White paper about specifics using CMOS sensors with rolling shutter

Rolling in the deep

Many CMOS sensors only offer a rolling shutter. There are pros and cons concerning the issue rolling shutter which you have to keep in mind. This white paper will examine this topic.

Some CMOS sensors which are used by our industrial cameras are working only with rolling shutter. This means that the exposure of the single image lines starts and ends at different times (see Figure 1).

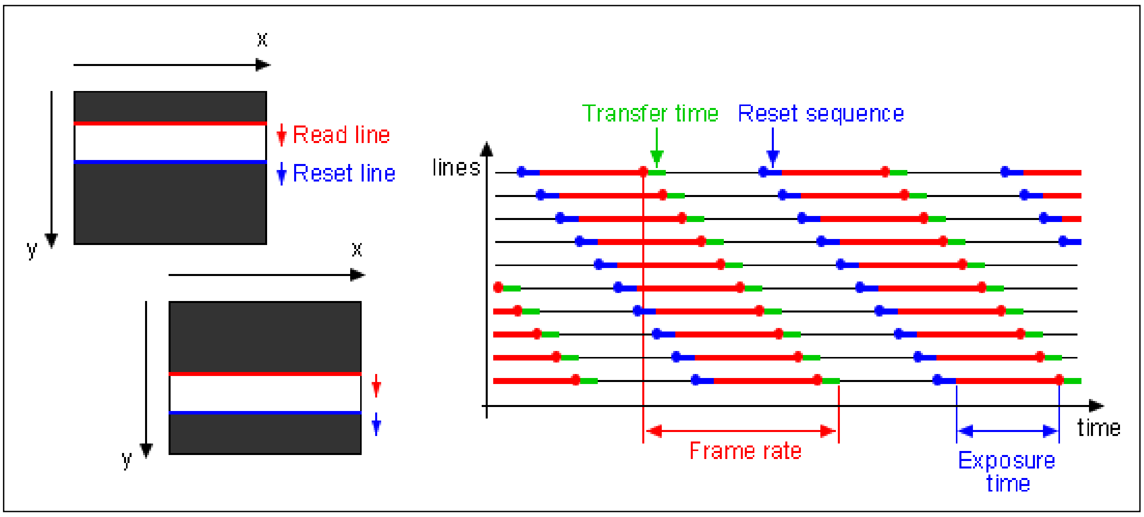

Figure 1: Exposure of every line starts and ends at different times

Figure 1 has two sections. The left side shows two states of a sensor with a line block, which shifts over the sensor. The white area represents the light sensitive area. This area shifts line-by-line top down the image. For example if you set the exposure time to 100 lines, this area will have a height of 100 lines. When the integration window shifts to the next line, the line first has to be reset ("Reset line"; blue in Figure 1). At the top of the area the line will be read out, after it was exposured for 100 lines ("Read line"; red in Figure 1).

Every line is opened according to the integration time, however, the exposure happens time-shifted. The right side of Figure 1 tries to clarify this with the help of a lines/time diagram. Line by line the start of the exposure ("Exposure time") shifts, i. e. rightwards in the diagram. Furthermore the right side of Figure 1 clarifies the phases of the image acquisition with a rolling shutter. Every line performs a reset sequence, a exposure process ("Exposure time") and a transfer process ("Transfer time"). The start of the transfer process of the first line and the end of the transfer process of the last line defines the frame rate. In short:

$$frame_{rate} = \frac{1}{transfer_{time} * image_{height}}$$

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If the exposure time longer than the transfer process, in the formula you have to replace the transfer time by the exposure time.

Exposure effects during horizontal movement

During an exposure if an object is moving horizontally you will receive a shifted image. Figure 2 shows how the object moves from left to right. During the line-by-line delayed acquisition the rolling shutter of the sensor, which has only three lines for clarification, notices only parts of the object at other positions. The composed acquisition in the example displays the image shift. Additionally the movement of the object causes small blur effects.

