NHL STENDEN
computer vision & data science

Computer Vision

Hyperspectral Imaging (HSI)

(Operators, first draft)

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j.van.de.loosdrecht@nhl.nl, jaap@vdlmv.nl

Hyperspectral Imaging operators overview

Overview:

- **3 types of Hyperspectral images in VisionLab**
- **Demo basic HSI operators**
- **Normalized Difference Vegetation Index (NDVI)**
- **Noise correction by Flat Field Correction (FFC)**
- **Exercise Flat Field Correction Line**
- **Analyse bands FX17 using 1st and 2nd derivative**
- **Short description of all Multi-Channel (MC) image operators**

VisionLab supports 3 types of Hyperspectrale Images

- **Multi-Channel (MC) images: The pixels are stored in memory in lines of MCPixels. Within one MCPixel the channels are sequential stored. This is the basic HSI type in VisionLab, this format is used by many MC operators. All pixels are stored in one image.**
- **Raw or Mosaic images: These are the raw images typically produced by hyperspectral area scan cameras. All pixels are stored in one images.**
- **Band images: Each channel (band) is stored in a separated image. The channels are "bundled" in an array script variable with in the array elements the names of the band images.**

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Multi-Channel (MC) image operators

- **MCViewer**
- **MosaicViewer**
- **BandViewer**
- **MC1stDerivative**
- **MC2ndDerivative**
- **MCCloneNrChans**
- **MCContrastStretch**
- **MCConvert**
- **MCFromBIL**
- **MCFromBands**
- **MCFromDemosaic**
- **MCGetChan**
- **MCGetChans**
- **MCGetNrChans**
- **MCGetPixel**
- **MCGetHeightWidth**
- **MCMerge**
- **MCNVDI**
- **MC(I)ReadENVI**
- **MCReorder**
- **MCROI**
- **MCROI2Points**
- **MCSelectRange**
- **MCSelectChans**
- **MCSetChan**
- **MCSetChans**
- **MCSetNrChans**
- **MCTile**
- **MCTranspose**
- **MCZoom**
- **MCZoomXY**

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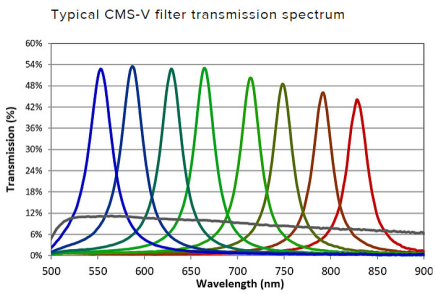
Example HSI MCFA camera, 9 bands



Source: www.silios.com/cms-cameras-1

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Silios CMS-V specs

FILTER SPECIFICATIONS	
Macro-pixel size	3x3 bands
Wavelength range	550 to 800 nm typical
Type of pixel	8 colors (narrow bands) + 1 B&W
Band 1	λc : 553 nm / FWHM : 30 nm / T_{max} : 57%
Band 2	λc : 587 nm / FWHM : 29 nm / T_{max} : 58%
Band 3	λc : 629 nm / FWHM : 28 nm / T_{max} : 57%
Band 4	λc : 665 nm / FWHM : 27 nm / T_{max} : 57%
Band 5	λc : 714 nm / FWHM : 26 nm / T_{max} : 54%
Band 6	λc : 749 nm / FWHM : 25 nm / T_{max} : 53%
Band 7	λc : 791 nm / FWHM : 25 nm / T_{max} : 50%
Band 8	λc : 829 nm / FWHM : 27 nm / T_{max} : 48%
Band 9	Neutral density : T_{mean} = 9% over [500-900] nm

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Demo basic MC image operators

- **Open file with MC image tomatos-Silios-VIS.jl**
- **Convert to Multi-Channel format with Demosaic image 3 3**
- **Look at Image Attributes (F11) for channel info**
- **Options setting MC Display (OneChan or Raw) govern the way MC images are displayed**
- **MC Pixel layout in Raw view on MC image**
- **MC Viewer, scroll in bands, adjust Gamma, extract one band**
- **MCROI image 50 50 100 200**
- **MCROI2Points LineTool height = width = 0**
- **MCROI2Points LineTool height & width != 0**
- **MCTile 3 3**
- **Extract Band Images with MCGetChans &$allBands (with &)**
- **Band Viewer $allBands (without &)**
- **MCReorder image (8,2,1,0,6,3,4,5,7)**
- **View bands and observer expected darker -> brighter for plants**

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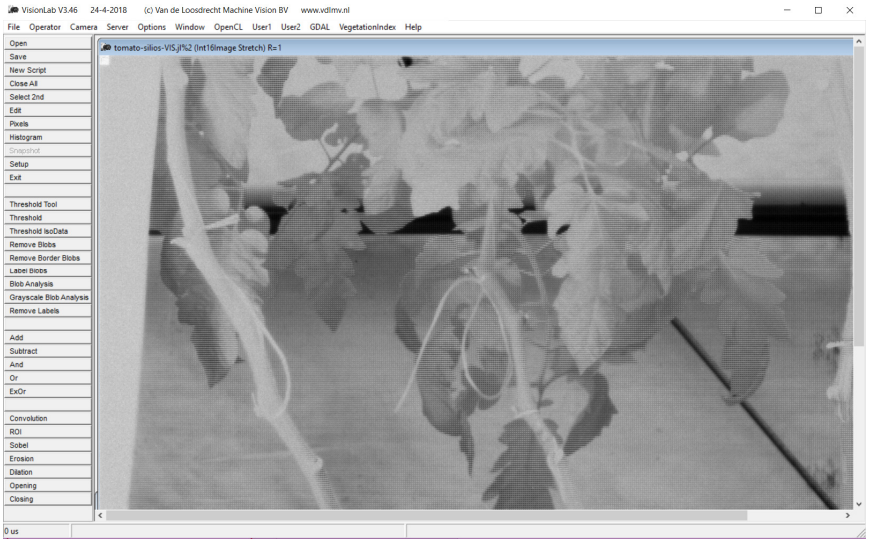
Hyperspectral mosaic image



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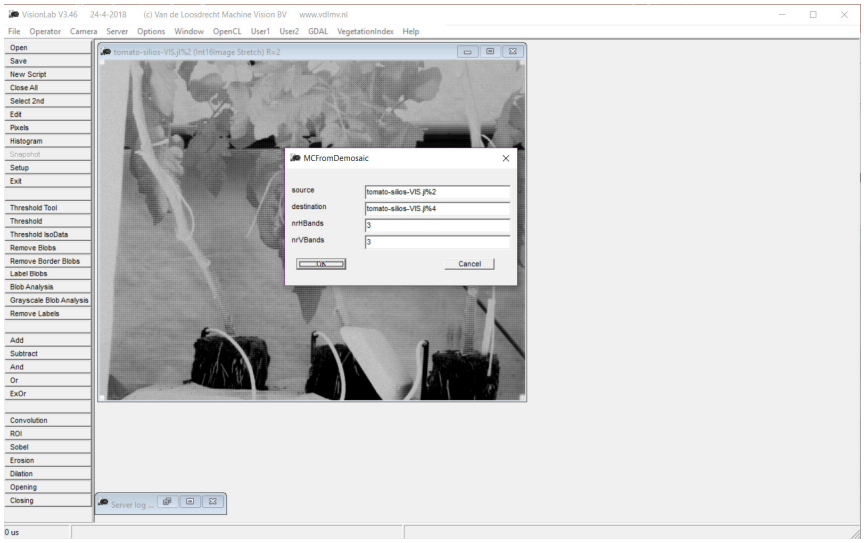
Convert to Multi-Channel format



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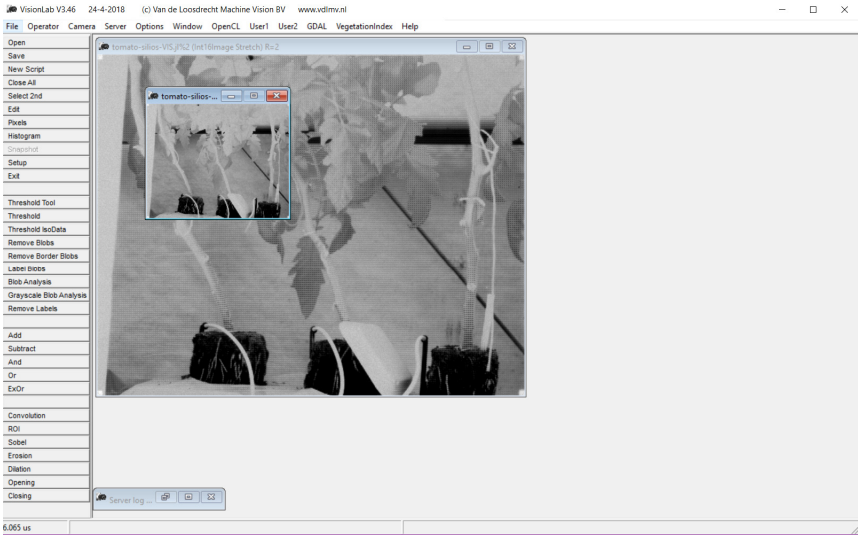
Converted to Multi-Channel format



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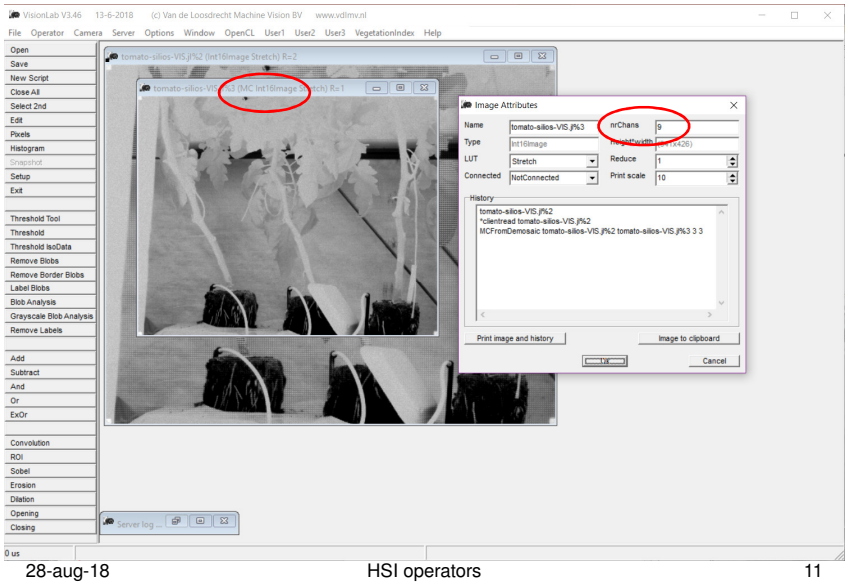
Double click on MC image for attributes



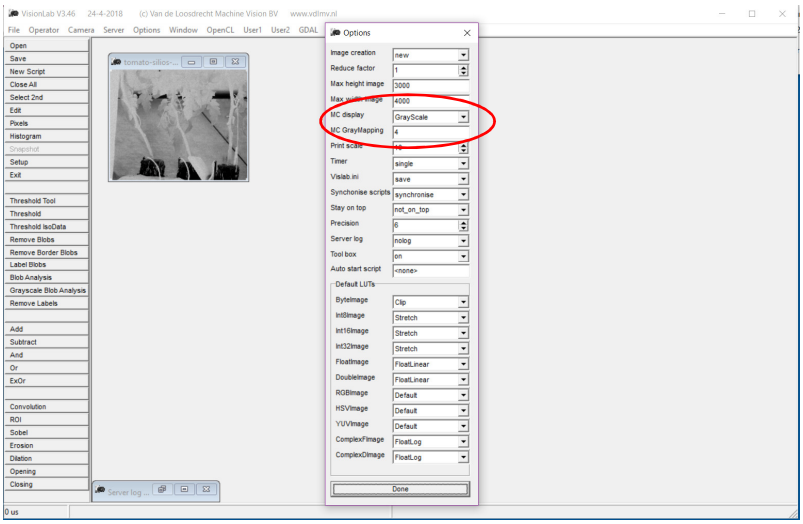
The way MC images are displayed are governed by the Options settings

The way MC images are displayed are governed by the Options setting MC Display:

- **OneChan: one channel of MC image is displayed, channel chosen is specified with Options MC Gray Mapping parameter**
- **Raw: the MC image is displayed as lines of MCPixels. Within one MCPixel the channels are sequential displayed. The raw image has the normal height, but the width is normal width * number of channels.**

Note: when MC Display is changed, all MC images will be redisplayed according to the specified display option

MC Display = GrayScale, MC Gray Mapping = channel 4



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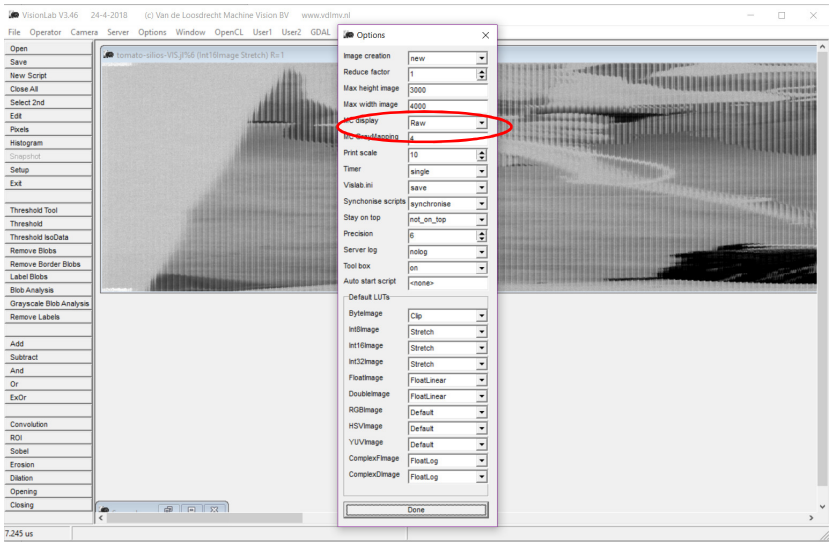
MC Display = Raw (MC Gray Mapping = don't care)



