

Programmable Scan Mode

Introduction

Programmable Scan Mode provides increased control over the rolling shutter exposure and read-out functionality of CMOS sensors. The rolling shutter read-out behavior is a common implementation on CMOS sensors, and Programmable Scan Mode provides access to the sensor timing settings to allow optimization around imaging requirements.

Rolling shutter readout implementations digitize pixel intensities one row at a time. A “reset” signal starts at the first row of the sensor and resets or clears the row of pixels of any collected signal, effectively starting the exposure. This reset signal sweeps downwards towards the last row, propagating at a rate defined as line-time: the amount of time it takes to activate each row of pixels.

The reset signal is followed by a “readout” signal which causes the amount of light captured by each row of pixels to be digitized and read out of the sensor. The readout signal signifies the end of the exposure or light capture. The time between the reset and readout signals is defined as the exposure time, the amount of time each pixel is in the light collection phase.

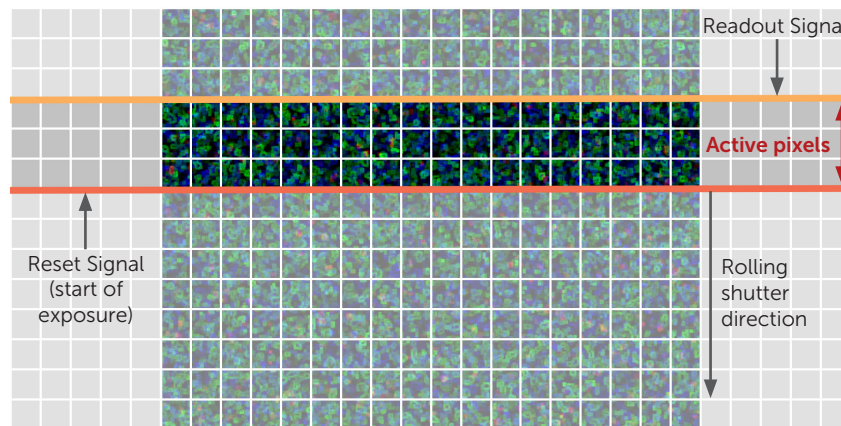


Figure 1: The highlighted region of the sensor between the reset signal and readout signal is the only area collecting light. As the rolling shutter proceeds down the sensor, the highlighted region sweeps from the top to the bottom. This can be synchronized to the sweep of an illumination laser for scanning light sheet microscopy.

The readout signal always follows the reset signal by a delay equal to the exposure time. This exposure time is always a multiple of the line-time of the sensor. If the exposure time is set to be equal to 10 line-times, the readout signal is behind the reset signal by 10 rows.

Increasing the Line-Time

Modifying and increasing the line-time of a sensor gives greater flexibility to control the number of rows between the reset and readout signals and the exposure time, allowing for both an optimized experimental setup and adequate signal levels.

Controlling the line-time makes synchronization between the illumination and acquisition simpler as well, providing control over the rate at which the exposing rows propagate down the sensor.

Programmable Scan Mode does not change the line-time of the sensor but provides the ability to add delays to the reset and readout signals. The addition of these delays delivers the same effect as if the line-time of the sensor has been increased (Figure 2).

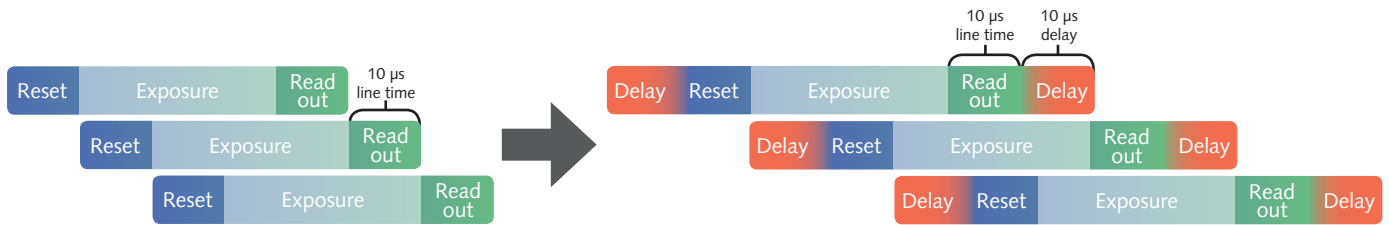


Figure 2: Delays added to the reset and readout signals allow the line-time of the sensor to be increased. In this case, the line time is doubled by adding an extra 10 µs delay to the readout signal.

