Application Note

The FIR Filter

Rev 1.0

AT - Automation Technology GmbH

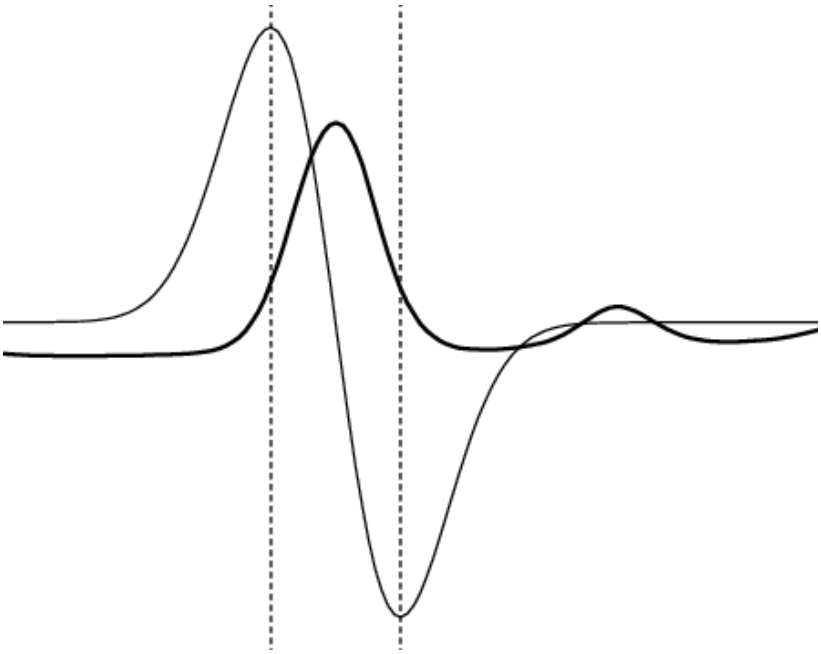


Table of Contents

Introduction

The FIR filter is a new implementation for the CX camera series enabling the application of a digital Finite Impulse Response filter (FIR) to the sensor image in order to precisely detect the laser line position.

The FIR can act as a differentiating or smoothing filter.

In 3D mode the FIR filter implementation is available as a stand-alone algorithm called FIR Peak. The FIR Peak algorithm analyses the intensity distribution by a mathematical derivation and by means of a zero-crossing detection (ZCD) precisely determines the position of laser line in the sensor image.

The FIR filter can be also used in combination with the other algorithms (TRSH, MAX, COG) as a pre-processor for smoothing the sensor image.

The following sections of this application note describe the implementation and configuration of the FIR filter over the GenICam interface of the camera as well as the Wizards of CX-Explorer.

How the FIR filter works

The FIR is a digital filter with up to nine coefficients (taps). These coefficients are selectable via a GenICam enumeration node, which provides pre-defined filter designs (templates). Each filter design differs from each other with respect to the number of coefficients and the value for each coefficient. For instance the template AV5 is an average filter with 5 coefficients, whereas the AV9 is an average filter using 9 coefficients.

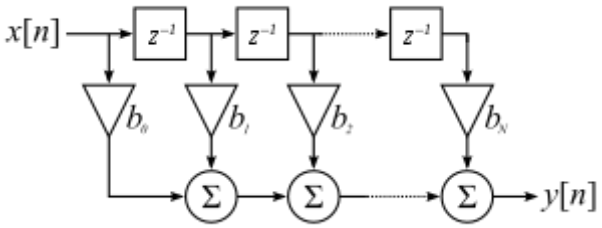


Figure 1: FIR filter with N+1 taps

Depending on the taps value, the filter operates in two different modes. For the FIR Peak algorithm the filter design is a derivative filter. For the COG, TRSH and MAX algorithm the FIR acts as a smoothing filter.

Following FIR templates are pre-defined for these two modes:

FIR Coefficients	FIR Mode	Availability
SG5	Derivative	FIR Peak, Image Mode
SG7	Derivative	FIR Peak, Image Mode
SG9	Derivative	FIR Peak, Image Mode
AV5	Derivative	*not available*
AV7	Derivative	*not available*
AV9	Derivative	*not available*
SG5	Smoothing	COG, TRSH, MAX, Image Mode
SG7	Smoothing	COG, TRSH, MAX, Image Mode
SG9	Smoothing	COG, TRSH, MAX, Image Mode
AV5	Smoothing	COG, TRSH, MAX, Image Mode
AV7	Smoothing	COG, TRSH, MAX, Image Mode
AV9	Smoothing	COG, TRSH, MAX, Image Mode

Table 1: Available FIR Coefficients

The following picture shows a typical laser line image and a line plot with the intensity distribution along an image column.