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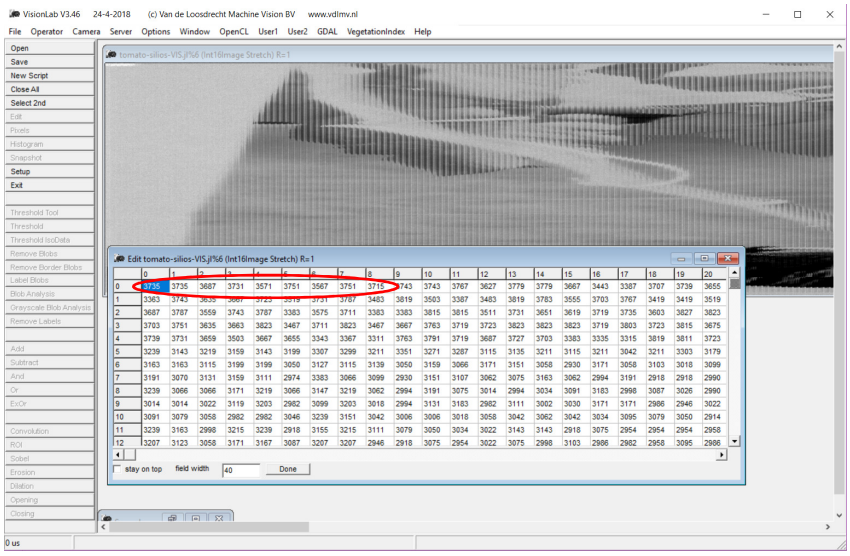
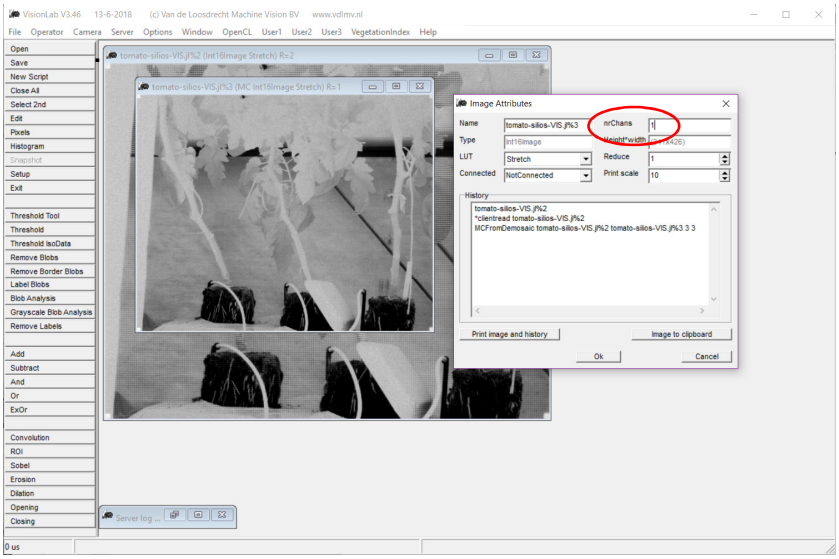
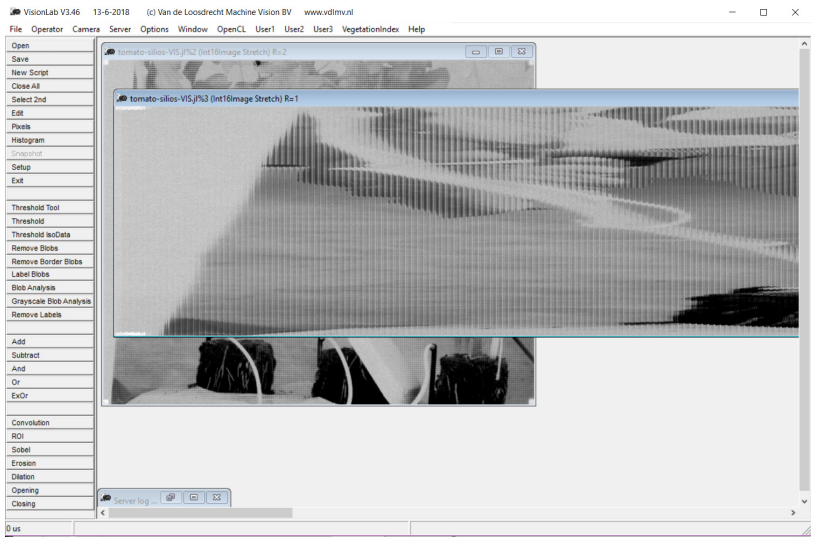
First MCpixel at left-top



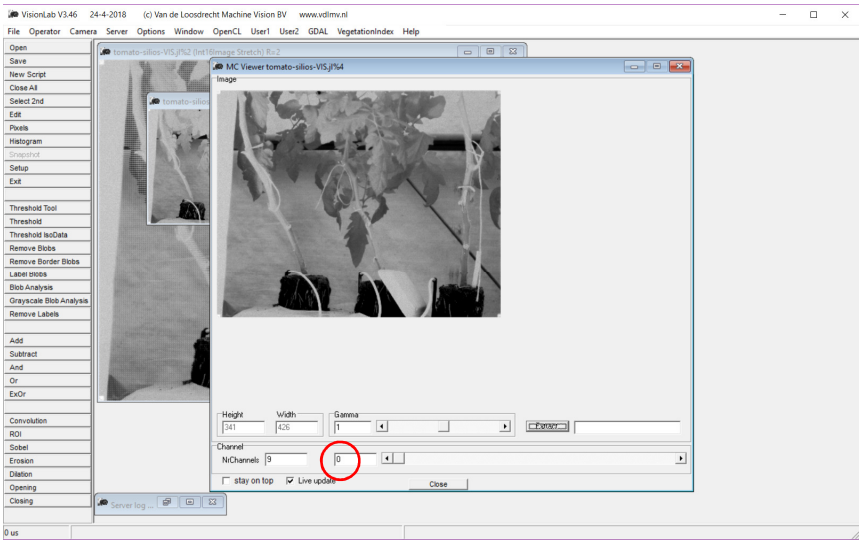
Alternative use MC image attributes nrChans ...



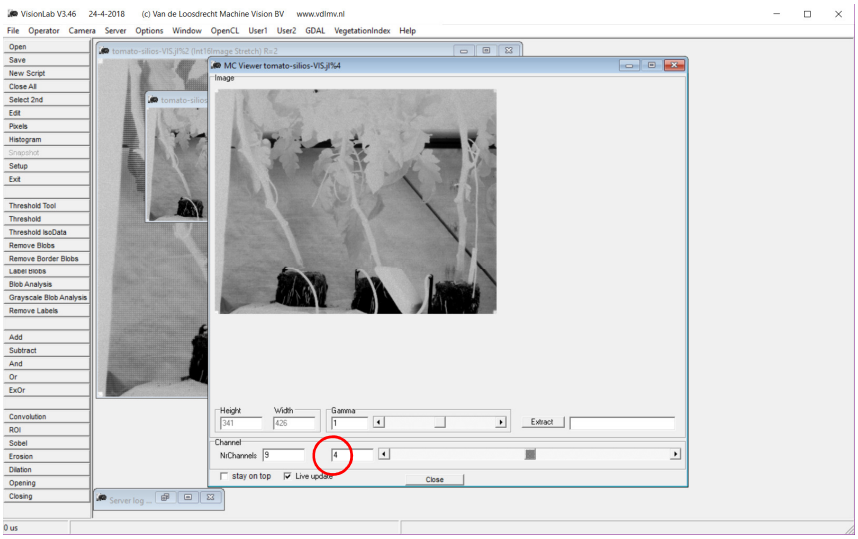
.. to see raw view on MC image



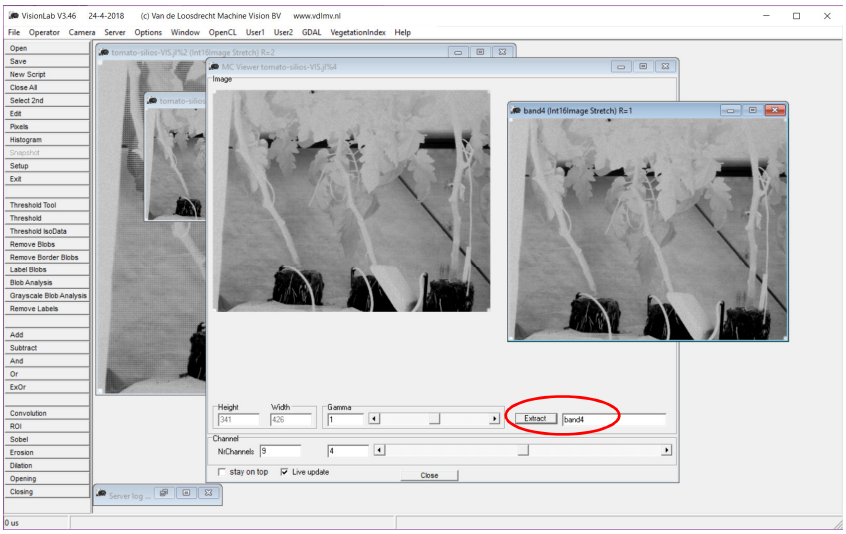
MC Viewer, band 0



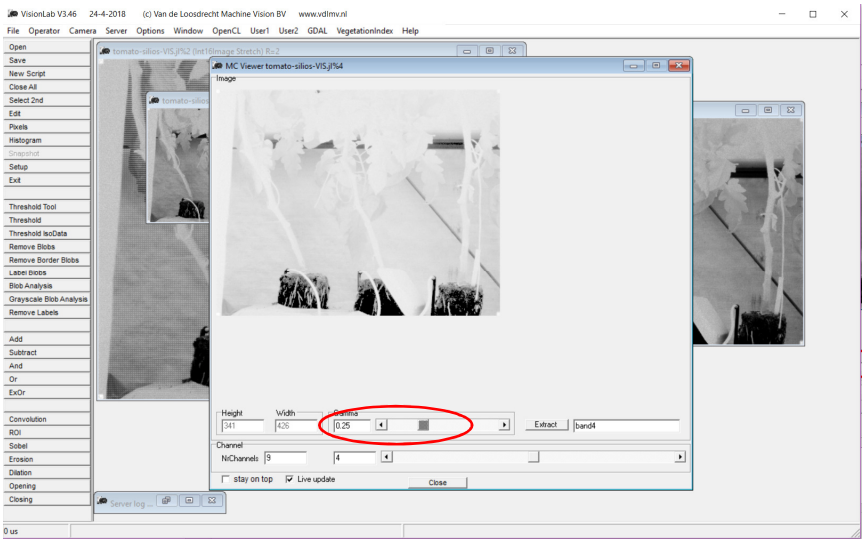
MC Viewer, band 4



Extract band 4



Modify Gamma for better contrast in display



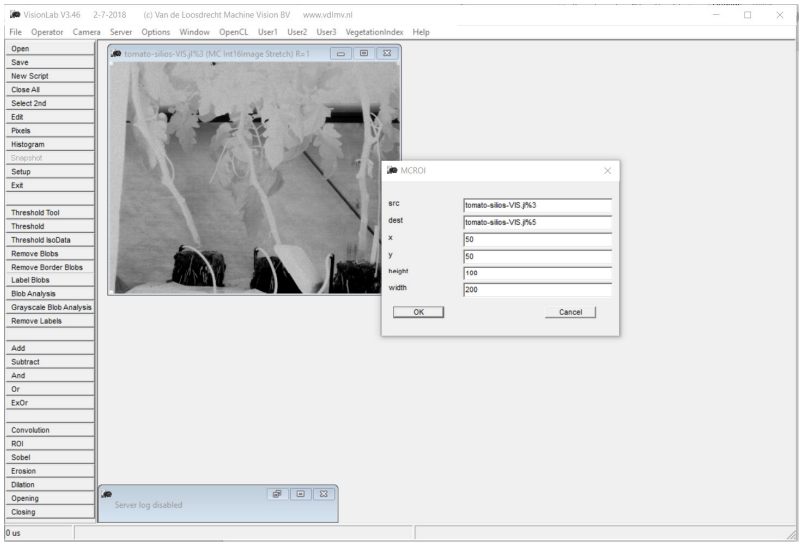
Multi-Channel ROIoperators

- **MCROI srcImage destImage x y height width**
  The MCROI operator copies the ROI specified by x, y, height and width in the MC srcImage to the MC dstImage.
  Note that x, y, height and width are defined for MC pixels.

- **MCROI2Points srcImage destImage leftTop rightBottom height width**
  This operator is intended to be used with the LineTool widget.
  The MCROI2Points operator copies a ROI rectangle in the MC srcImage to the MC dstImage.
  If height = 0 the rectangle is defined by the leftTop and rightBottom coordinates.
  If height != 0 the rectangle is defined by the leftTop coordinate, height and width.
  Note that leftTop and rightBottom coordinates, height and width are defined for MC pixels.

MCROI

x, y, height and width are defined for MC pixels



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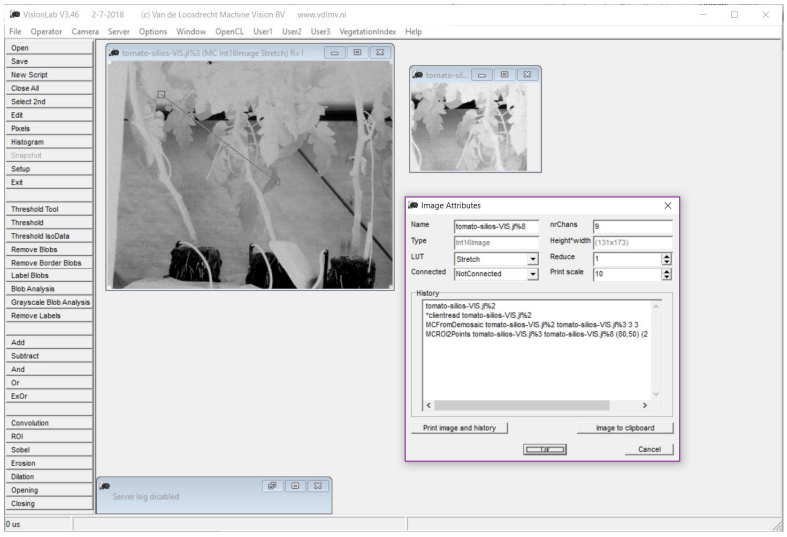
MCROI

