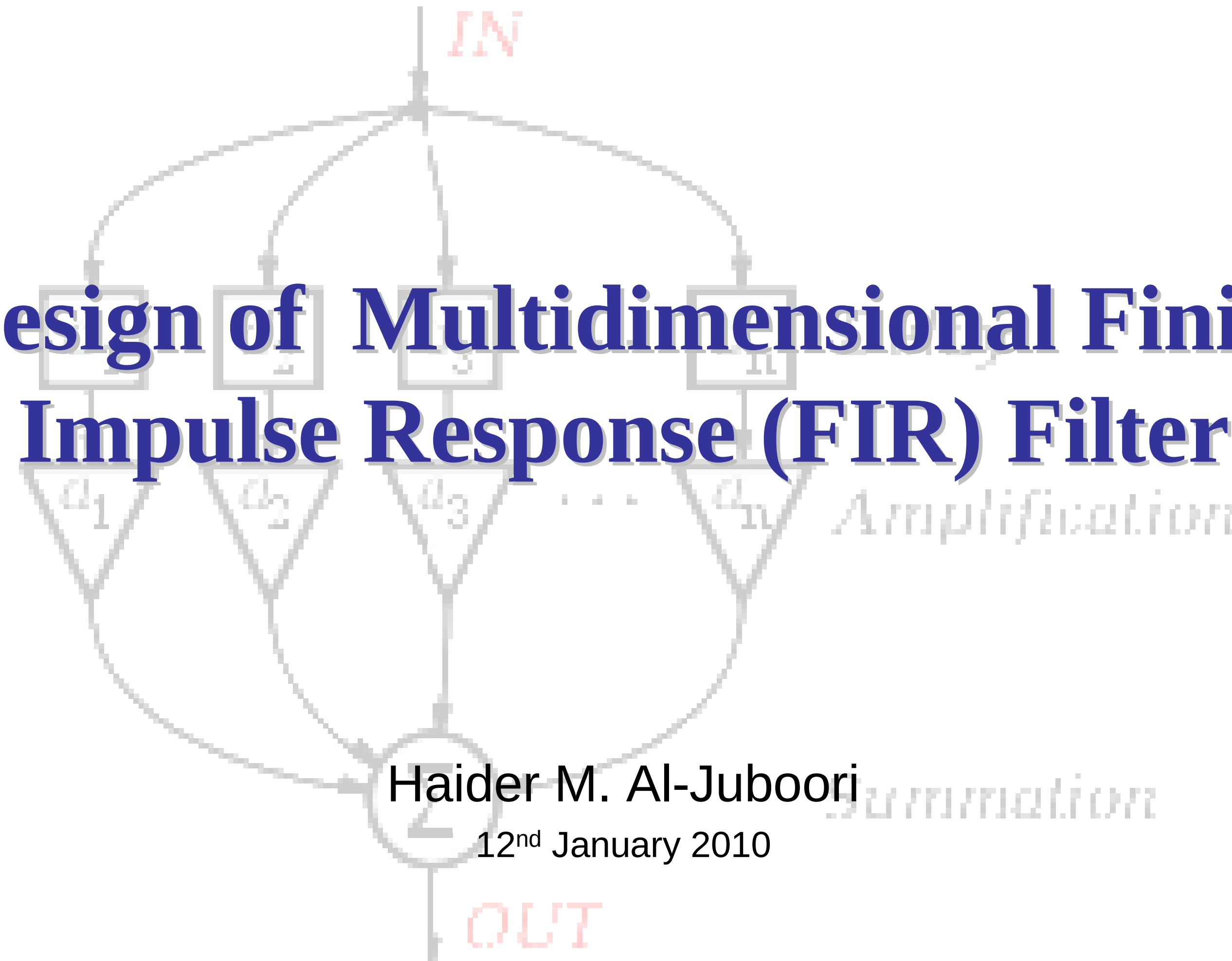
Design of Multidimensional Finite Impulse Response (FIR) Filter