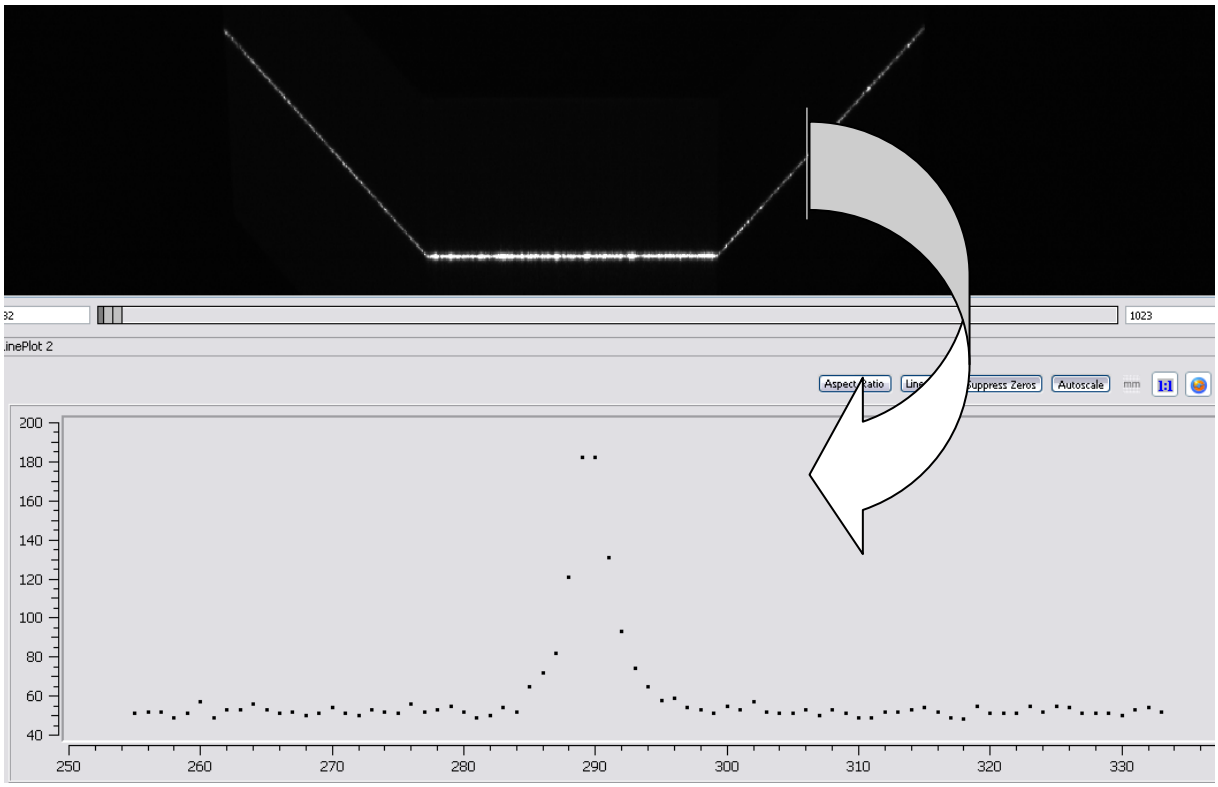


Figure 2: Laser line intensity distribution along a column with FIR= Off

The peak position of the laser line can be detected by different algorithms, like MAX, TRSH, COG and FIR Peak.

First Derivative Mode of FIR Filter

The FIR filter can be activated by following GenICam nodes.

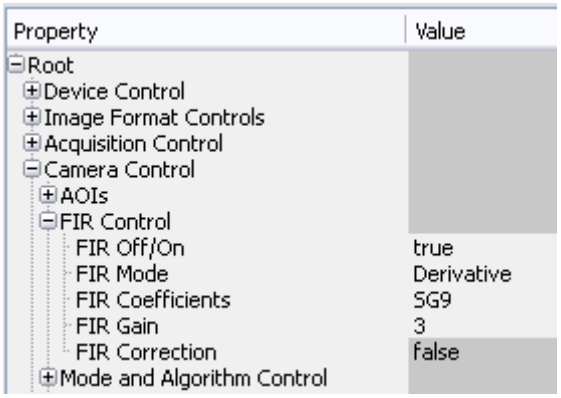


Figure 3: XML view with enabled FIR and FIR Mode=Derivative

When the camera is configured to Image Mode, setting the FIR Mode to *Derivative*, enables the camera to output the first derivative of the image intensity. This mode can be used to validate the quality of the laser line.