Result ROI with MCImage



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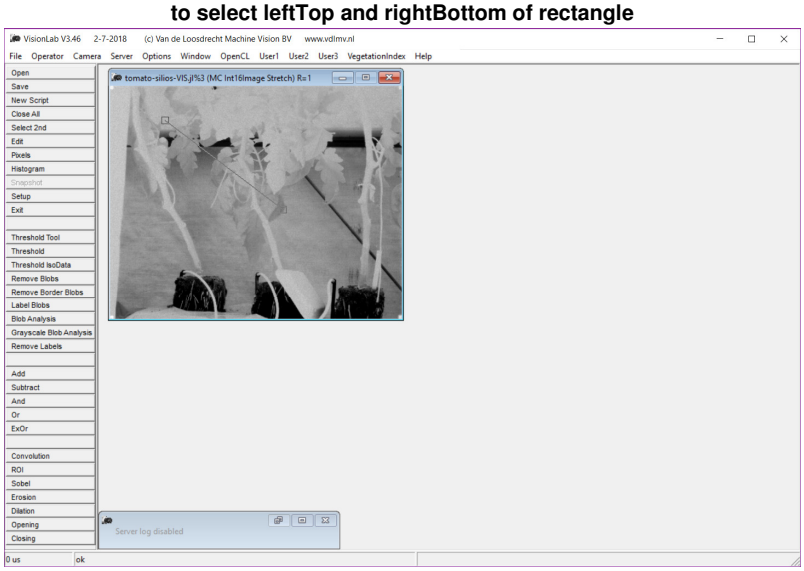
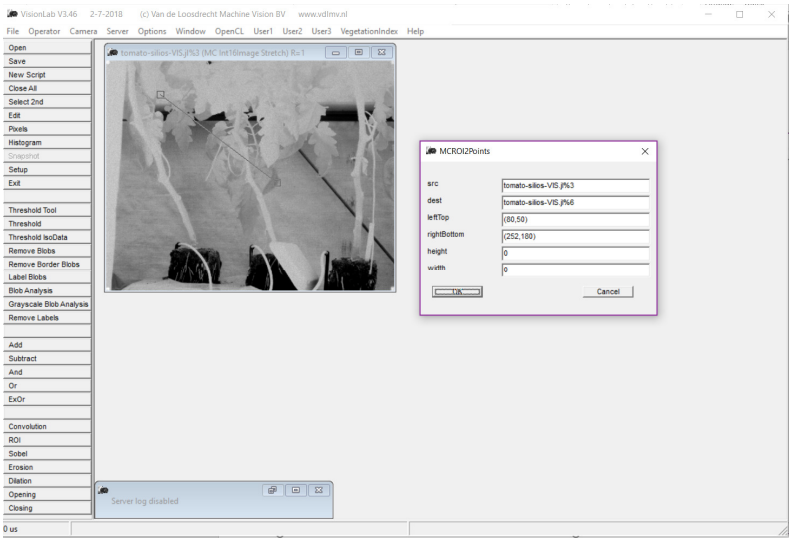
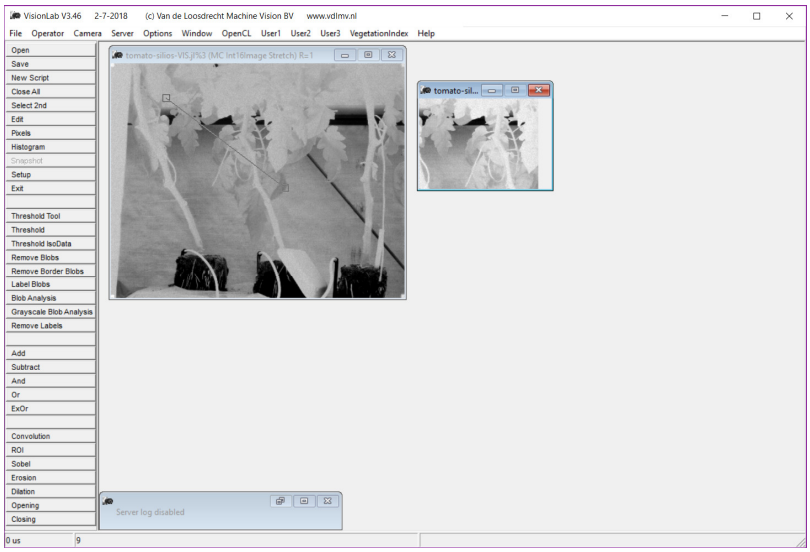
Use menu Operator | Widget Tools | MCROI2Points
to select leftTop and rightBottom of rectangle



Select MCROI2Points operator
(note: height = width = 0)



Result MCROI2Points defined by leftTop-rightBottom



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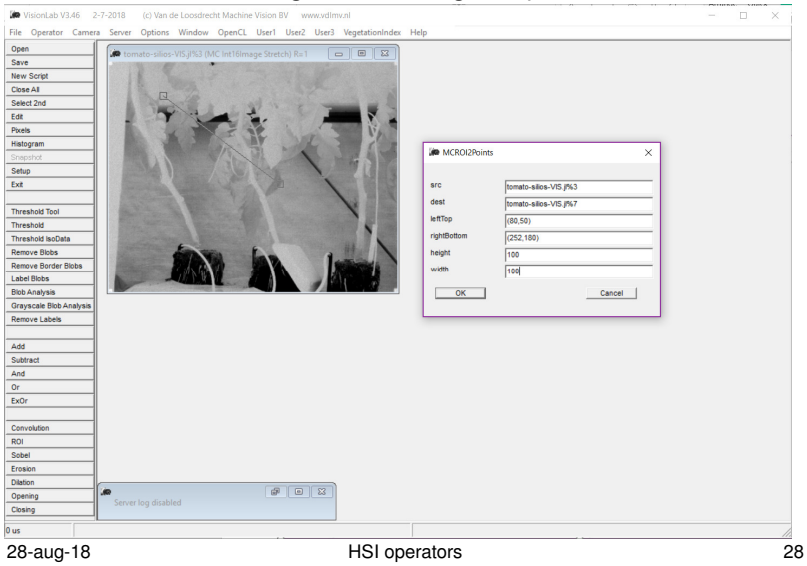
Select MCROI2Points operator

(note: leftTop from widget, height and width are specified by user, rightBottom is neglected)



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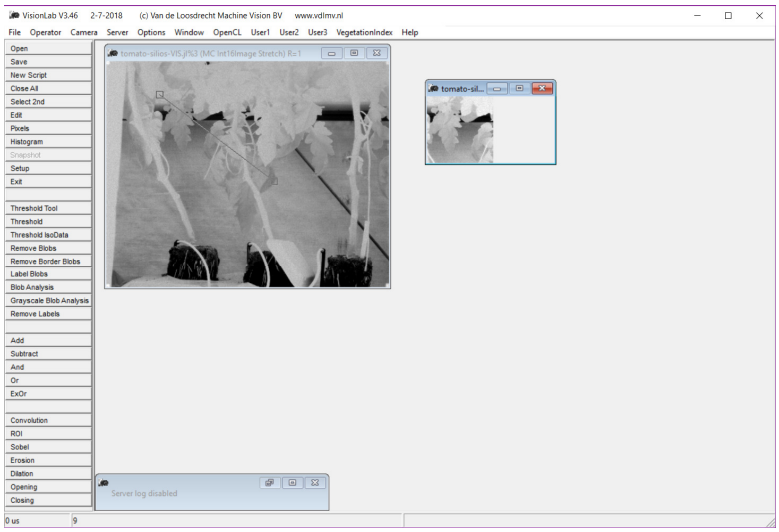
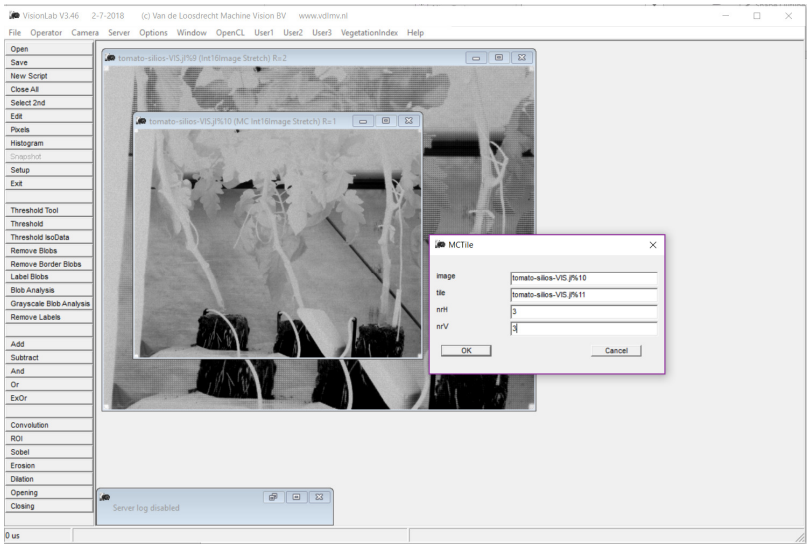
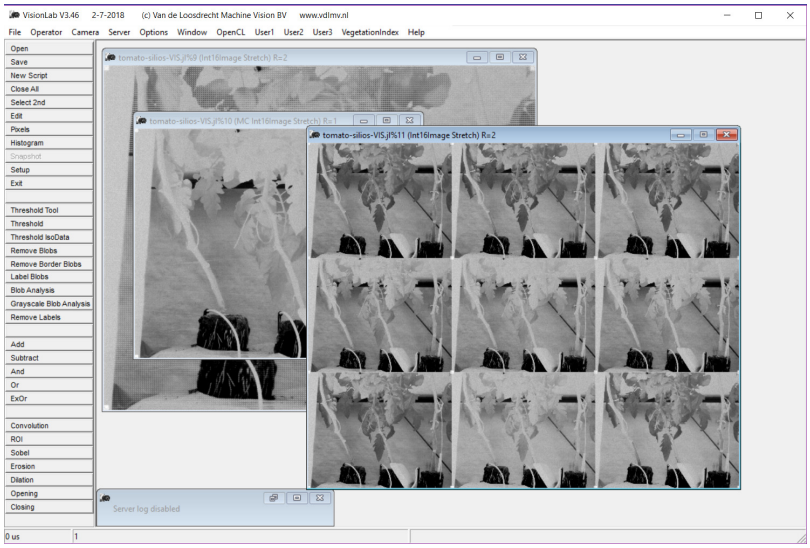
Result MCROI2Points defined by leftTop, height and width



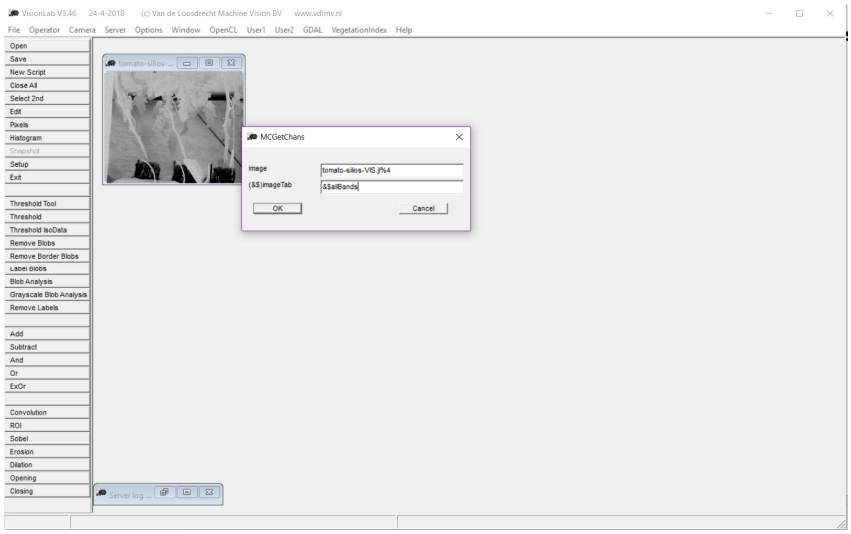
MCTile operator



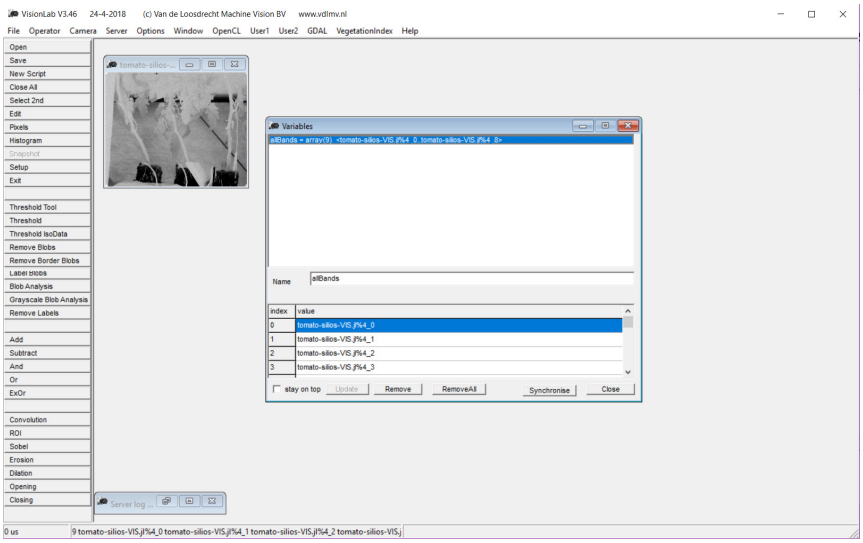
Result MCTile



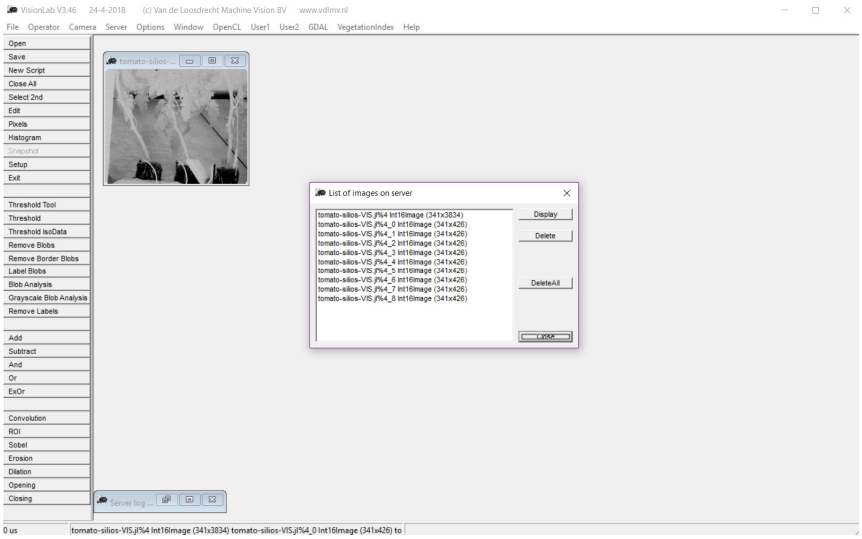
Extract all channels in "bundled" array script variable



Variable array $allBands contains names of all images <imageName>-bandNr



Variable array $allBands contains names of all images <imageName>-bandNr



Ordering of channels within MCPixel

According to Silios specifications the channels (bandnr -1) are ordered in the mosaic sensor:

3	2	1
5	6	7
4	8	0

In VisionLab channels for a 3x3 mosaic are ordered:

0	1	2
3	4	5
6	7	8

MCReorder operator

MCReorder srcImage destImage orderList

Menu: Operator | HSI

The MCReorder operator copies the MC srcImage to the MC destImage and reorder the channels in the MC destination pixel according to orderList. The orderList is specified as a tuple with the desired channel order of the new channels using the channel numbers of the original image.

Ordering of channels within MCPixel

According to Silios specifications the channels (bandnr -1) are ordered in the mosaic sensor:

3	2	1
5	6	7
4	8	0

Order list:
(8,2,1,0,6,3,4,5,7)
chan 8 -> chan 0
chan 2 -> chan 1
etc.