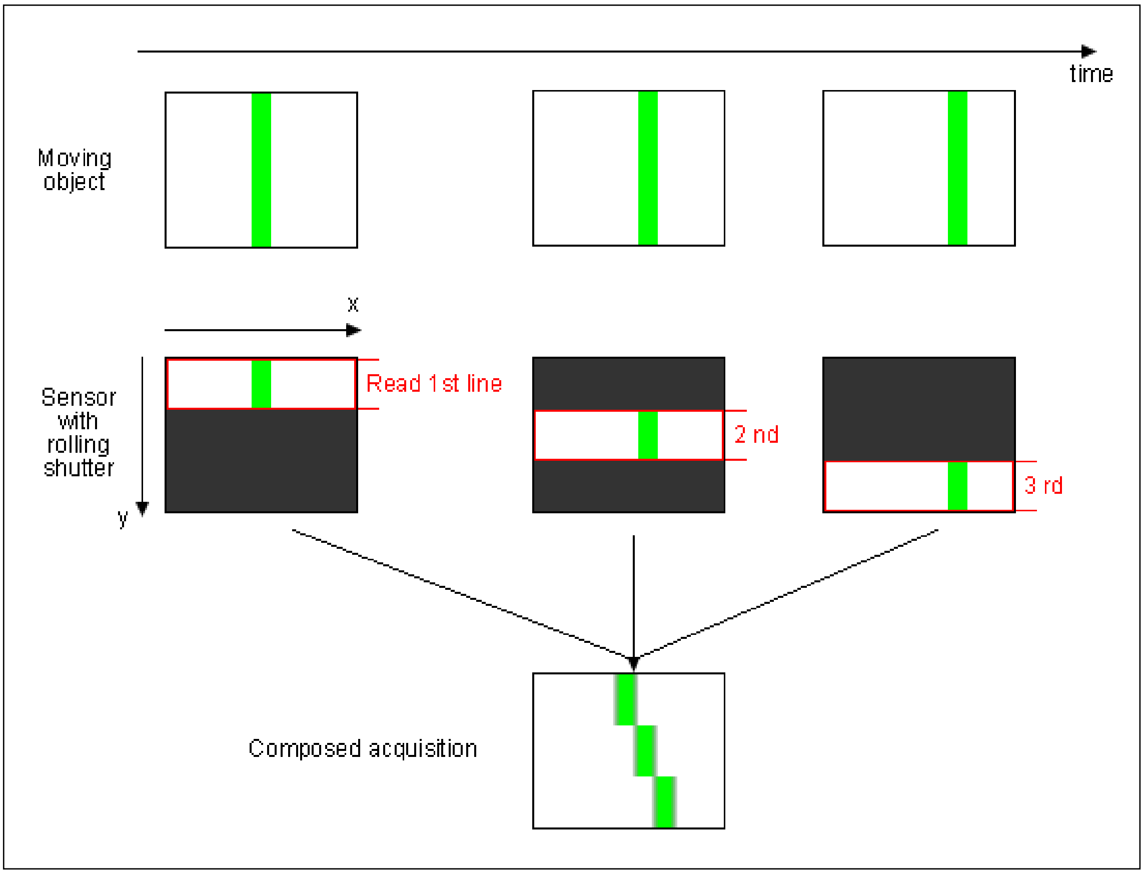

Figure 2: Shifted image during horizontal object movement

Looking at the line-by-line movement of the object, it is exciting, how short the covered distance of the object is. For example: If we have a rolling shutter sensor with the height of 480 pixels and a frame rate of 30Hz (30 images per second) an object with the speed of 10 meters per second (36 km/h) will cover a distance of 0.694 millimeters during every line change.

14400 lines are read out every second:

$$read_{lines} = 30Hz * 480lines = 14400\frac{lines}{s}$$

The outcome of this is, every 0.0000694 seconds a line change happens:

$$line_{change} = \frac{1}{14400} = 0.0000694\,s$$

If the object has a speed of 10 m/s, it covers a distance of 0.694mm during every line change:

$$s = v * t$$

$$s = 10\frac{m}{s} * 0.0000694s$$

$$s = 0.000694m = 0.694mm$$

For this reason a rolling shutter sensor is suited for movement analyses with high frame rates.

Exposure effects during vertical movement

During an exposure if an object is moving vertically you will receive a compression or dilation. This depends on the direction of the movement. In Figure 3 an object moves vertically in opposition to the exposure direction of the sensor, which has only three lines for clarification. The example shows that the object is compressed. The image of the composed acquisition verifies this.