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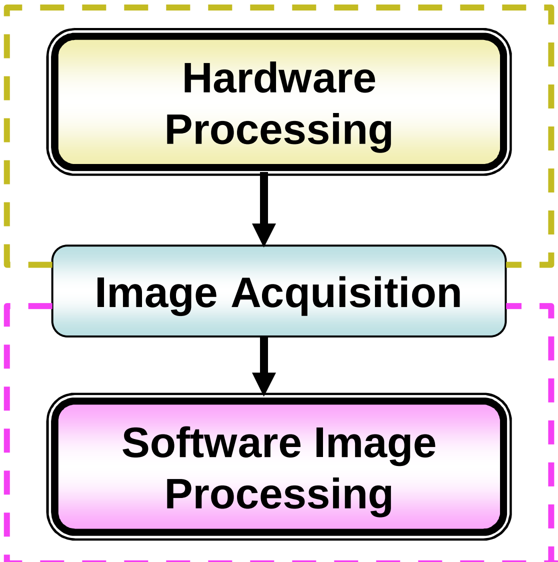
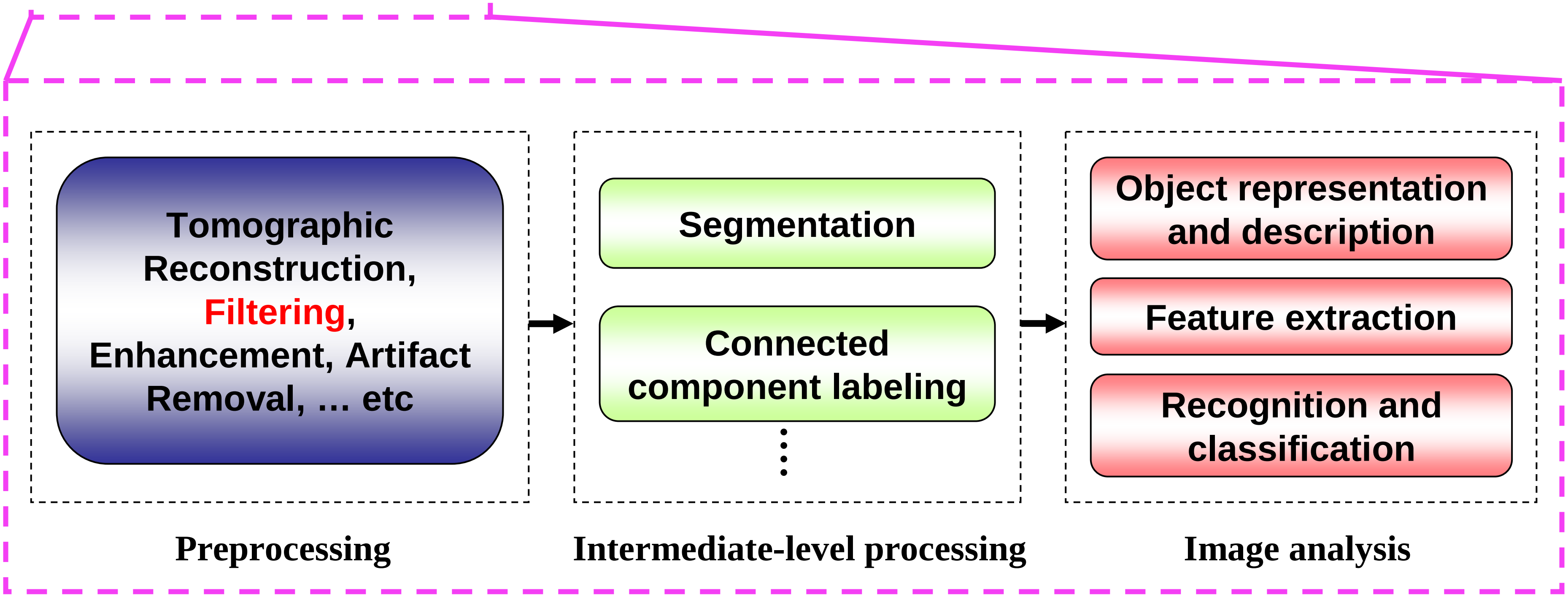
Presentation Outline

- Image processing and analysis pipeline
- Spatial filter ↔ Digital image processing
- Frequency-selective operations
- Digital filter design
    - FIR filter design using windowing method
    - FIR filter ↔ Digital image processing
- FIR filter ↔ Multidimensional filtering
- Conclusions and future works

Image Processing and Analysis Pipeline



The image processing and analysis pipeline can be divided into four stages, the following figure depicts this pipeline. As seen in this diagram, these stages include image acquisition, preprocessing, intermediate-level processing, and image analysis. The preprocessing stage is also known as ***low-level processing***.