In VisionLab channels for a 3x3 mosaic are ordered:

0	1	2
3	4	5
6	7	8

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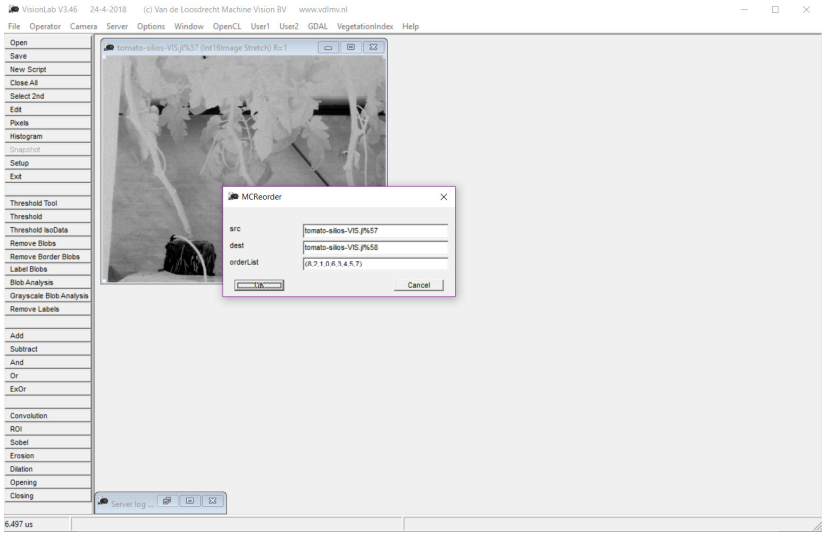
Reorder channels in order of longer wave lengths



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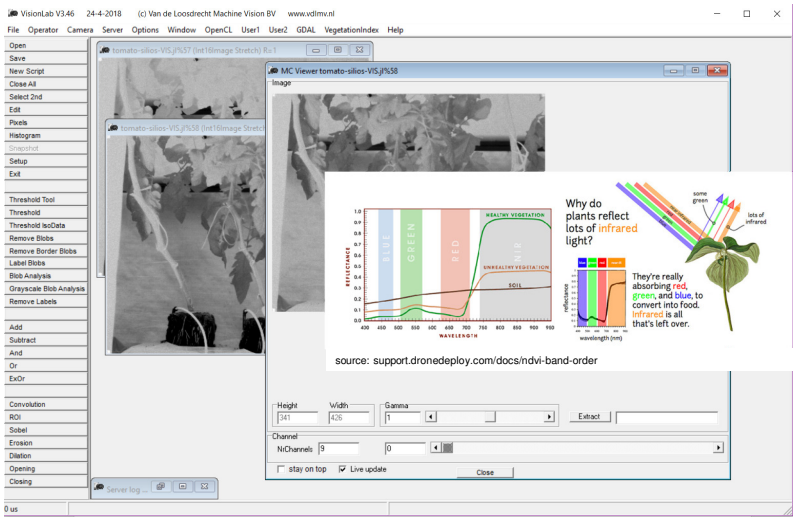
Browse through channels will give expected behaviour of healthy plant



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View 3 channels in false colors

Note all operators can be found in menu HSI

- **Open image tomato-silios-VIS.jl**
- **MCFromDemosaic image 3 3**
- **MCReorder image (8,2,1,0,6,3,4,5,7)**
- **MCSelectChans image (0,4,7)**
- **MCContrastStretch image (0,0,0) (255,255,255)**
- **MCConvert image RGB888Image**

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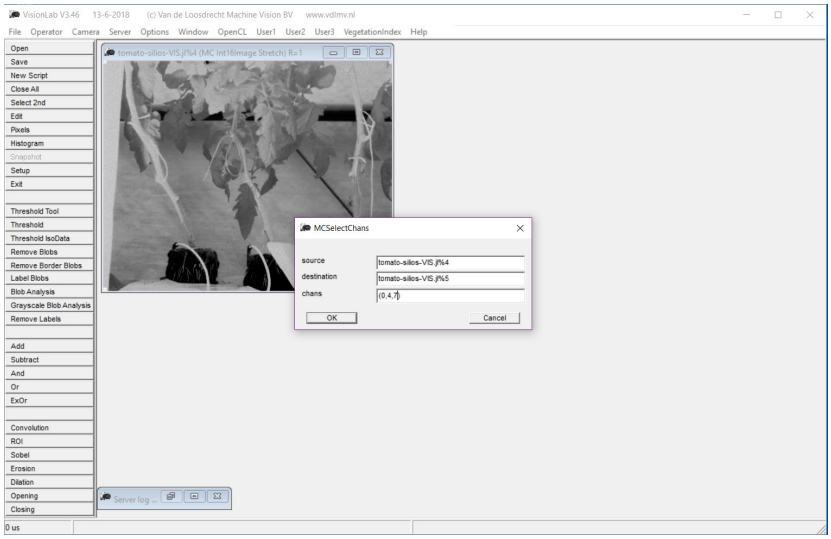
Select 3 of the 9 channels



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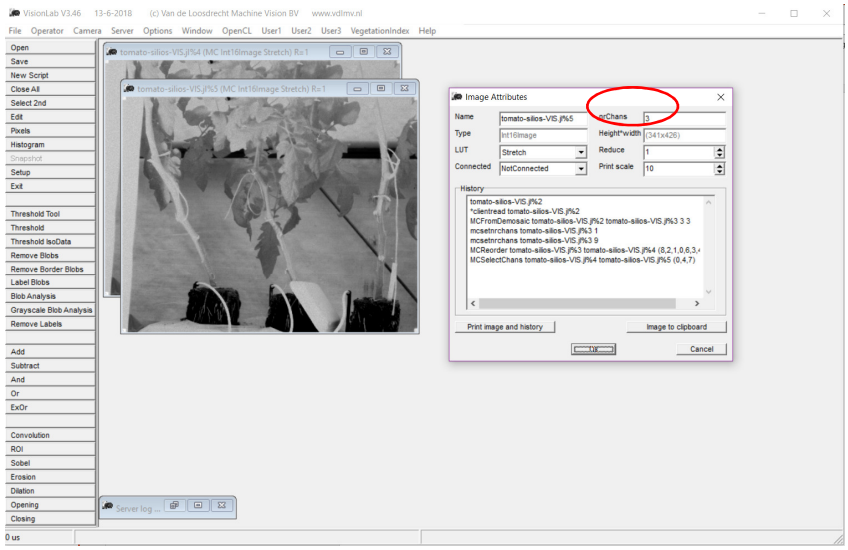
3 channels selected



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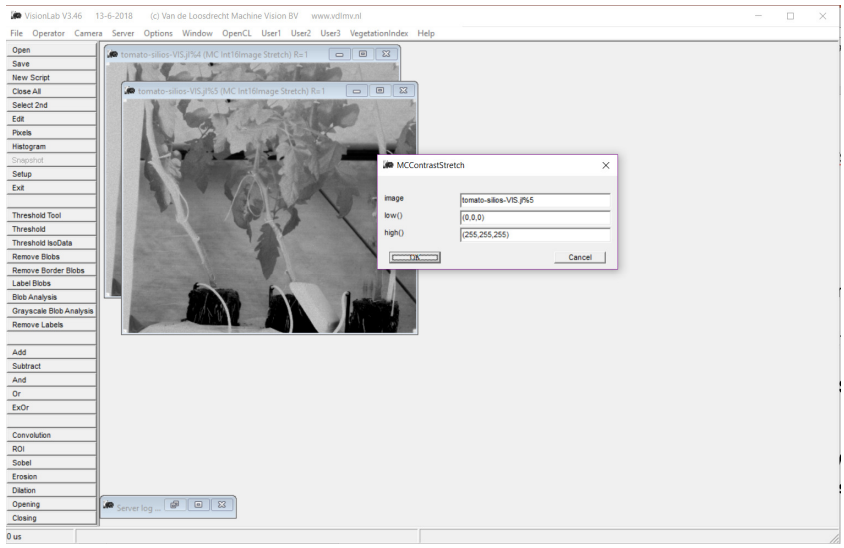
Contrast Stretch all 3 channels to range for RGB888



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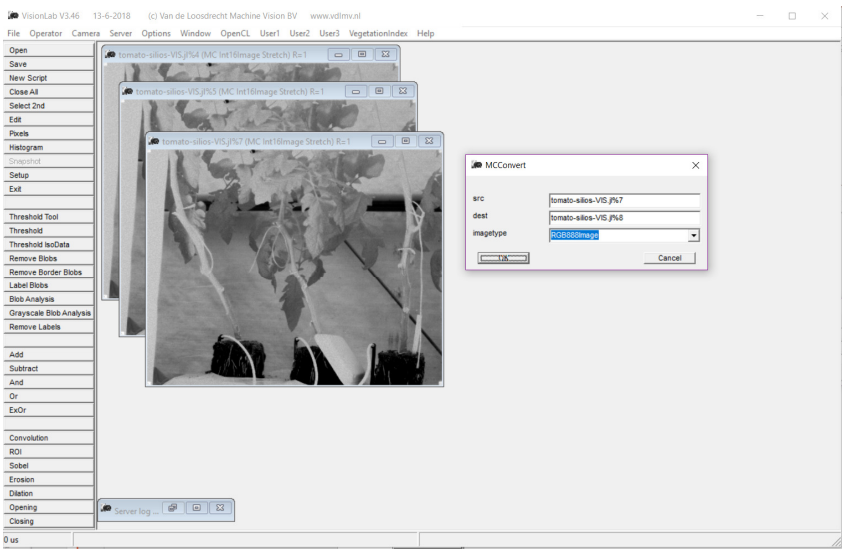
Convert to RGB888



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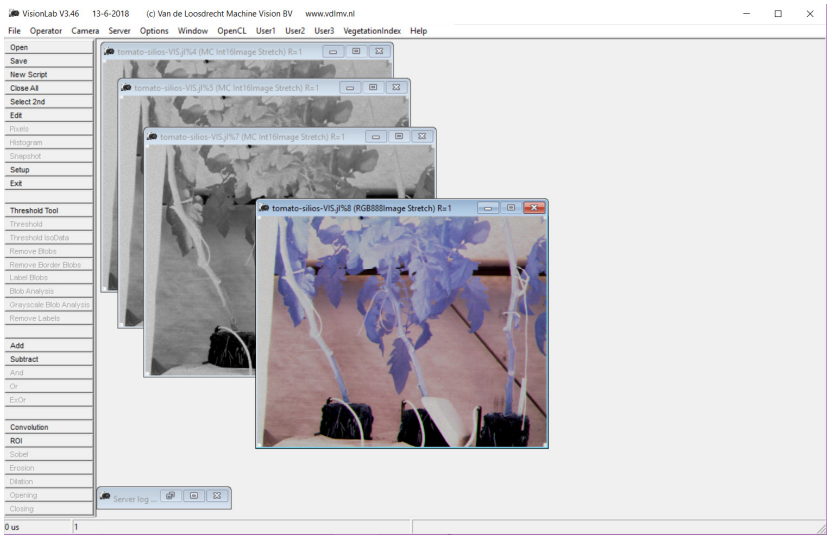
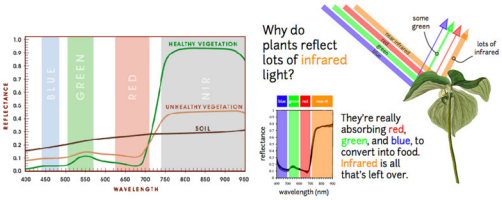
Result in false colors



Normalized Difference Vegetation Index (NDVI)

NDVI = (NIR – Red) / (NIR + Red)



source: support.dronedeploy.com/docs/ndvi-band-order

FILTER SPECIFICATIONS	
Macro-pixel size	3x3 bands
Wavelength range	550 to 800 nm typical
Type of pixel	8 colors (narrow bands) + 1 B&W
Band 1	λc : 553 nm / FWHM : 30 nm / T_{max} : 57%
Band 2	λc : 587 nm / FWHM : 29 nm / T_{max} : 58%
Band 3	λc : 629 nm / FWHM : 28 nm / T_{max} : 57%
Band 4	λc : 665 nm / FWHM : 27 nm / T_{max} : 57%
Band 5	λc : 714 nm / FWHM : 26 nm / T_{max} : 54%
Band 6	λc : 749 nm / FWHM : 25 nm / T_{max} : 53%
Band 7	λc : 791 nm / FWHM : 25 nm / T_{max} : 50%
Band 8	λc : 829 nm / FWHM : 27 nm / T_{max} : 48%
Band 9	Neutral density : T_{mean} = 9% over [500-900] nm

Select band 4 and band 8

Note in mosaic channel nr starts at 0

- **band 4 = chan^{s} 3 = chan^{vl} 0 (red)**
- **band 8 = chan^{s} 7 = chan^{vl} 5 (nir)**

Silios chans			VisionLab chans		
3	2	1	0	1	2
5	6	7	3	4	5
4	8	0	6	7	8

Demo Normalized Difference Vegetation Index (NDVI)

- **Open file with MC image Silios-potato-field.jl**
- **Demosaic image 3 3**
- **MCNDVI image 5 8**
- **Open file BlueGreen256LUT.jl for LUT**
- **Select RangeToFalseColor operator from Color menu**
  RangeToFalseColor image lut (2nd select) 0 0.3

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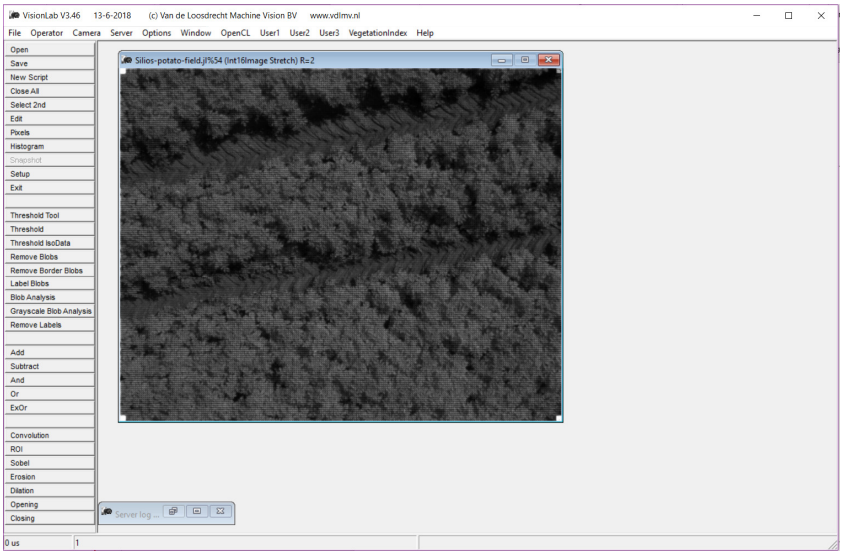
Open file Silios-potato-field.jl



