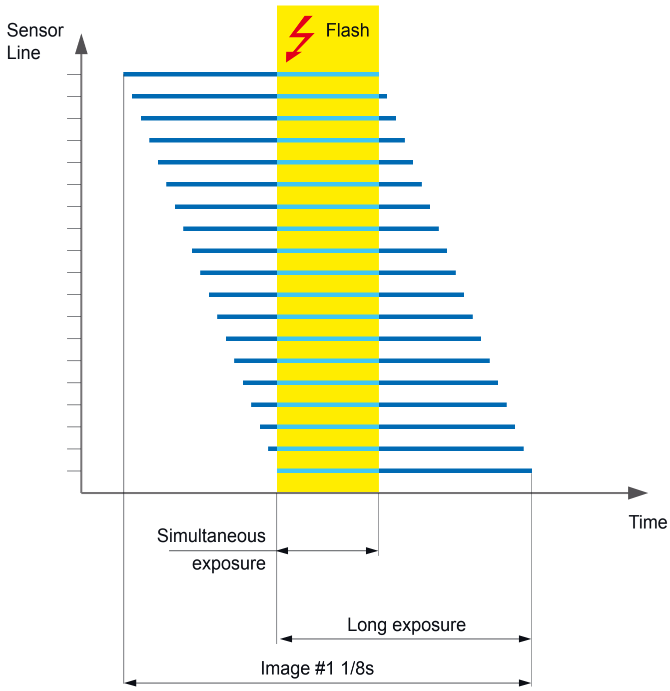

Fig. 10: Compensation for the rolling shutter effect through timely use of flash. The flash must start at exactly the moment when the exposure of the last row commences and cease at the moment when the exposure of the first row closes.

Increasing the exposure time is another way to prevent distortions.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 correspondingly 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 images 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.

8. Summary

The market for industrial image processing is also becoming increasingly interesting for sensor manufacturers. In recent years, CMOS technology in particular has advanced significantly due to massive technical improvements and has surpassed CCD sensors step by step in their historical domain of image quality. The traditional problem areas of CMOS sensors, such as limited long-term exposure, short product lifecycles and the non-existent global shutters have entirely disappeared by now, which makes them the preferred choice for nearly all applications.

Mass production for the high-end consumer market, where CMOS sensors with rolling shutters are installed as a standard in smartphones, for example, is continuously driving technical innovations forward. A good example of this is the improved image quality of rolling shutter sensors coupled with increased readout speed. Since this reduces the rolling shutter effect, the sensors are also becoming more interesting for applications which were previously reserved for global shutter CCD cameras.

As far as the technological progress is concerned, the end of this line has not yet been reached.

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Dominik Lappenküper is responsible for Basler's ace, Basler beat and racer cameras series, and oversees market launches for new camera models. He is also the first point of contact when new features are rolled out for these camera families. He is additionally responsible for liaising with the market to better understand its needs.

Dominik started at Basler in 2011 as part of a work/study program in industrial engineering, and successfully earned his Bachelor of Engineering. He has since completed a Master of Science at the Polytechnical University of Wedel alongside his work at Basler.

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