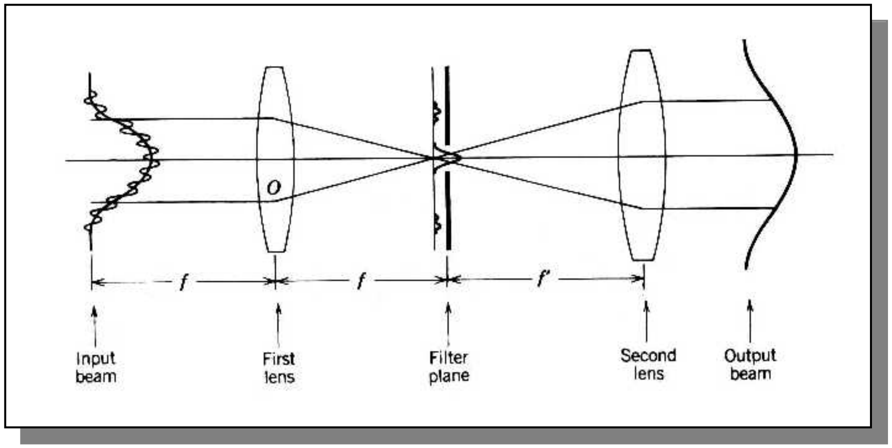
Spatial Filter ↔ Digital Image Processing

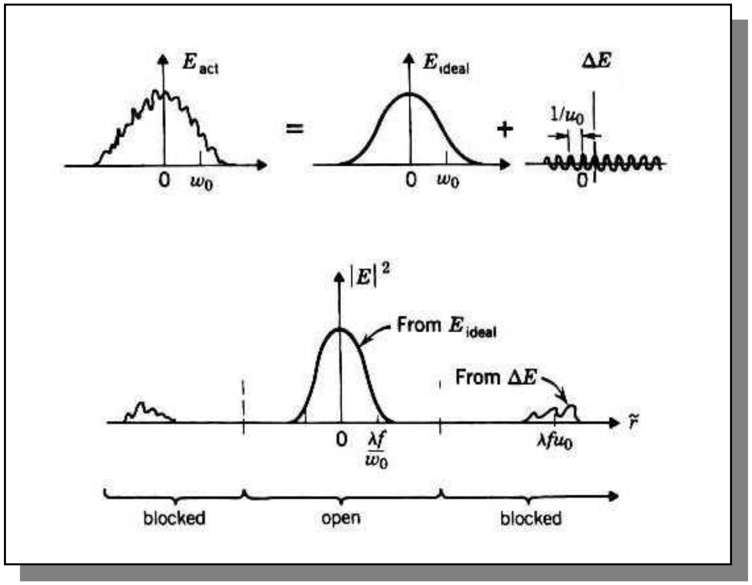
The spatial filter is designed to remove the most unwanted ripples while passing most of the laser beam energy.

a spatial filter is a low-pass filter, and the pin-hole diameter controls which spatial frequencies up to a cut-off (C_f) are passed.