Modes

Programmable Scan Mode provides access to three modes:

1. Auto

When Programmable Scan Mode is set to Auto, the line-time is set to 1 line. This provides the highest framerates and minimal control over the ability to set the width between the reset and readout signals. There is no delay added after the line time. This is the default mode and represents normal sensor operation.

2. Line Delay

When Programmable Scan Mode is set to Line Delay, a delay can be added after the line-time, slowing the propagation of the reset and readout signals. This causes the effective line time of the sensor to be increased. This delay is added onto the default line time in increments equal to the line-time.

$$\text{Scan Line Time} = \text{Line Time}_{\text{Sensor}} + (\text{Line Time}_{\text{Sensor}} \times \text{Scan Line Delay})$$

A value of 1 adds a delay equal to 1 line-time. This results in an effective line-time equal to double the value of line time.

$$\text{Line Time}_{\text{Sensor}} = 10\mu\text{s}$$

$$\text{Scan Line Delay} = 1$$

$$\text{Delay} = 10\mu\text{s} \times 1 = 10\mu\text{s}$$

$$\text{Scan Line Time} = 10\mu\text{s} + 10\mu\text{s} = 20\mu\text{s}$$

A value of 10 adds a delay of 10 line-times which results in an effective line-time equal to 11 times longer than the default line-time.

$$\text{Line Time}_{\text{Sensor}} = 10\mu\text{s}$$

$$\text{Scan Line Delay} = 10$$

$$\text{Delay} = 10\mu\text{s} \times 10 = 100\mu\text{s}$$

$$\text{Scan Line Time} = 100\mu\text{s} + 10\mu\text{s} = 110\mu\text{s}$$

The frame rate when imaging in this mode is determined by the number of rows being imaged and the Effective Line Time.

$$\text{Readout Time}_{\text{Image}} = \text{Scan Line Time} \times N_{\text{Rows}}$$

$$\text{Frame Rate} = \frac{1}{\text{Readout Time}_{\text{Image}} + \text{Exposure Time}}$$

The minimum line delay value is 1. This is also the default value when Line Delay mode is selected.

When in Line Delay mode, Scan Width, the number of rows between the reset and readout signals will be calculated automatically.

$$\text{Scan Width}_{(\text{Lines})} = \frac{\text{Exposure Time}_{(\text{Lines})}}{\text{Scan Line Delay}}$$

A Scan Width parameter is available and reports the number of rows between the reset and readout signals.

3. Scan Width

When Programmable Scan Mode is set to Scan Width, the number of rows between the reset and readout signal can be set. It gives direct control to set the size of the imaging region.

Scan Width = Number of Rows between Reset and Readout

When the Scan Width is set, the effective line time required is automatically calculated.

$$\text{Scan Line Delay} = \frac{\text{Exposure Time}_{(\text{Lines})}}{\text{Scan Width}_{(\text{Lines})}}$$

$$\text{Scan Line Time} = \text{Line Time}_{\text{Sensor}} + (\text{Line Time}_{\text{Sensor}} \times \text{Scan Line Delay})$$

The Effective Line Time is reported as the Scan Line Time parameter in nanoseconds.

Scan Line Delay is the line delay value that can be changed to increase or decrease the delay between reset and the readout. This parameter can be changed only when in Line Delay Scan Mode. When the scan mode is set to Scan Width, this parameter becomes Read-only and automatically calculates the number of line delays based on the settings for the Scan Width and exposure time.

The three scan modes can be selected in the Device Property Browser dialog box of Micro-Manager as shown in Figure 3.

Camera-1-ScanDirection	Down
Camera-1-ScanDirectionReset	Yes
Camera-1-ScanLineDelay	1 < >
Camera-1-ScanLineTime	10,260,000
Camera-1-ScanMode	Auto
Camera-1-ScanWidth	Auto
Camera-1-SerialNumber	Line Delay
Camera-1-ShutterCloseDelay	Scan Width