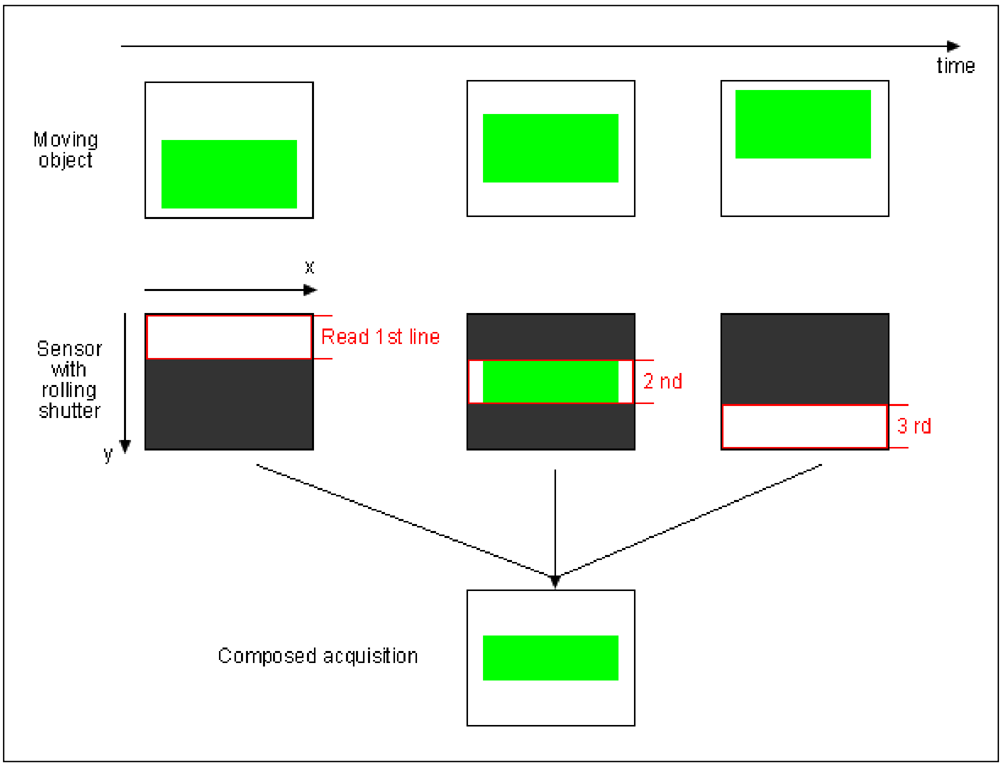

Figure 3: Compression during vertical object movement

The rolling shutter effect can be used in own interest. The line-by-line integration reduces the blur of a fast moving object. Consequently the integration time can be doubled.

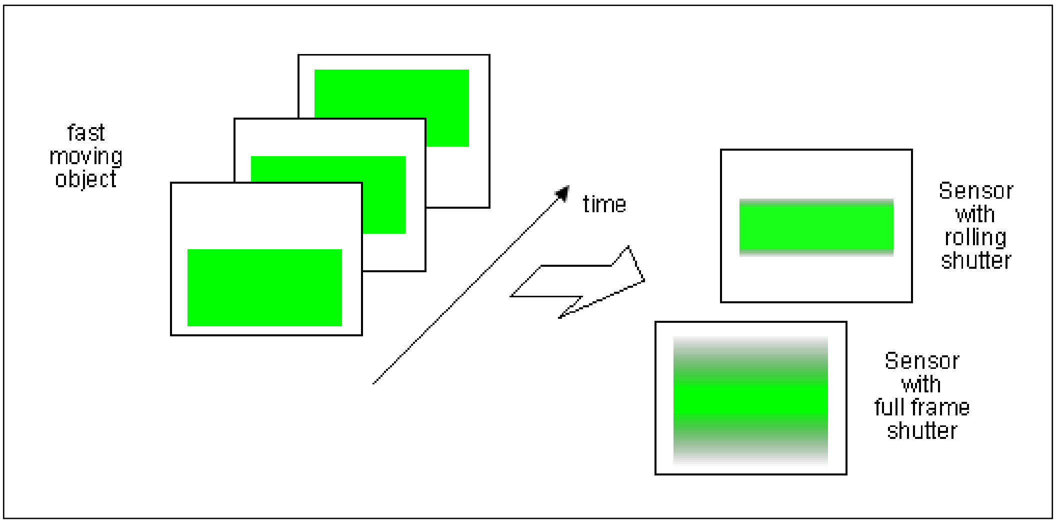

Figure 4: Reduced blur with rolling shutter

Flash control on CMOS sensors with rolling shutter

Flash control on CMOS sensors with rolling shutter is limited. The exposure time has to be long enough to flash all lines at the same time (see Figure 4 “All row integration”). The flash moment has to be in the area of “All row integration” and the flash time may not be longer than “All row integration”.

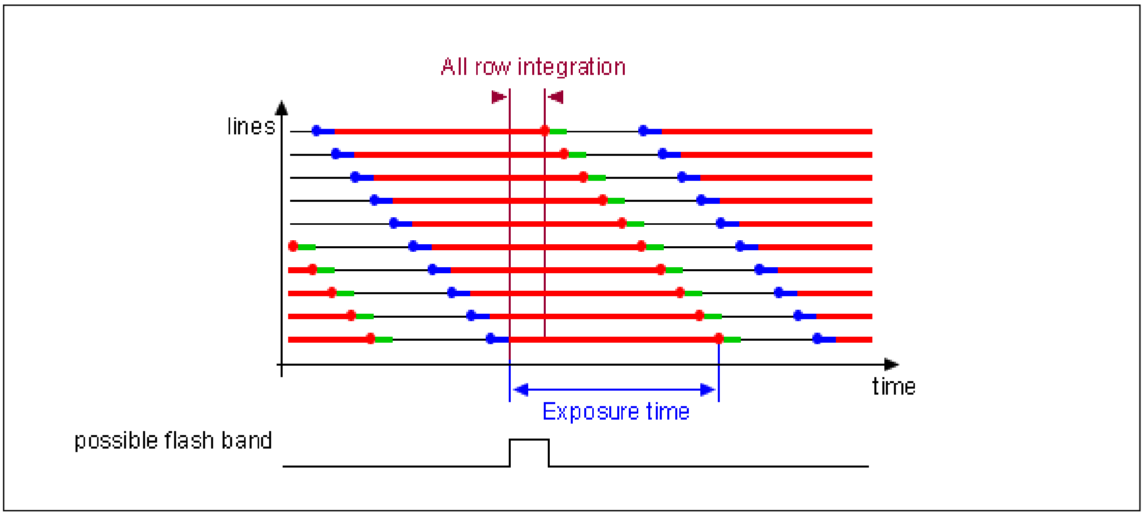

Figure 5: Possible flash window

In this modus operandi you have to mind, that there is no extraneous light during the exposure of the lines („Exposure time“).