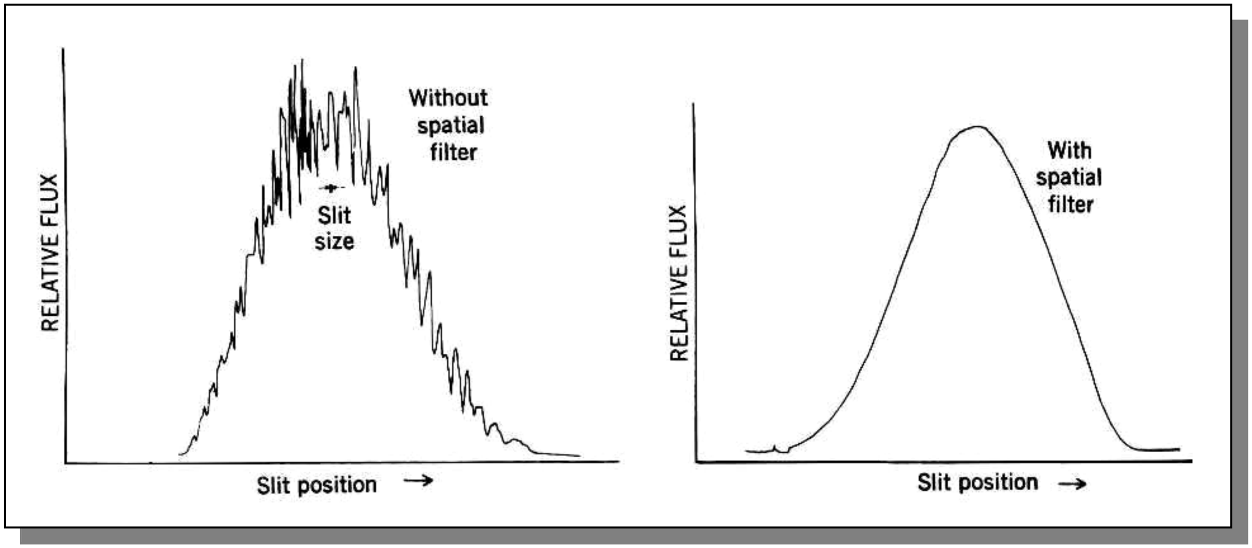
A low-pass filter consists of a small aperture that blocks all of the high frequency components of the object so that the image is "smooth out".

$$E_{actual} = E_{ideal} + \Delta E$$

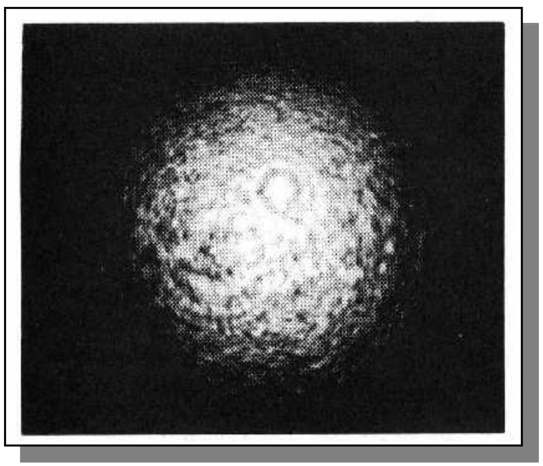




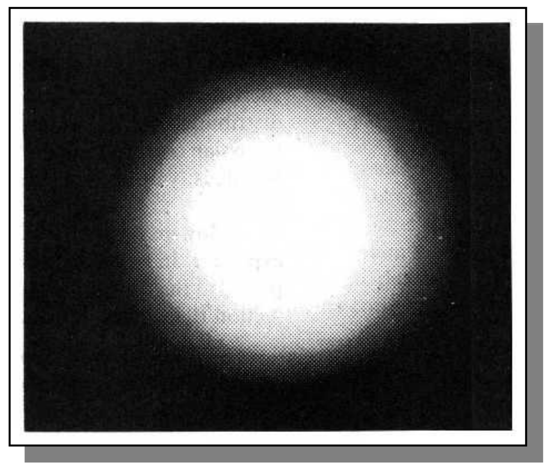
Spatial Filter ↔ Digital Image Processing



Without spatial filter

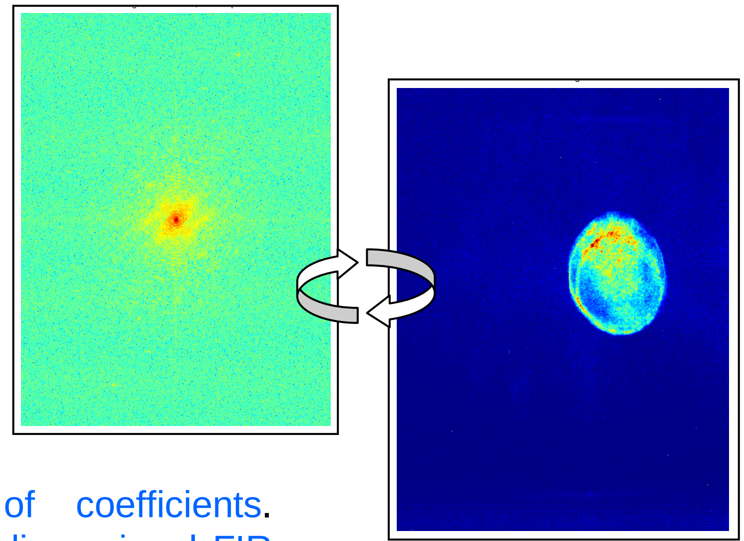


With spatial filter



The effect of spatial filtering on a uniphase Laser beam. The plots show the results of scanning across the beam with a narrow slit in front of a photometer. (Illustrations courtesy of Spectra-Physics, Inc) .