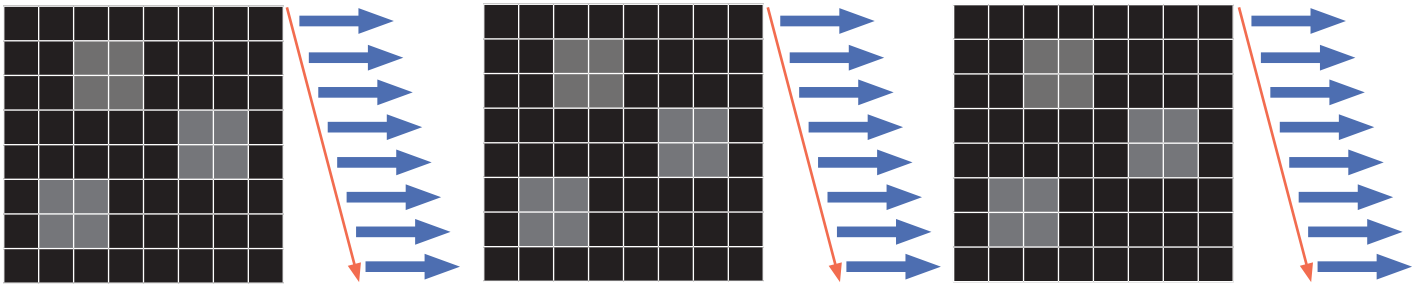
Figure 3: Scan Mode selection as displayed in Micro-Manager

Scan Directions

To help with integrating CMOS cameras into imaging systems, Programmable Scan Mode also provides control over the direction of readout for the rolling shutter. Programmable Scan Mode provides three options to select from.

1. Down

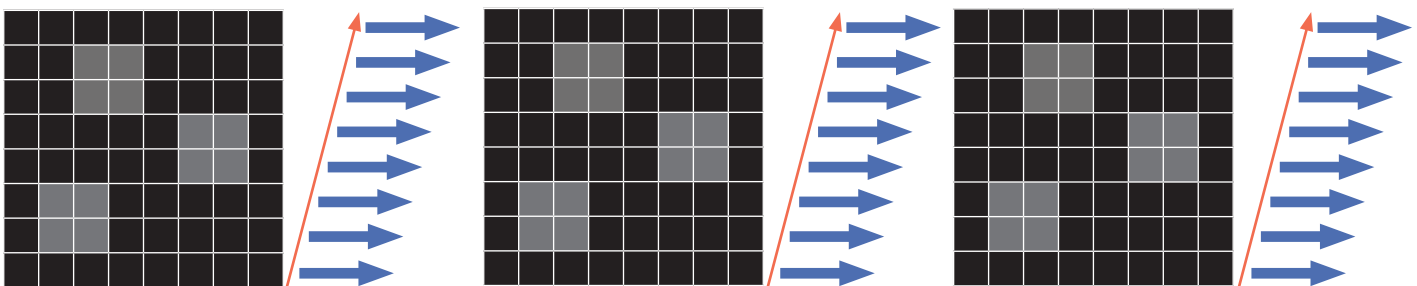
A scan direction of Down is the default readout direction for all CMOS cameras. The rolling shutter starts at the topmost row of the sensor and propagates downwards towards the bottommost row.



Each subsequent frame acquisition restarts at the topmost row.

2. Up

A scan direction of Up inverts the direction of read out. The rolling shutter starts at the bottommost row and propagates upwards towards the topmost row.

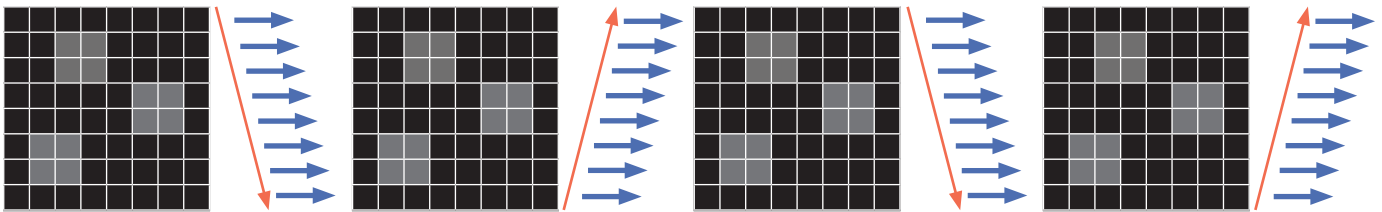


Each subsequent frame acquisition restarts at the bottommost row.

The image orientation when acquired in this mode will not be inverted and will be consistent with the Down scan direction.