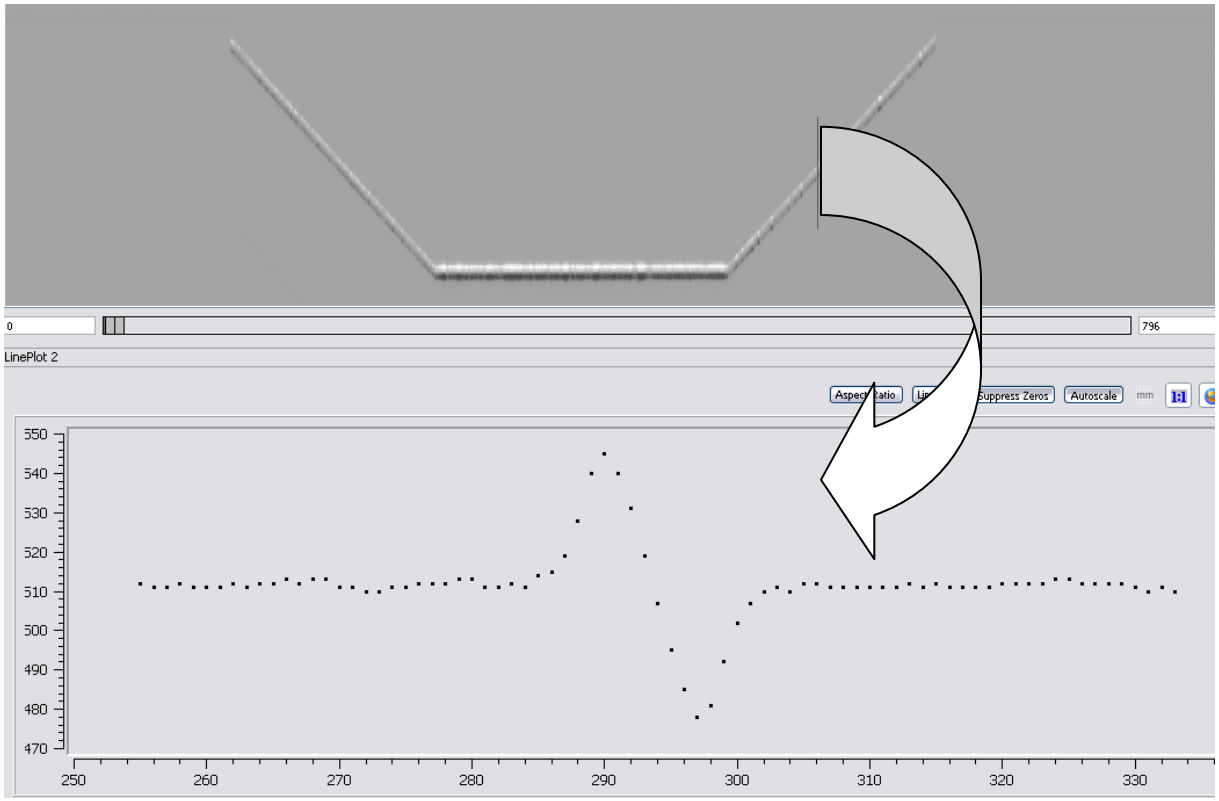


Figure 4: Distribution of first derivative of intensity with FIR=ON, FIR Mode=Derivative, FIR Coefficients=SG9, FIR Gain=3

Smoothing Mode of FIR Filter

The FIR can be also used as a smoothing filter, by setting the FIR mode to "*Smoothing*".

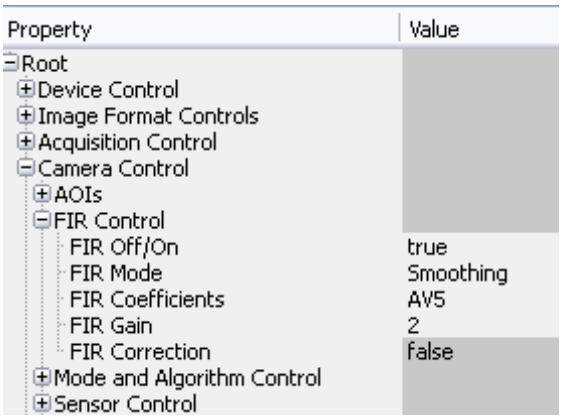


Figure 5: XML view with enabled FIR and FIR Mode=Derivative

The following figure shows the intensity distribution for one column with activated Smoothing filter.