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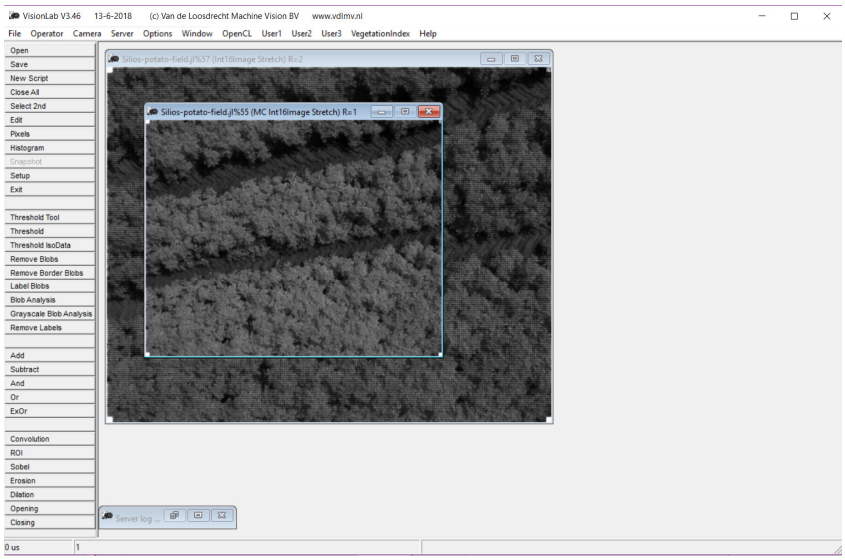
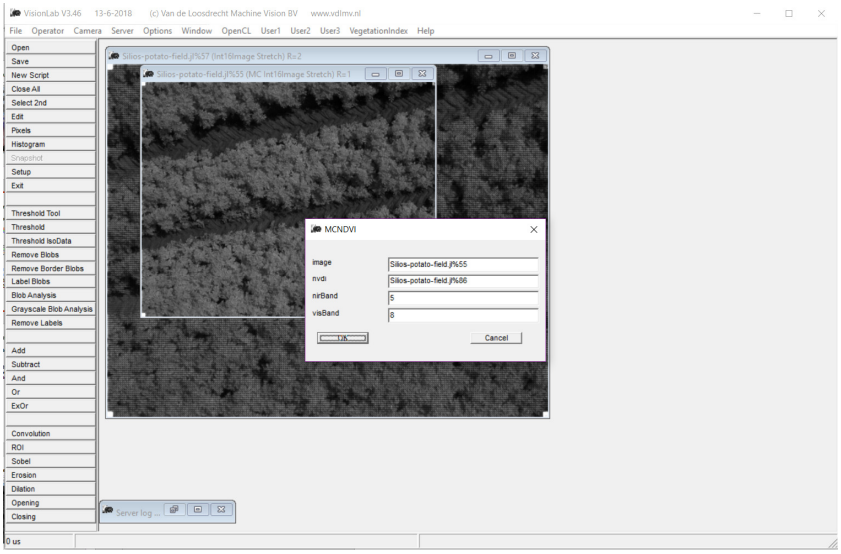
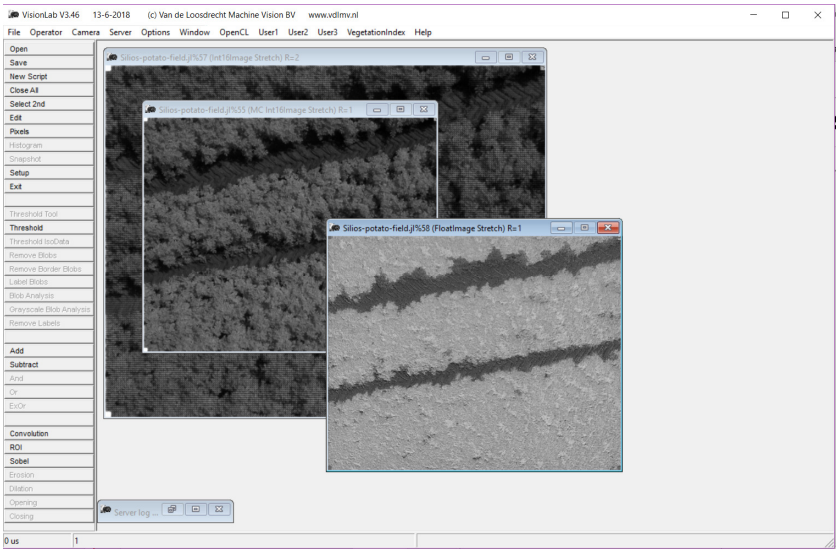
Demosaic image



Select MCNDVI operator from HIS menu



Floating point image result of MCNDVI operator



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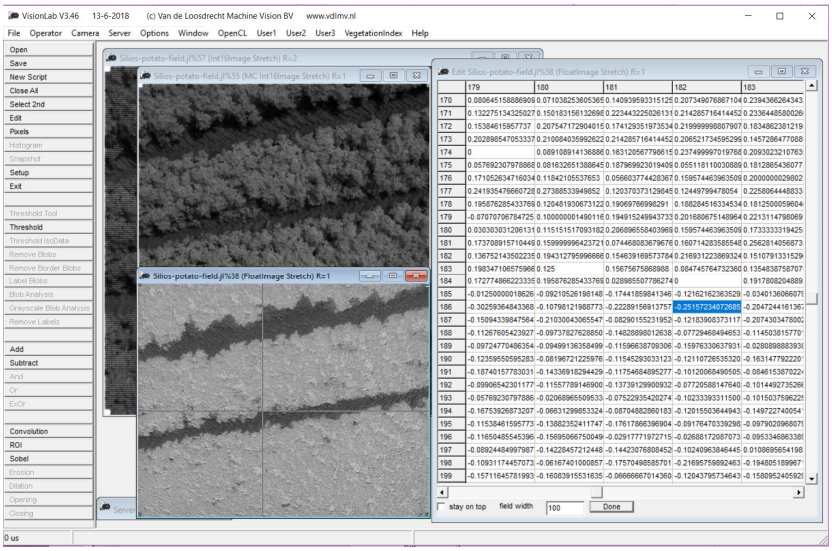
Floating point image result of MCNDVI operator



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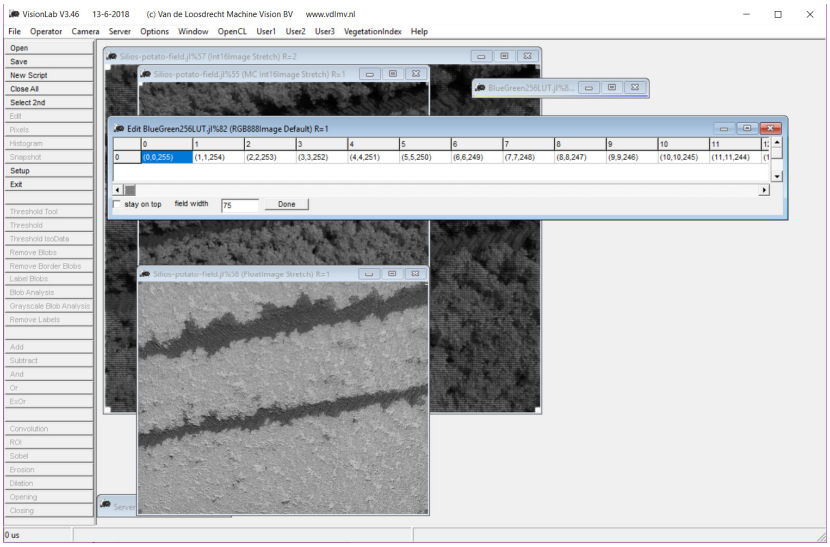
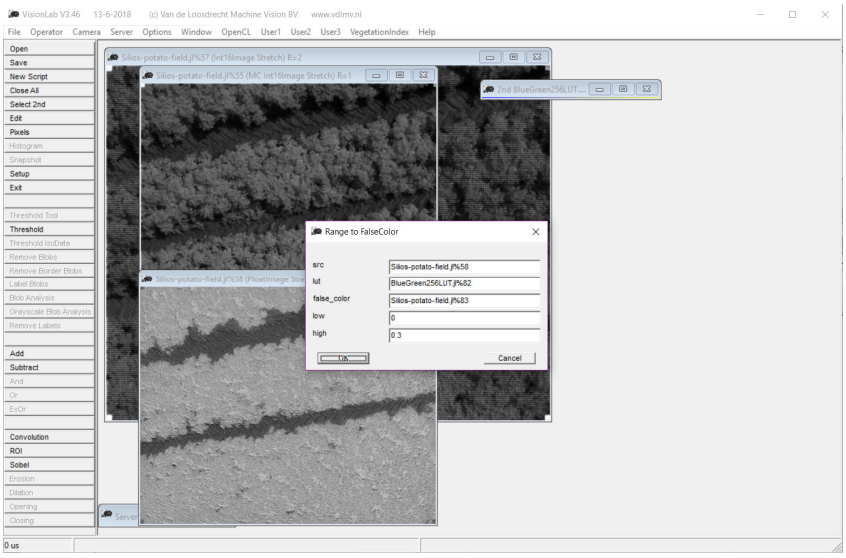
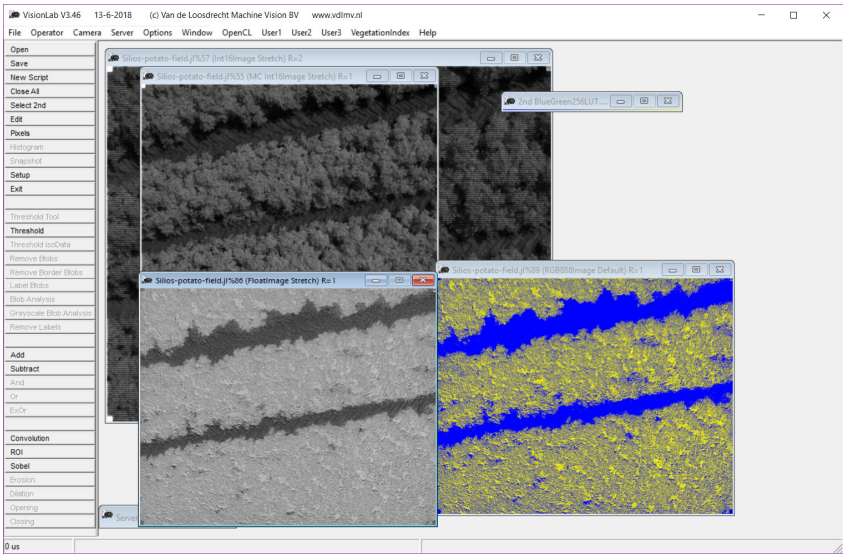
Open BlueGreen256LUT.jl



Select RangeToFalseColor operator from Color menu



NDVI in false colors



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Single camera multi shot
Push-broom scanner

Specim FX10 VIS/NIR, 400 - 1000 nm, 224 bands
Specim FX17 NIR/SWIR, 900 - 1700 nm, 224 bands

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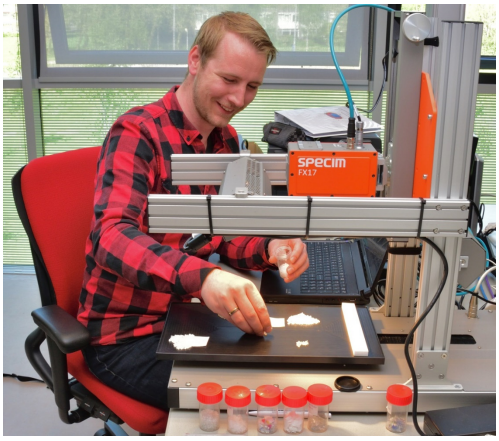
Hyperspectral linescan camera

Transparent plastic sorting
In collaboration with NHL Stenden Lectoraat Circular Plastics



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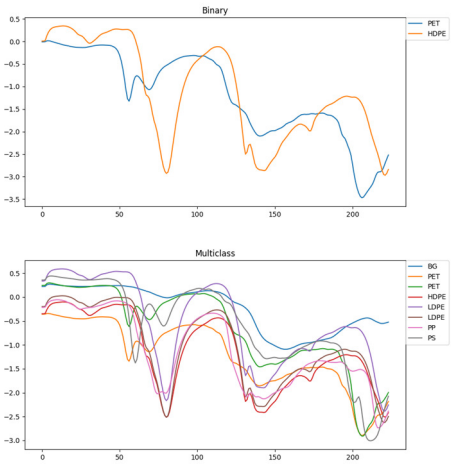
Chemical finger printing
Application plastic sorting

The SWIR absorbance depends on the type of polymer



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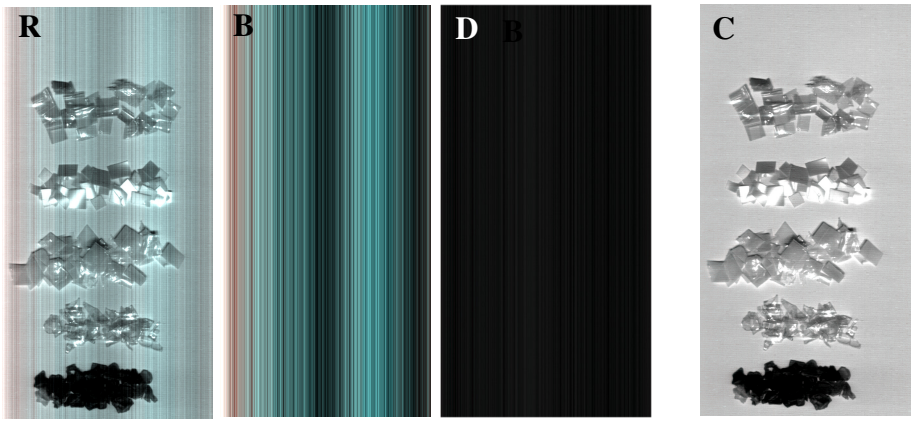
Flat Field Correction

$$C = \frac{R - D}{B - D}$$

R = Raw
C = Corrected
B = Brightfield
D = Darkfield



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Demo noise correction by Flat Field Correction (FFC) part 1

- **Open ENVI file Plastic.raw (must use local VisionLab server)**
- **Image Attributes (menu Operator | Analyses) shows 224 bands**
- **Examen image with MCViewer, change gamma to 0.25 browse through bands, note noise in lower and high 10 bands**
- **Open DARKREF.raw and WHITEREF.raw**
- **Use FlatFieldLine (menu Operator | Point) to generate single line DarkRef and WhiteRef images**
- **Because FlatFieldLine is not an MC operator, use Image Attributes of DarkRef and WhiteRef to set NrChans to 224**
- **Apply Flat Field Correction Line (menu Operator | Point) to plastic image using DarkRef as 2nd and WhiteRef as 3rd image**
- **Because Flat Field Correction Line is not an MC operator, set result image NrChans to 224**