3. Down-Up Alternate

A scan direction of Down-Up alternates the direction of acquisition. The rolling shutter starts at the topmost row and propagates downwards towards the bottommost row. For the next frame, the rolling shutter will begin at the bottommost row and propagate upwards towards the topmost row. The acquisition will continue to alternate the readout direction between frames.



The image orientation when acquired in this mode will have no inverted frames and will be consistent with the Down scan direction.

The three scan directions can be selected in the Device Property Browser dialog box of Micro-Manager as shown in Figure 4.

Camera-1-ScanDirection	Down
Camera-1-ScanDirectionReset	Down
Camera-1-ScanLineDelay	Down/Up Alternate
Camera-1-ScanLineTime	Up
Camera-1-ScanMode	Auto
Camera-1-ScanWidth	1

Figure 4: Scan Direction selection as displayed in Micro-Manager

A Scan Direction Reset parameter is also available (Figure 5). The default setting for this parameter is Yes. This ensures that the first frame of each new acquisition sequence will start at the topmost row and propagate downwards.

When the Scan Direction Reset parameter is set to False, the first frame for each new acquisition will start at the location of the last frame in the previous sequence. If the last frame ended at the bottommost row, the first frame of the subsequent acquisition will begin at the bottommost row and propagate upwards.

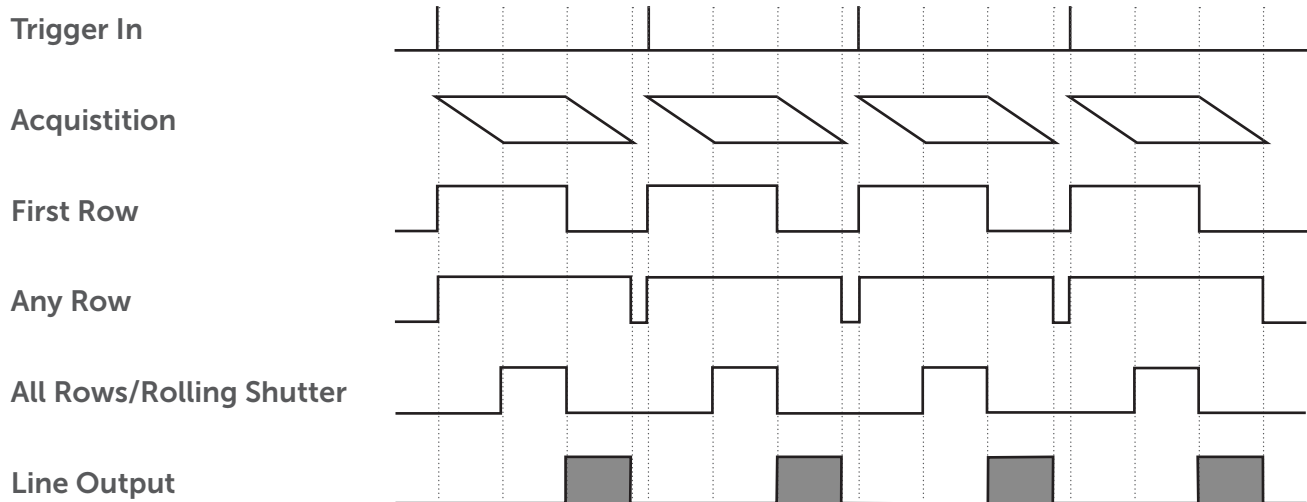
Camera-1-ScanDirection	Down
Camera-1-ScanDirectionReset	Yes
Camera-1-ScanLineDelay	1
Camera-1-ScanLineTime	10,260,000
Camera-1-ScanMode	Auto
Camera-1-ScanWidth	1

Figure 5: Scan Direction Reset selection as displayed in Micro-Manager

Expose-Out Modes

A Line Output expose out mode has been added as an option. This expose out mode provides a rising edge for each row the reset signal propagates past. This provides a hardware signal that indicates the progress as the acquisition moves across the sensor.

The triggering and expose out mode behavior is shown in the diagram below:



References

Optics Express, Vol. 20, Issue 19, pp. 21805 – 21814, 2012.

Appendix I

Camera	Interface	Mode	Line Time
Iris 15	PCI-Express	16-bit HDR	10.26 μsec
Iris 9	PCI-Express	16-bit HDR	10.26 μsec
Prime BSI	PCI-Express, USB 3.0	16-bit HDR, 12-bit CMS	11.28 μsec