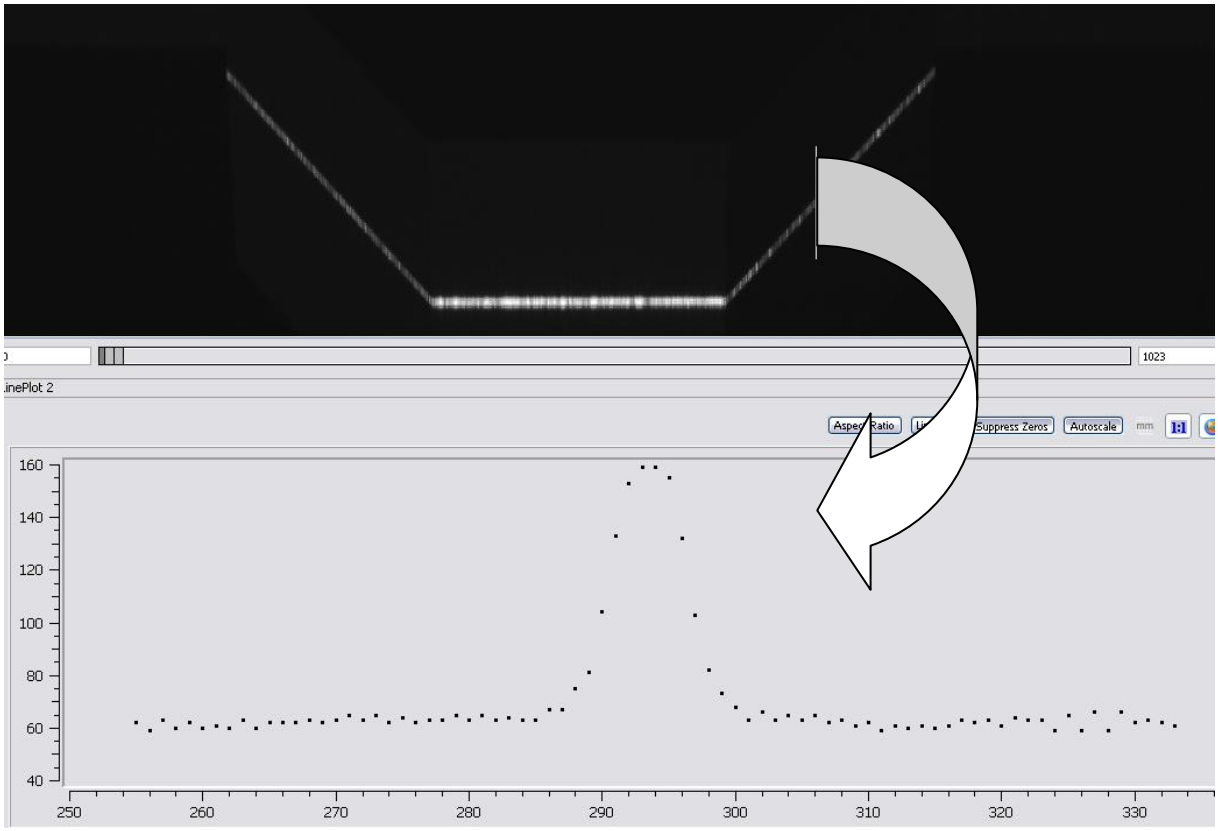


Figure 6: Smoothed intensity distribution with FIR=On, FIR Mode=Smoothing, FIR Coefficients=AV5, FIR Gain=2

This mode is useful in cases in which the normal intensity distribution is noisy and it is recommended to be used in combination with 3D algorithms MAX, TRSH and COG. The latter delivers the highest accuracy, when it is applied to a smoothed Gaussian distribution.

In this case the FIR mode is locked to *Smoothing*, due to the fact that these algorithms are applied to the intensity of the laser line (no differentiation is required).

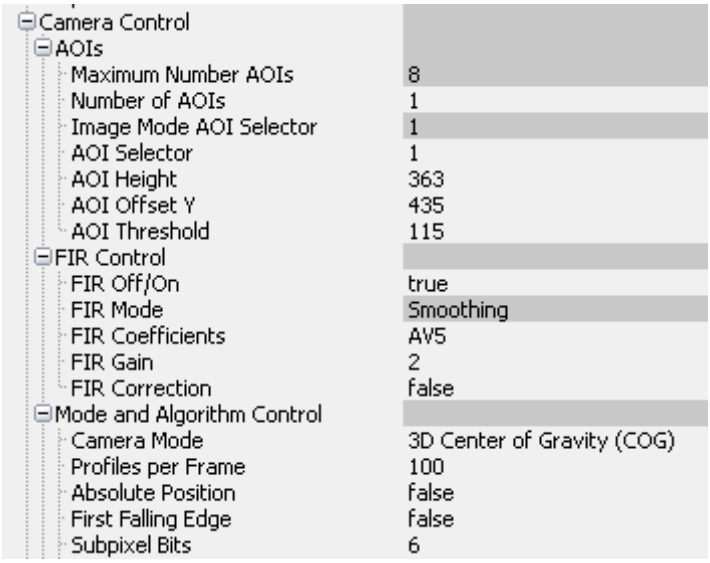
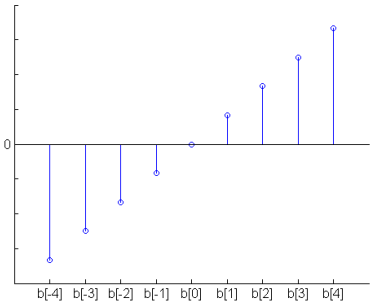


Figure7: XML view for the COG mode with Smoothing

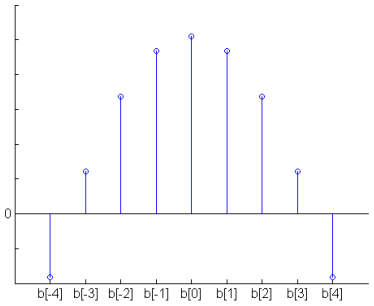
Furthermore, the AOI Threshold is applied to the *smoothed* intensity distribution. The valid range is from 0 to 1023 (Pixel Format = Mono16).