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Demo noise correction by Flat Field Correction (FFC) part 2

- **Note: results looks brighter because result is FloatImage, which has default display LUT FloatLog**
- **Use Image Attributes to change LUT to FloatLinear, examen result with MCViewer and gamma = 0.25**
  Note noise reduced in lower and high 10 bands and compare with original image

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Open ENVI file Plastic.raw

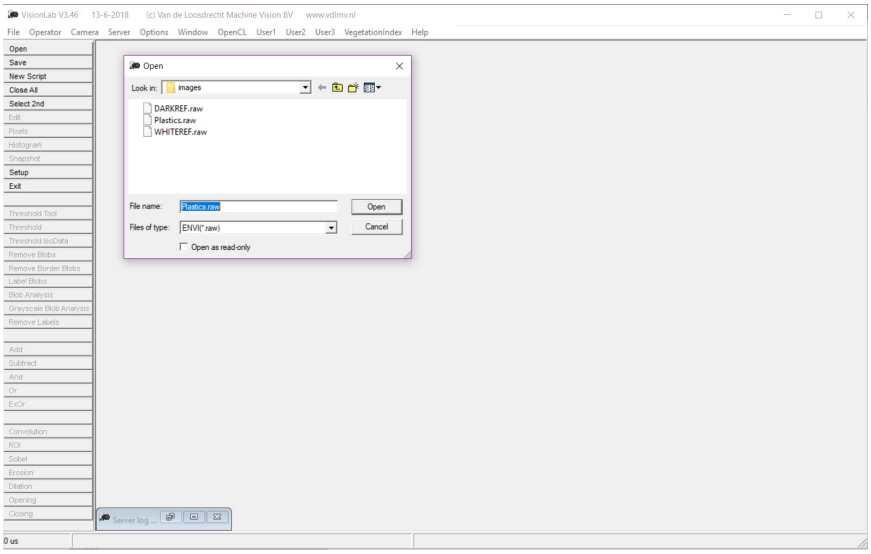

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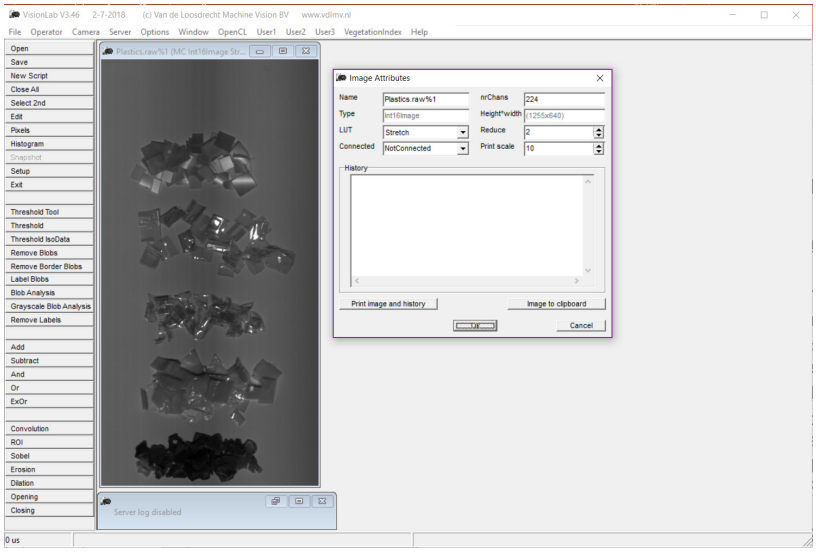
Image attributes: set nrChans to 224 channels



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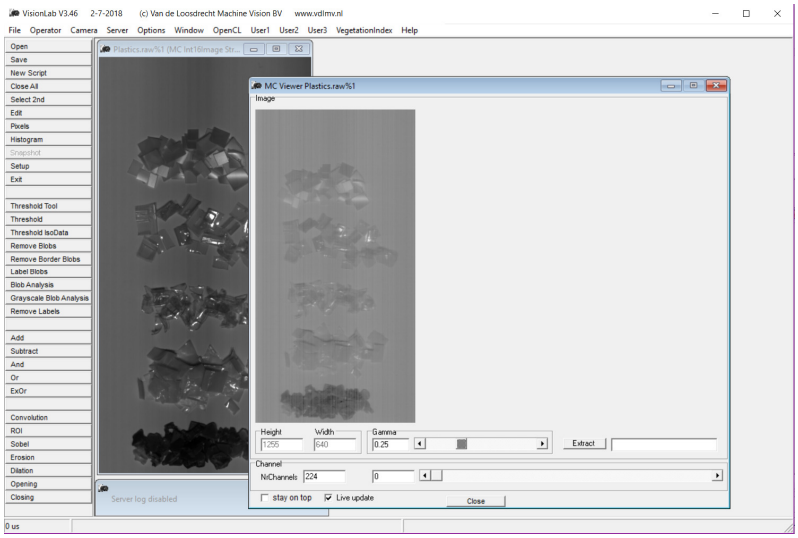
Adjust Gamma to 0.25

The first and last 10 channels contain a large amount of noise



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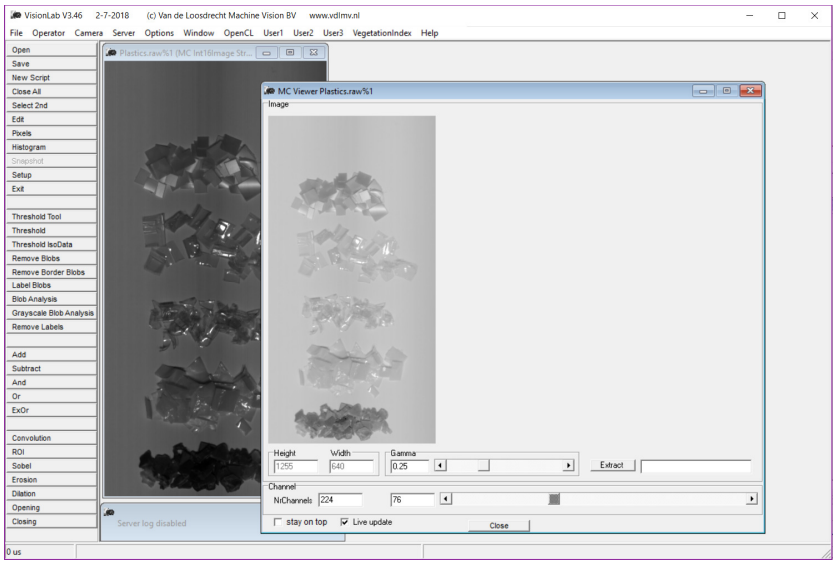
Browse through channels to see spectral response



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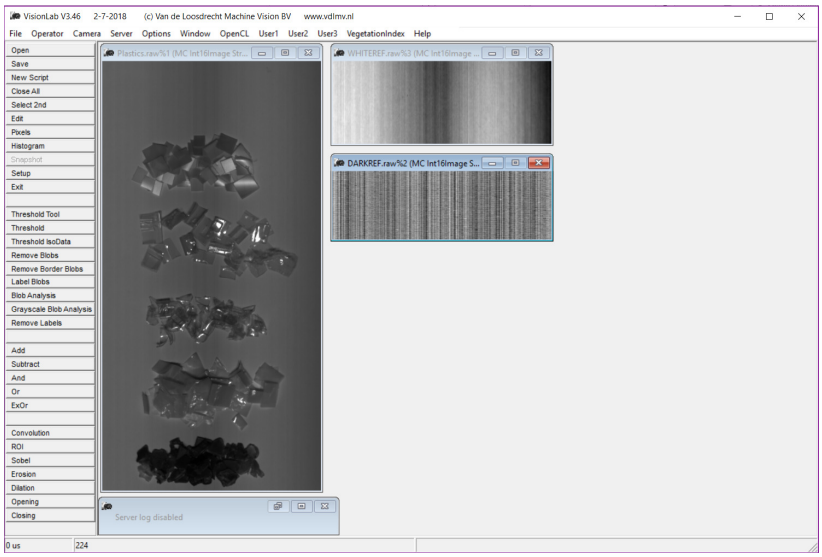
Open White and Dark reference images



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Flat Field (Correction) Line operators

These operators are used to perform a Flat Field Correction for line-scan images

FlatFieldLine image flatfield
FlatFieldCorrectionLine raw dark bright corrected

Class: ordImage, see Image hierarchy overview
Menu: Operator | Point

The operator FlatFieldLine generates from a reference image (dark field or bright field) an averaged flat field image of height 1
The operator FlatFieldCorrectionLine performs the Flat Field correction based on darkfield image dark and brightfield image bright and produces the corrected image

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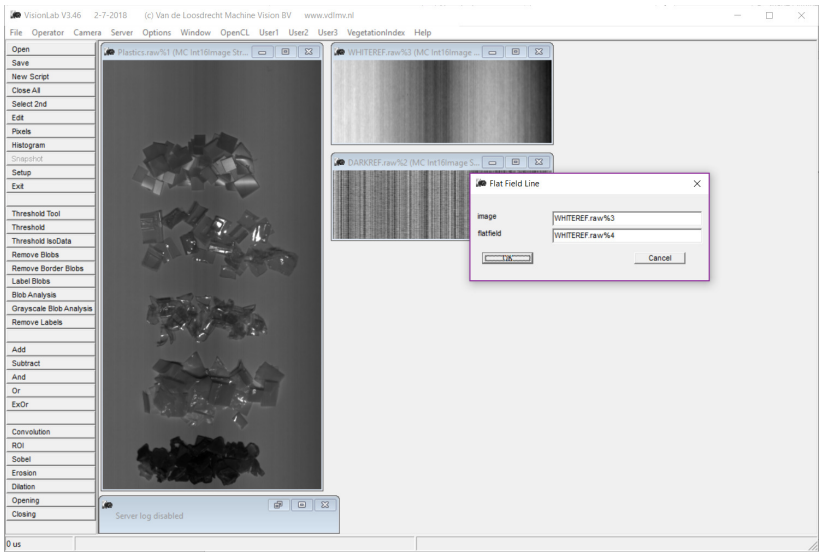
FlatFieldLine (menu Operator | Point)



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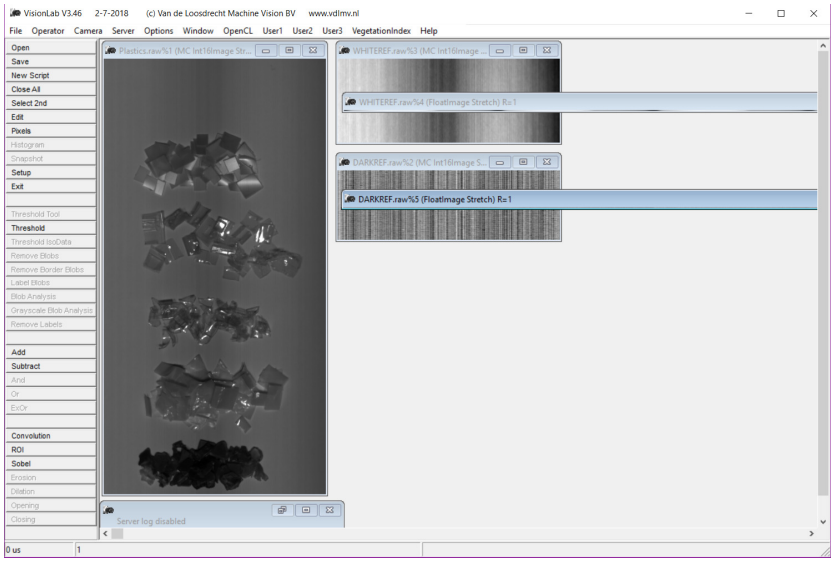
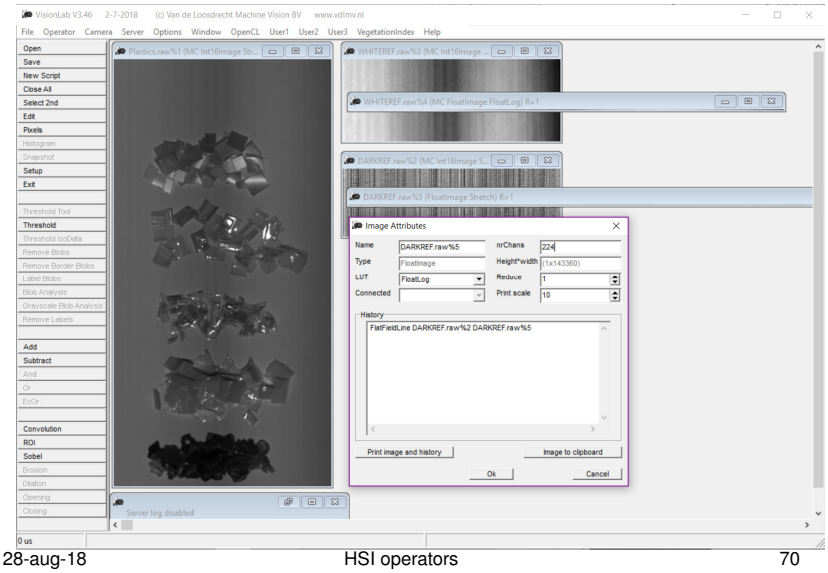
Examen both results

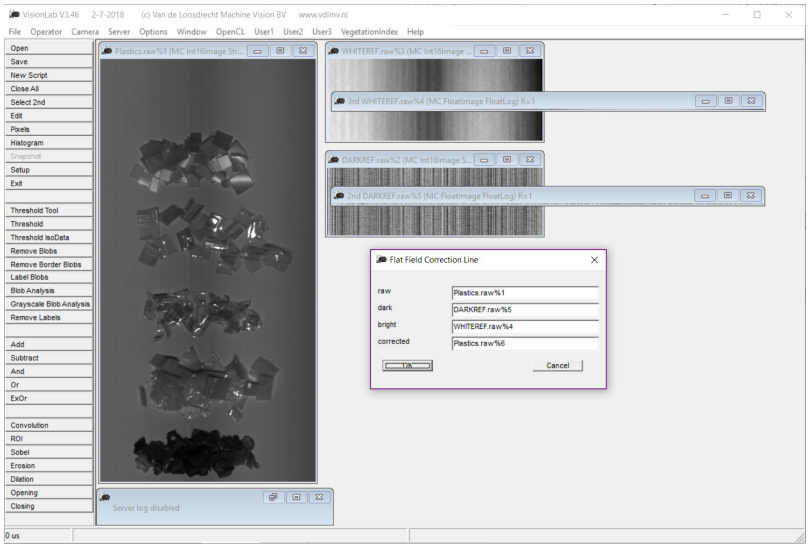


Because FlatFieldLine is not an MC operator, use Image Attributes of DarkRef and WhiteRef to set nrChans to 224