FIR Filter Coefficients

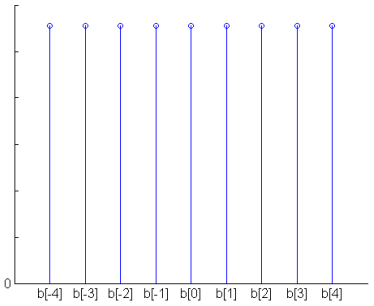
The most important part for designing a digital filter is the parameterization of the taps. Depending on the values for each coefficient the behavior may completely change. For this sensitive part the FIR implementation includes pre-defined templates for the smoothing and derivation tasks. The figure below shows three different filter designs. All supported filter coefficients are explicitly listed in *Table 1* and section *Desciption of FIR parameters in the GenICam interface*.



SG9, 9 taps, Derivation



SG9, 9 taps, Smoothing



AV9, 9 taps, Smoothing

FIR Filter Gain

The FIR Gain is a digital amplifier to increase the amplitude of the filtered output image. The valid range is from min=1 to max=10. This range is the same for all FIR modes and coefficients. Depending on the filter mode and filter coefficients, a gain greater than 5 may lead to a filter overflow and thus the output becomes zero. In this case the gain must be reduced to get good output values.

FIR Filter Correction

FIR filter of order N consists of N+1 taps and N delays (see Figure 1). The group delay for the FIR filter implementation with a maximum of 9 taps is a constant shift of 4 pixels in the position value. The FIR Filter correction compensates the shift of the position value. With enabled correction the position values for the FIR Peak are the same as without using the FIR and by choosing one of the traditional algorithms, such as COG, TRSH, MAX. This has the advantage to compare the results and accuracy between these algorithms.

The 3D FIR Peak algorithm

The 3D FIR Peak algorithm can be activated over the GenICam node *CameraMode*. The following GenICam nodes have been modified to support the FIR Peak mode.

<table>
<tr><th>Name</th><th>Type</th><th>Visibility</th><th>Description</th></tr>
<tr><td>CameraMode</td><td>IEnumeration</td><td>Beginner</td><td>Selects the camera mode and/or the algorithm

<table><tr><th>Symbolic</th><th>Value</th></tr><tr><td>Image</td><td>0</td></tr><tr><td>Threshold</td><td>1</td></tr><tr><td>MaximumIntensity</td><td>2</td></tr><tr><td>CenterOfGravity</td><td>3</td></tr><tr><td>FIRPeak</td><td>4</td></tr></table></td></tr>
<tr><td>NumSubPixel</td><td>IInteger</td><td>Beginner</td><td>Number of subpixel bits of COG and FIR-Peak output<table><tr><td>Minimum</td><td>0</td></tr><tr><td>Maximum</td><td>6</td></tr><tr><td>Increment</td><td>1</td></tr></table></td></tr>
</table>

When the 3D FIR Peak Mode is selected the camera detects and outputs the "zero-crossing" (ZCD) of the first derivative of intensity with subpixel accuracy.

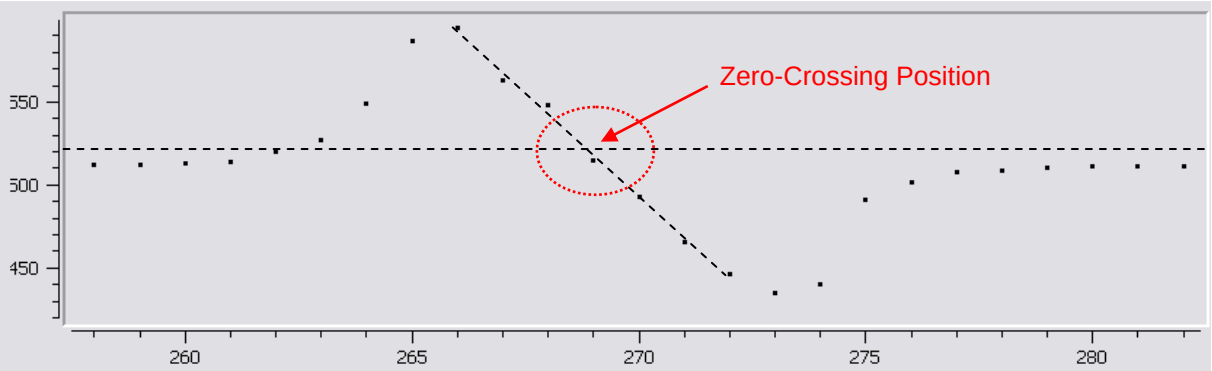


Figure 8: Zero-Crossing Detection (ZCD) of the first derivative of Gaussian intensity distribution

The AOI Threshold refers to derivative values, ranging from 513 to 1023 (Pixel Format = Mono16).

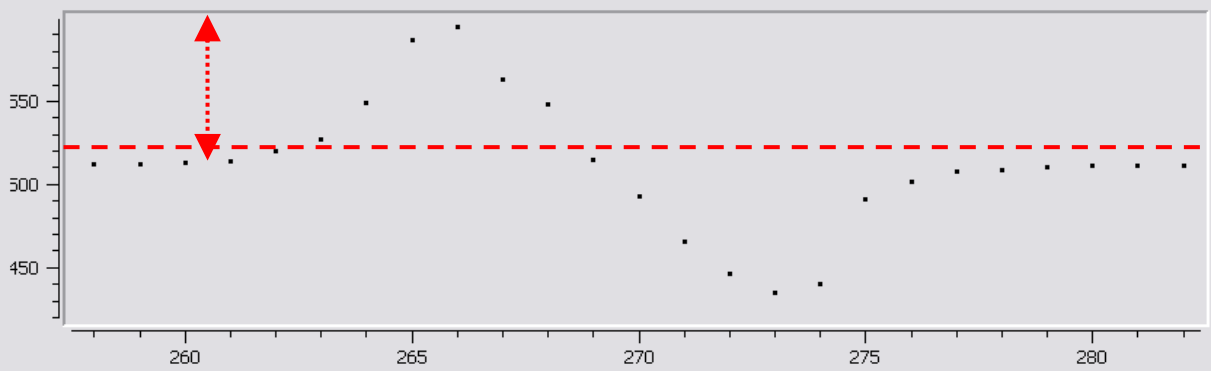


Figure 9: User defined AOI Threshold in Derivative mode. The valid range is from 513 to 1023 (Mono16)

The AOI Threshold is used in the FIR Peak mode to detect the first rising edge of the first derivative of the Gaussian intensity distribution. It acts the same way as with the other algorithms, where the threshold value is used to detect the *Left Edge* (P_L) of the Gaussian distribution (for more details see camera manual section "Camera Algorithms").

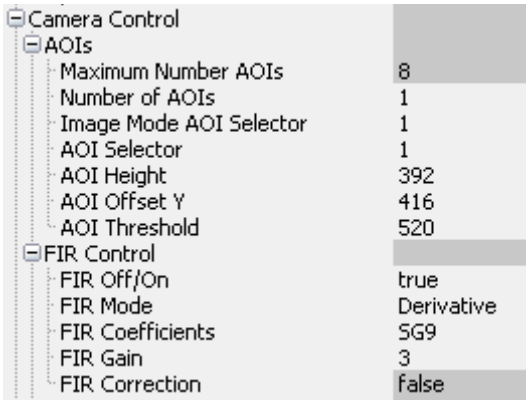


Figure 10: XML view of the GenICam AOIs and FIR categories

The figure below shows a typical configuration in the XML view for the FIR Peak mode.

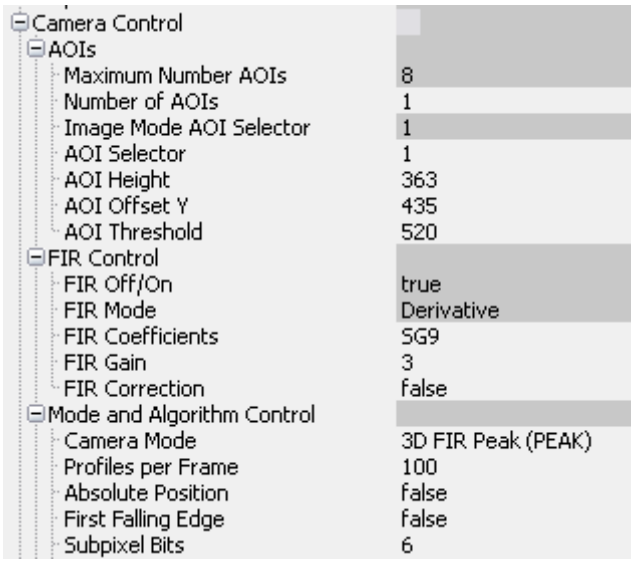


Figure 5: XML view for the FIR Peak mode

As shown above, the FIR Peak mode uses the FIR filter exclusively in *Derivative* mode, This is necessary because the first derivative image is mandatory for the zero-crossing detection (ZCD). The detected zero-crossing is then output over the data channel DC2.