Flat Field Correction Line

Select Dark as 2nd and White as 3rd image



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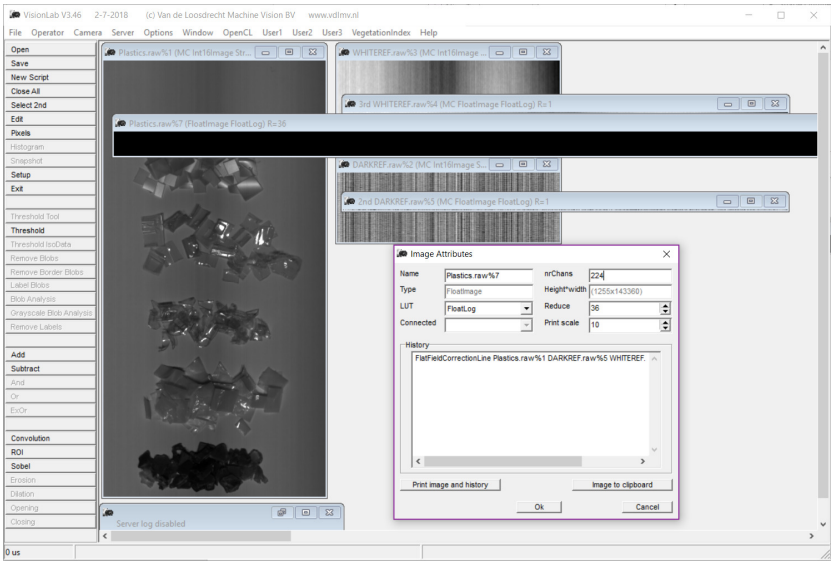
Examen result FFC and set nrChans to 224



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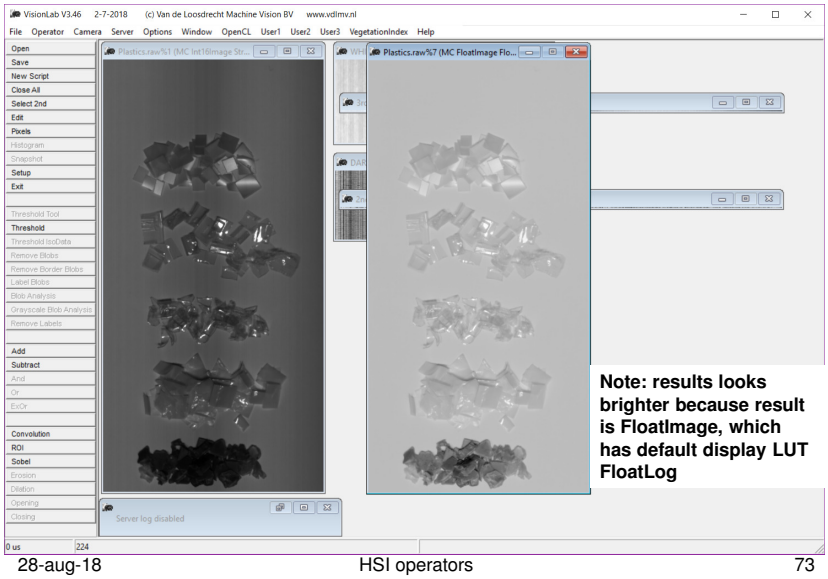
Examen result FFC



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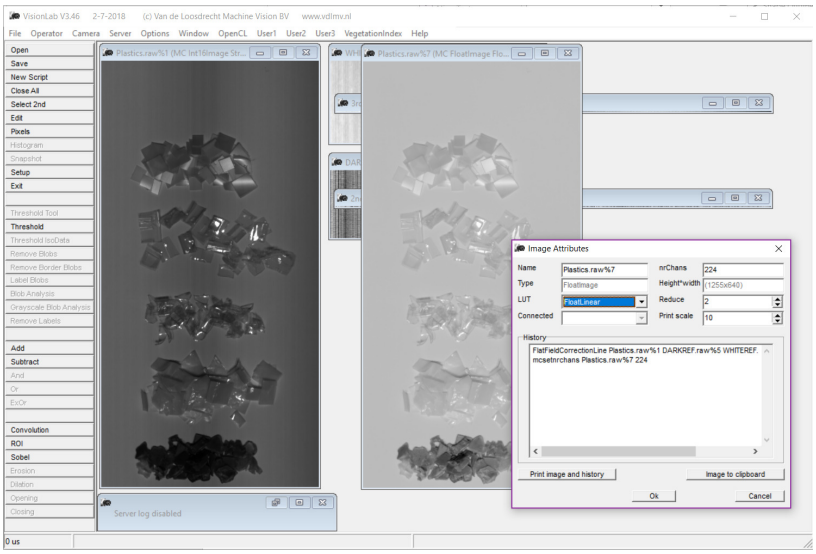
Set displayLut to FloatLinear



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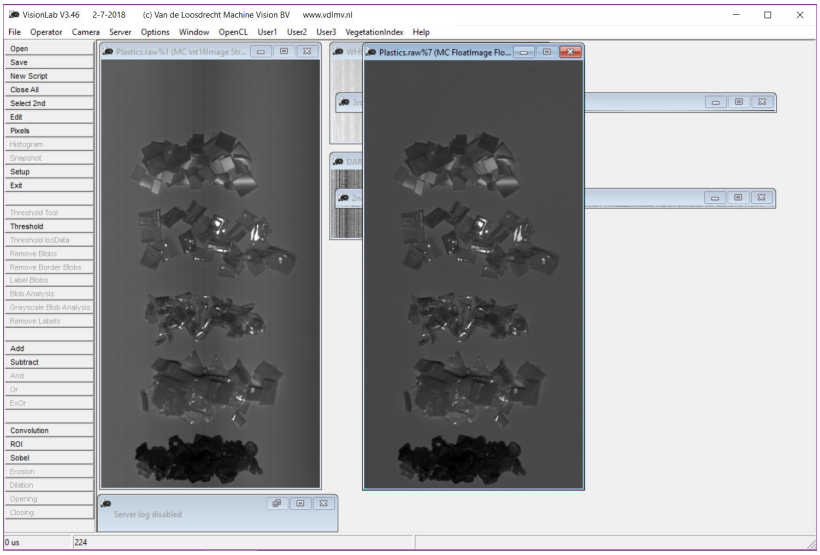
Examen result



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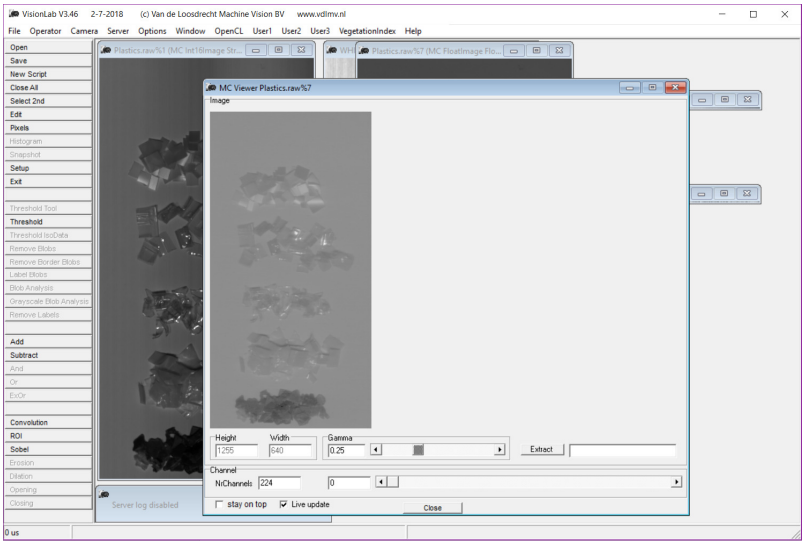
Browse through bands with MCViewer
Note noise reduced in lower and high 10 bands



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Exercise Flat Field Correction Line

Write a script that performs a FFCLine on image Plastics.raw using Dark.raw and White.raw using only the basic Image Math operators and operators like SumColumns and ExtendBorder

Use script FlatFieldCorrPlastics.jls in exercises as framework. This contains a regression test to test the result

The resulted image should have the name CorEx

See FlatFieldCorrPlastics.jls in answers directory for answer

Demo analyse bands FX17

Run script FFC-Plastics.jls

- **FFC Plastics and convert to Int16Image**
- **Extract one column with MCPixels**
- **Use Analyse Pixels (F11) to examine the bands in horizontal pixels**
- **Calculate 1st and 2nd derivative of MCPixels**
- **Exam the bands in 1st derivative**
- **Exam the bands in 2nd derivative**
- **Calculate 2nd derivatives for high 1st derivatives**
- **Exam 2nd derivatives for high 1st derivatives**

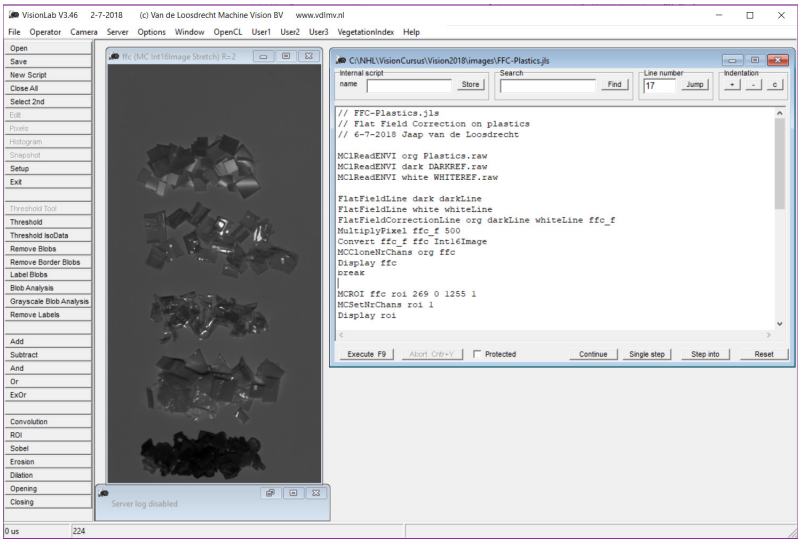
script FFC-Plastics.jls

```
// FFC-Plastics.jls
// Flat Field Correction on plastics
// 6-7-2018 Jaap van de Loosdrecht

MCIReadENVI org Plastics.raw
MCIReadENVI dark DARKREF.raw
MCIReadENVI white WHITEREF.raw

FlatFieldLine dark darkLine
FlatFieldLine white whiteLine
FlatFieldCorrectionLine org darkLine whiteLine ffc_f
MultiplyPixel ffc_f 500
Convert ffc_f ffc Int16Image
MCCloneNrChans org ffc
Display ffc

MCROI ffc roi 269 0 1255 1
MCSetNrChans roi 1
Display roi
```

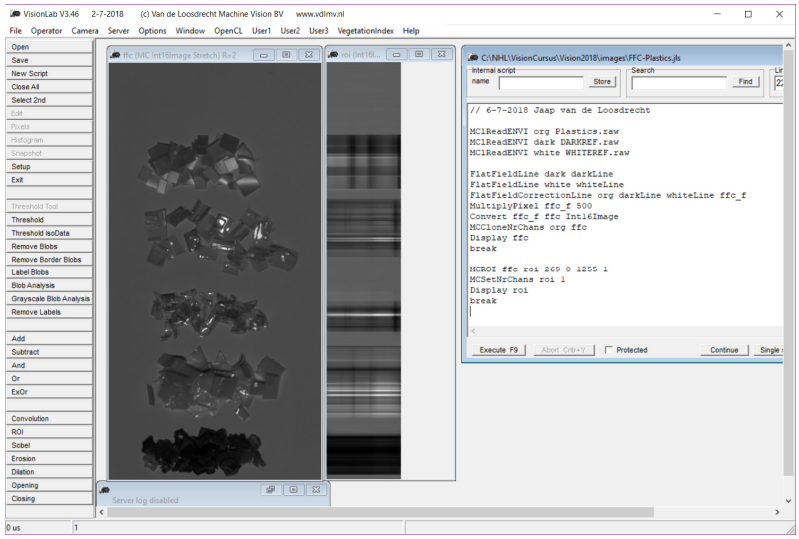
// 2nd part

```
MC1stDerivative ffc D1
MC2ndDerivative ffc D2
MCROI D1 D1roi 269 0 1255 1
MCROI D2 D2roi 269 0 1255 1
MCSetNrChans D1roi 1
MCSetNrChans D2roi 1
Display D1roi
Display D2roi

Copy D1roi D1roiThres
threshold D1roiThres 5 1000
Copy D1roi D1roiHigh
Abs D1roi
Multiply D1roiHigh D1roiThres
Copy D2roi D2roiMax
Multiply D2roiMax D1roiHigh
Display D2roiMax
```


FFC Plastics and convert to Int16Image



Extract one column with MCPixels



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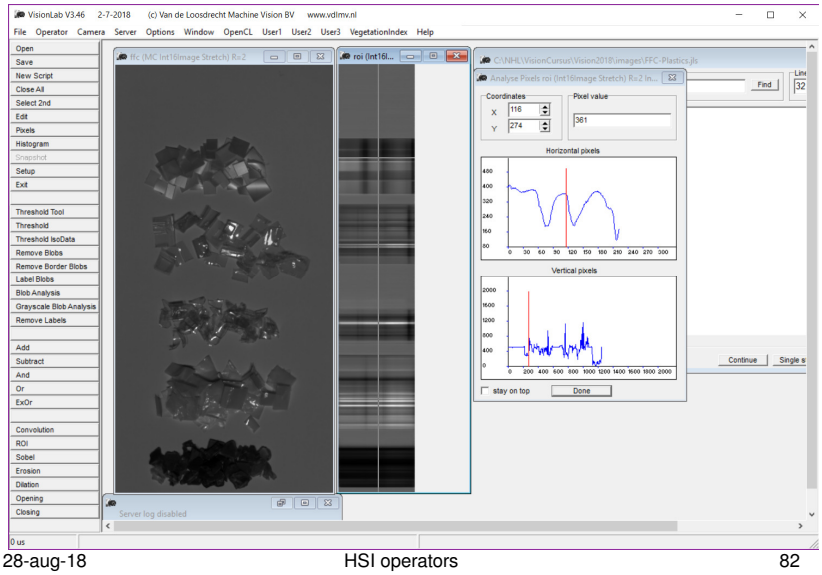
Use Analyse Pixels (F11) to examine the bands in horizontal pixels