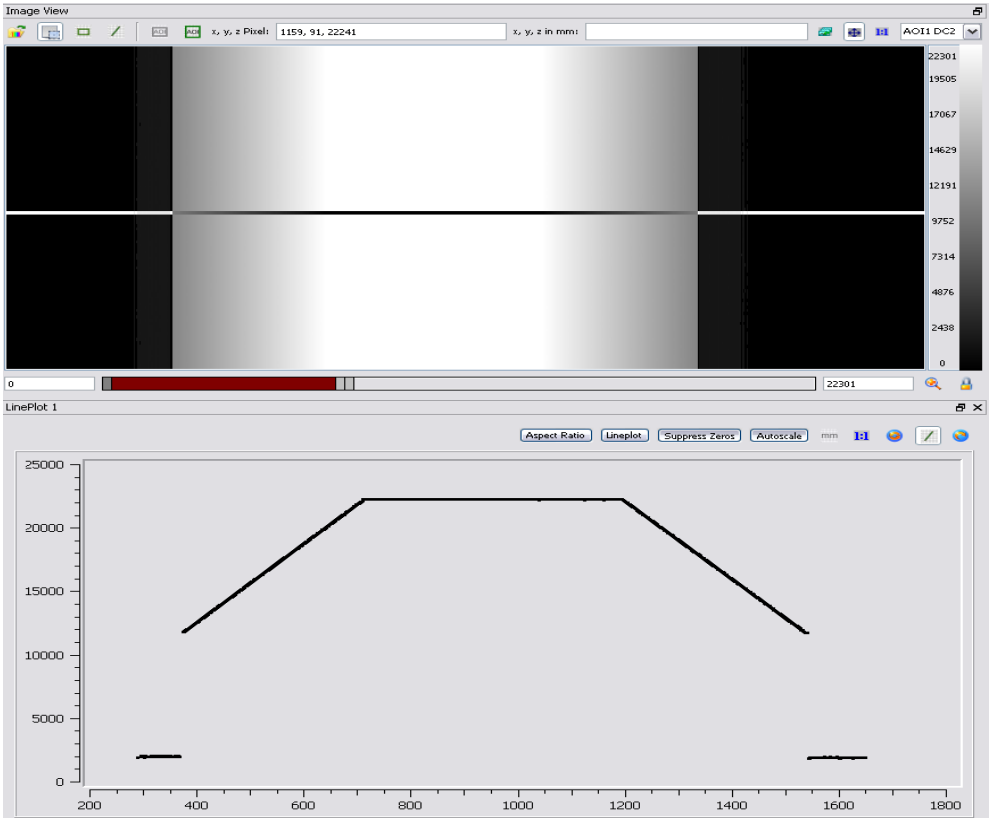


Figure 6: Image View of a 3D range map with additional single profile plot

Description of FIR parameters in the GenICam interface

<table>
<tr><th>Name</th><th>Type</th><th>Visibility</th><th>Description</th></tr>
<tr><td>FIRControl</td><td>ICategory</td><td>Beginner</td><td>Features relating to FIR</td></tr>
<tr><td>FIR</td><td>IBoolean</td><td>Beginner</td><td>Enables the FIR when set to TRUE.
FIR is disabled when set to FALSE</td></tr>
<tr><td>FIRMode</td><td>IEnumeration</td><td>Beginner</td><td>Selection of the FIR Mode

<table><tr><th>Symbolic</th><th>Value</th></tr><tr><td>Smoothing</td><td>0</td></tr><tr><td>Derivative</td><td>1</td></tr></table></td></tr>
<tr><td>FIRCoef</td><td>IEnumeration</td><td>Beginner</td><td>Selection of the FIR Coefficients

<table><tr><th>Symbolic</th><th>Value</th></tr><tr><td>SG5</td><td>0</td></tr><tr><td>SG7</td><td>1</td></tr><tr><td>SG9</td><td>2</td></tr><tr><td>AV5</td><td>3</td></tr><tr><td>AV7</td><td>4</td></tr><tr><td>AV9</td><td>5</td></tr></table>
AV5 - Smoothing mode only
AV7 - Smoothing mode only
AV9 - Smoothing mode only</td></tr>
<tr><td>FIRGain</td><td>IInteger</td><td>Beginner</td><td>FIR Gain

<table><tr><td>Minimum</td><td>1</td></tr><tr><td>Maximum</td><td>10</td></tr><tr><td>Increment</td><td>1</td></tr></table></td></tr>
<tr><td>FIRCorrection</td><td>IBoolean</td><td>Expert</td><td>If TRUE it cancels the effect of filter index mismatch in 3D mode</td></tr>
</table>

The CX-Explorer Wizards for Image and 3D Mode

The Wizards of CX-Explorer for Image and 3D Mode have been extended in order to help configuring easily the FIR parameters.

The FIR functionality is supported by the CX-Explorer version 2.5.0 and higher

Image Wizard

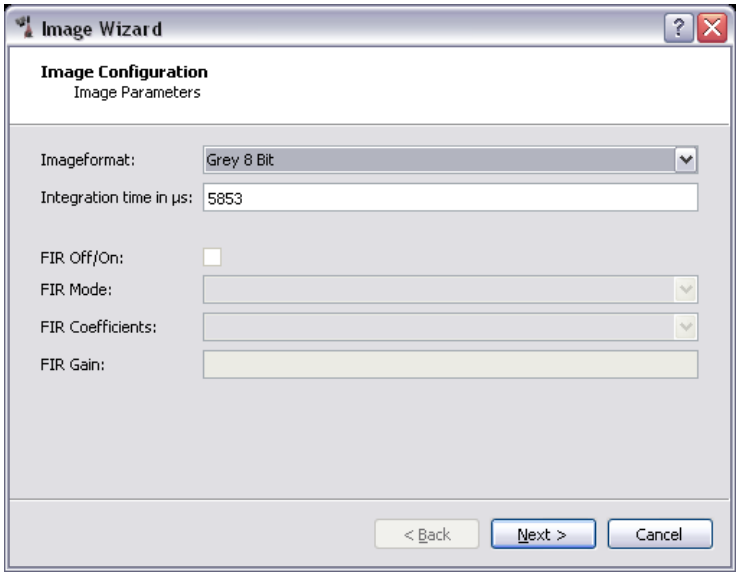


Figure 13 Image Wizard without use of FIR filter

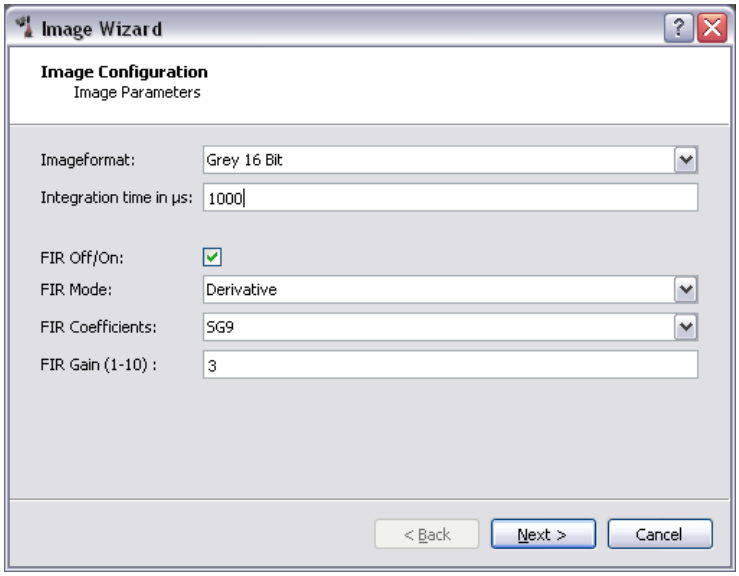


Figure 74: Image Wizard with use of FIR filter

3D Wizard

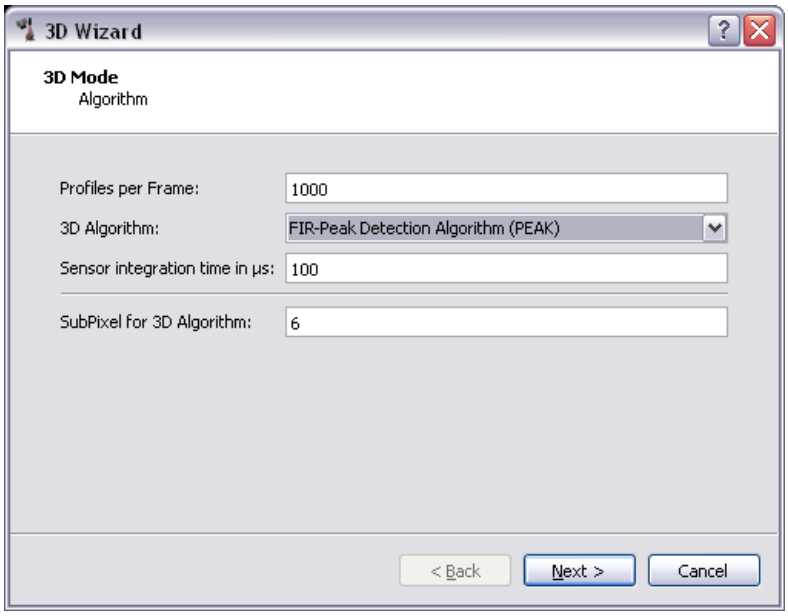


Figure 15: 3D Wizard with selected FIR Peak algorithm

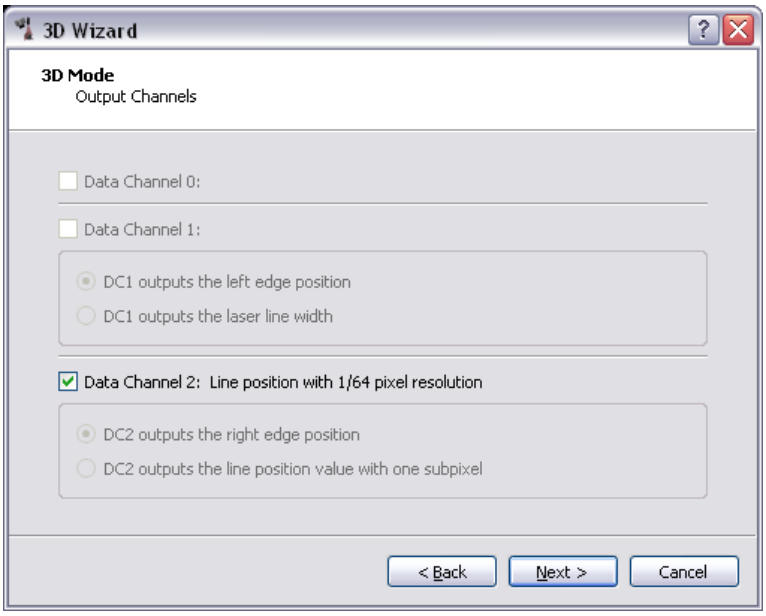


Figure 16: 3D Wizard for output channels in FIR Peak mode

Document Revision

Rev. Nr.	Date	Modification
1.0	02.04.2014	First draft