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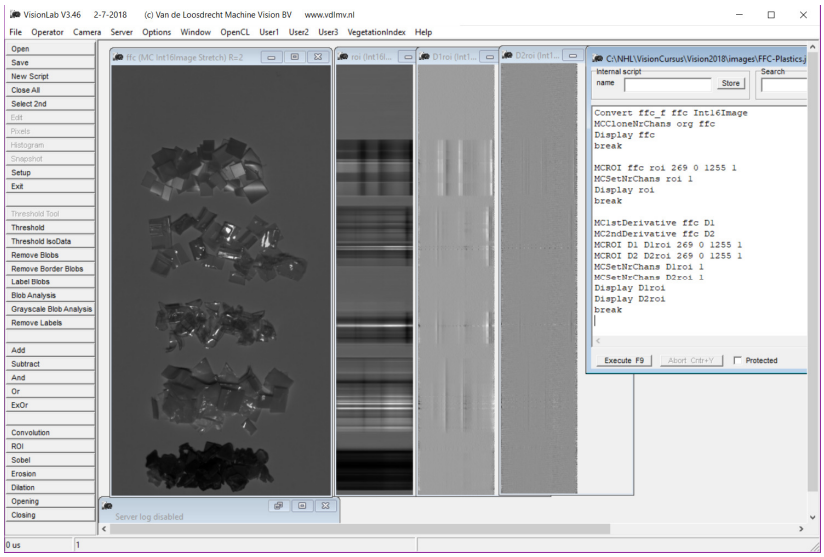
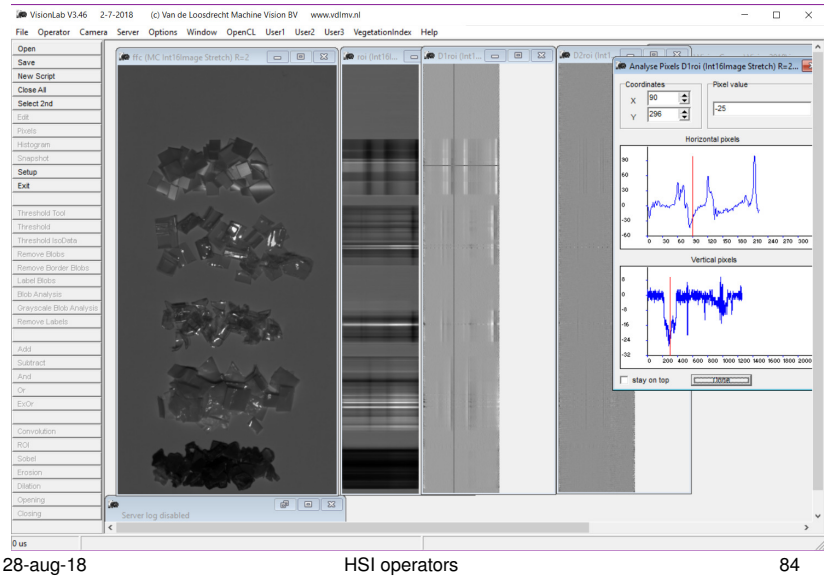
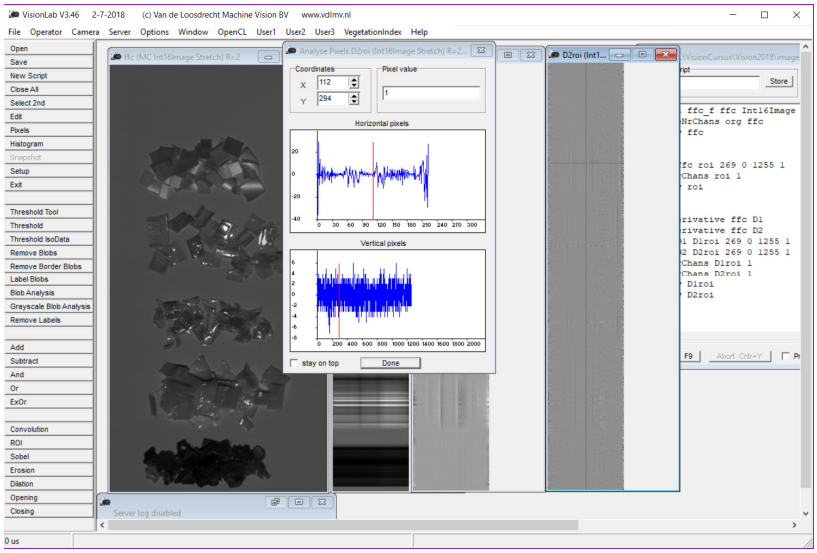
Calculate 1st and 2nd derivative of MCPixels



Exam the bands in 1st derivative



Exam the bands in 2nd derivative



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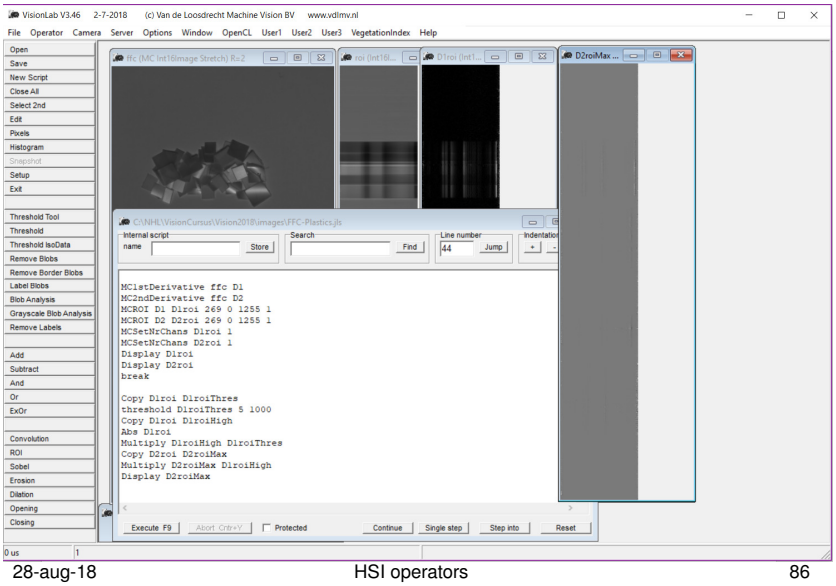
Calculate 2nd derivatives for high 1st derivatives



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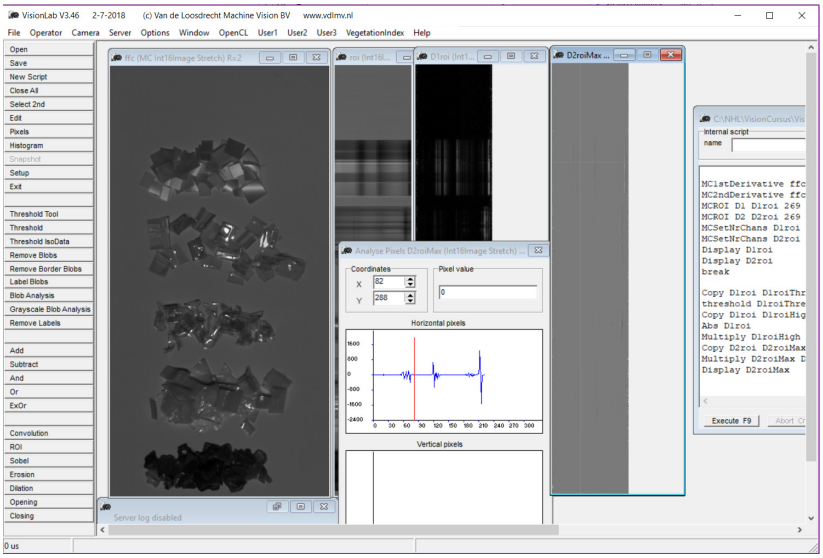
Exam 2nd derivatives for high 1st derivatives



Multi-Channel (MC) image operators

All MC operators can be found in menu Operator | HSI

- **MCViewer**
  With this form a Multi Channel image can be inspected. With the Channel scroll bar the channel to be inspected can be chosen. The contract in the displayed channel can be adapted with the Gamma scroll bar.

- **MosaicViewer**
  With this form a Raw mosaic image can be inspected.
  The number of horizontal and vertical pixels in one MCPixel must be specified.
  With the Channel scroll bar the channel to be inspected can be chosen. The contract in the displayed channel can be adapted with the Gamma scroll bar.

Multi-Channel (MC) image operators

- **BandViewer**
  With this form a Band image can be inspected.
  The array script variable with in the array elements the names of the band images must be specified.
  With the Channel scroll bar the channel to be inspected can be chosen. The contract in the displayed channel can be adapted with the Gamma scroll bar.

- **MC1stDerivative srcImage destImage**
  The MC1stDerivative operator calculates for each MCPixel in the srcImage the first derivative and stores this in the destImage.

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Multi-Channel (MC) image operators

- **MC2ndDerivative srcImage destImage**
  The MC2ndDerivative operator calculates for each MCPixel in the srcImage the second derivative and stores this in the destImage.

- **MCCloneNrChans srcImage destImage**
  The operator MCCloneNrChans set the number of channels of the MC srcImage to the MC destImage.
  This operators is commonly used after a non-MC operator is applied to a MC image that results in new image.
  The new image will have its nrChans attribute set to 1. If the new image is to be used as MC image, nrChan has to be set to the correct value.

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Multi-Channel (MC) image operators

- **MCContrastStretch image low high**
  The operator MCContrastStretch will stretch the contrast in all channels of the MC image.
  The parameters low and high contain tuples with the low and high boundries for the stretch. Note all channels will be stretched individually.

  Example for image mc with 3 channels:|
  MCContrastStretch mc (0,0,0) (255,255,255)

- **MCConvert srcImage destImage imageType**
  The operator MCConvert converts the srcImage to a destImage of the specified imageType.

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Multi-Channel (MC) image operators

- **MCFromBIL BIL_image MC_image nrBands**
  The MCFromBIL operator creates a MC image from an image with BIL (Band Interleaved by Line) format.
  The number of bands in the BIL image has to be specified.

- **MCFromBands image &$imageTab**
  The MCFromBands operator creates a MC image using the specified band image with the array variable imageTab.
  Note: the array variable name should be specified with &$, example: &$imageTab.

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Multi-Channel (MC) image operators

- **MCFromDemosaic srcImage destImage nrHBands nrVBands**
  The operator MCFromDemosaic converts the raw mosaic srcImage to a MC destImage. The number of horizontal and vertical bands in the mosaic are specified with nrHBands and nrVBands.
- **MCGetChan image channelImage chanNr**
  The MCGetChan operator copies the channel chanNR in MC image to specified channelImage.
- **MCGetChans image &$imageTab**
  The MCGetChans operator converts the specified MC image to a band image specified with the array variable imageTab.
  Note: the array variable name should be specified with &$, example: &$imageTab.

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Multi-Channel (MC) image operators

- **MCGetNrChans image**
  The MCGetNrChans returns the number of channels of the MC image.
- **MCGetPixel image pixel x y**
  The MCGetPixel operator selects the MC pixel at position (x,y) and convert it to an image with name pixel.
- **MCGetHeightWidth image**
  The MCGetHeightWidth operator returns the tuple (height,width) of the MC image in MC pixels.

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Multi-Channel (MC) image operators

- **MCMerge src1Image src2Image destImage**
  The MCMerge operator merges the channel of two MC source images into the MC destionation images.|
  The source images should have the same height and width in MC pixels.

- **MCNVDI srcImage destImage nirBand visBand**
  The MCNVDI calculated the Normalized Difference Vegetation Index in the MC src image using the specified nirBand and visBand.
  The result is stored in destImage of type FloatImage.

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Multi-Channel (MC) image operators

- **MCReadENVI imageName filename**
  The ENVI file with fileName is read and added to the server with imageName.
  Note that one ENVI file "comes in pairs", one file with extension .raw and one file with extension .hdr .
  The .raw or .hdr file must be specified as fileName.
  ReadENVI uses file path of server, MClReadENVI file path of client.
  Note: not all sub-types of the ENVI are supported. No support yet for Write_ENVI.

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Multi-Channel (MC) image operators

- **MCReorder srcImage destImage orderList**
  The MCReorder operator copies the MC srcImage to the MC destImage and reorder the channels in the MC destination pixel according to orderList.
  The orderList is specified as a tuple with the desired channel order of the new channels using the channel numbers of the original image.
  Example for an MC image with 25 channels:
  (1,0,3,2,5,4,7,6,9,8,11,10,13,12,15,14,17,16,19,18,21,20,23,22,24)

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Multi-Channel (MC) image operators

- **MCROI srcImage destImage x y height width**
  The MCROI operator copies the ROI specified by x, y, height and width in the MC srcImage to the MC dstImage.
  Note that x, y, height and width are defined for MC pixels.

- **MCROI2Points srcImage destImage leftTop rightBottom height width**
  This operator is intended to be used with the LineTool widget.
  The MCROI2Points operator copies a ROI rectangle in the MC srcImage to the MC dstImage.
  If height = 0 the rectangle is defined by the leftTop and rightBottom coordinates.
  If height != 0 the rectangle is defined by the leftTop coordinate, height and width.
  Note that leftTop and rightBottom coordinates, height and width are defined for MC pixels.

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Multi-Channel (MC) image operators

- **MCSelectChans srcImage destImage (c1,..,cn)**
  The MCSelectChans operator copies the specified channels MC srcImage to MC destImage.
  Note that the selected channels are specified as a vector with no spaces in the string.

- **MCSelectRange srcImage destImage first last**
  The MCSelectRange operator copies the range of channel between first and last of MC srcImage to MC destImage.
  Note that the selected channels are specified as a vector with no spaces in the string.

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Multi-Channel (MC) image operators

- **MCSetChan image channelImage chanNr**
  The MCSetChan operator replaces channel chanNR in MC image with specified channelImage.

- **MCSetChans image &$imageTab**
  The MCSetChans operator converts a band image specified with the array variable imageTab to a MC image with name image.
  Note: the array variable name should be specified with &$, example: &$imageTab.

- **MCSetNrChans image nrChans**
  The MCSetNrChans operator sets the number of channels of the MC image to nrChans.

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Multi-Channel (MC) image operators

- **MCSetPixel image pixel x y**
  The MCSetPixel operator sets the MC pixel at position (x,y) to the image with name pixel.
- **MCTile srcImage destImage nrH nrV**
  The MCTile converts a MC image to an ordinary image with tiles. Each tile represents a channel. The number of horizontal tile is specified with the parameter nrH and and vertical with nrV.
- **MCTranspose srcImage destImage**
  The MCTranspose operator performs a transpose operation, with respect to the multi-channel pixel, on the srcImage and stores the result in destImage.

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Multi-Channel (MC) image operators

- **MCZoom srcImage destImage height width interpolation**
  MCZoomXY srcImage destImage factorX factorY interpolation
  The MCZoom operator initialises a destination MC image by enlarging of reducing the source MC image with the specified height and width using the specified interpolation technic.
  The MCZoomxy operator initialises a MC destination image by enlarging of reducing the source MC image with the specified factors for x and y direction using the specified interpolation technic.
  Note: both operators have a c++ prototype with the same name MCZoom.

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