Frequency-Selective Operations



Two-Dimensional Fourier Transform (FT)

the idea behind the FT is to represent the temporal (time) or spatial (space) variations in the signals in terms of some sinusoidal basis functions (i.e., sinusoidal signals of different frequencies).

2-D FIR Filter Features

FIR filters have several characteristics that make them ideal for image processing, such as;

1. The FIR filters are easy to represent as matrices of coefficients.
2. The Two-dimensional FIR filters are natural extensions of one-dimensional FIR filters.
3. The FIR filters can be designed to have linear phase, which helps to prevent distortion.
4. The FIR filters are always stable and are free from limit cycles that arise as a result of finite word-length representation of multiplier constants and signal values.

2-D FIR Filter Design

FIR filters can be achieved by using several methods, such as;

1. The frequency transformation method, which transforms a one-dimensional FIR filter into a two dimensional FIR filter.
2. The frequency sampling method, which creates a filter based on a desired frequency response.
3. The windowing method, which multiplies the ideal impulse response with a window function to generate the filter.

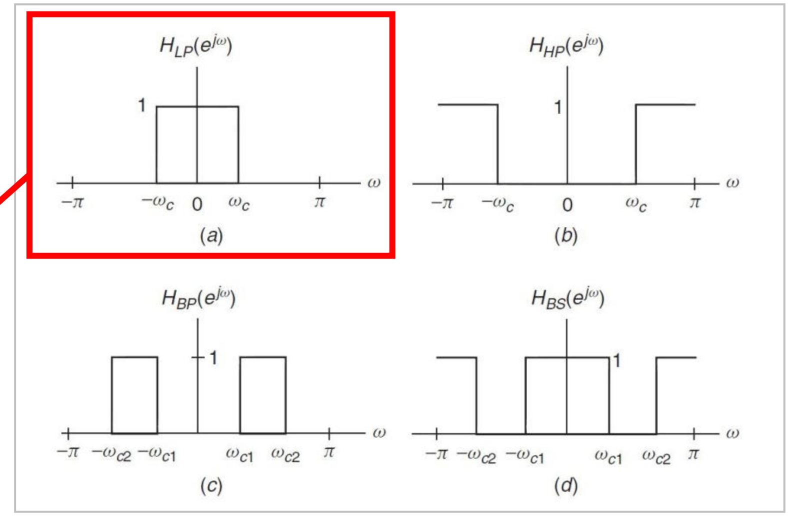
Digital Filter Design

Specifying an FIR Filter

The magnitude response of FIR filter can designed according to the application:

The frequency response of ideal low-pass filter satisfies:

$$H_{\mathrm{LP}}(e^{j\omega}) = \begin{cases} 1, & 0 \le \omega \le \omega_c \\ 0, & \omega_c < \omega \le \pi \end{cases}$$



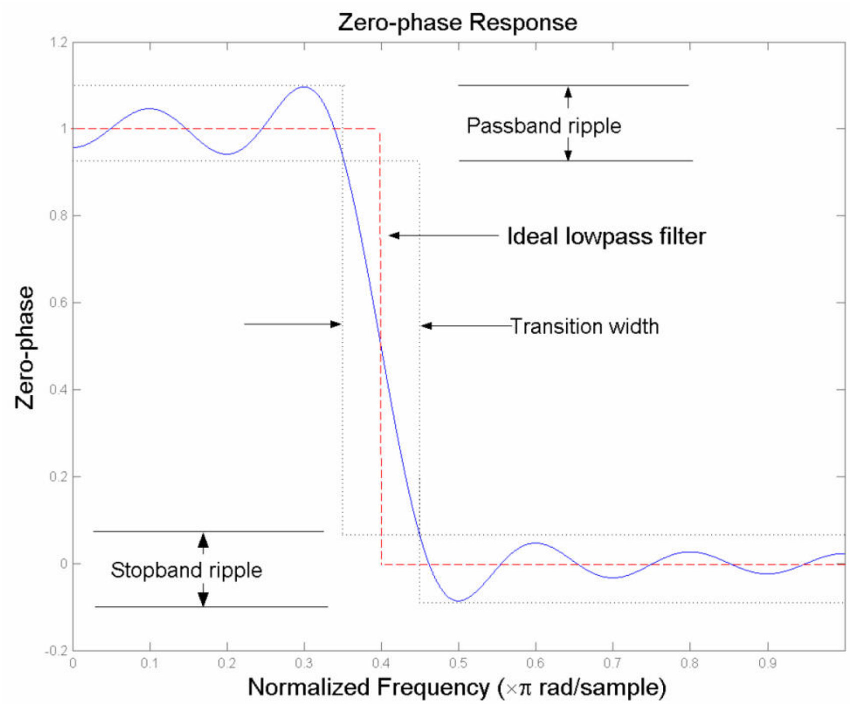
The impulse response of the ideal low-pass filter can easily be found to be:

$$h_{\mathrm{LP}}[n] = \frac{\sin(\omega_c n)}{\pi n}, \quad -\infty < n < \infty$$

Finite length approximations to the ideal impulse response lead to the presence of ripples in both the passband ($\omega < \omega_c$) and the stopband ($\omega > \omega_c$) of the filter.

Type of Window	$\Delta\omega_M$	$\Delta\omega$	A_{sl} (dB)	A_s (dB)
Rectangular	$4\pi/(2M+1)$	$0.92\pi/M$	13	20.9
Bartlett	$4\pi/(M+1)$	—[a]	26.5	—[a]
Hann	$8\pi/(2M+1)$	$3.11\pi/M$	31.5	43.9
Hamming	$8\pi/(2M+1)$	$3.32\pi/M$	42.7	54.5
Blackman	$12\pi/(2M+1)$	$5.56\pi/M$	58.1	75.3

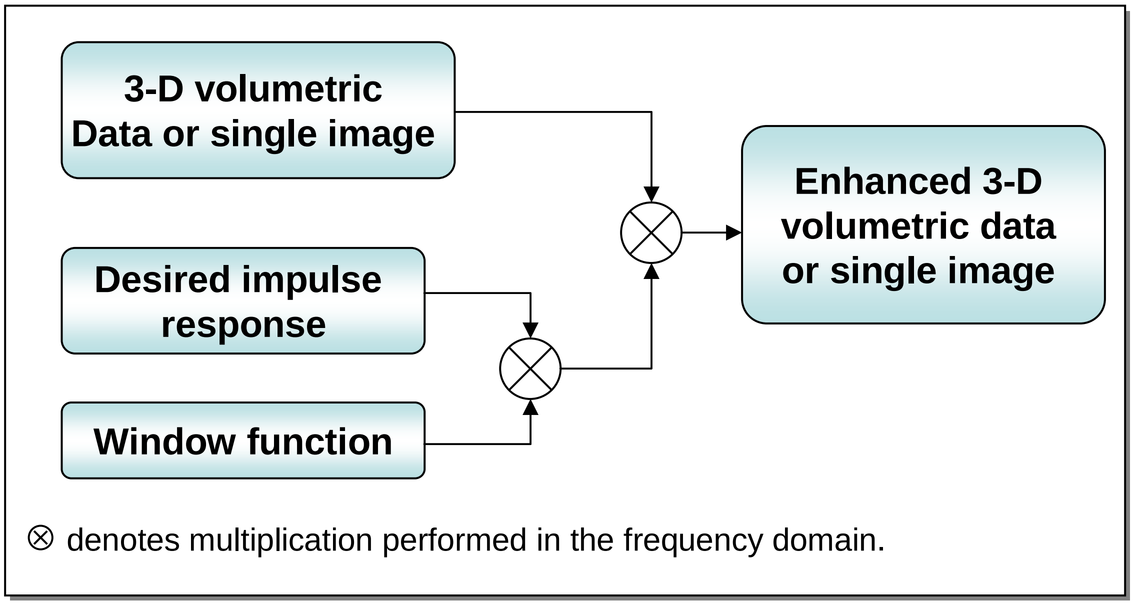
[a] The frequency response of the Bartlett window decreases monotonically and therefore does not have sidelobes. So the transition bandwidth and sidelobe attenuation cannot be found for this window.



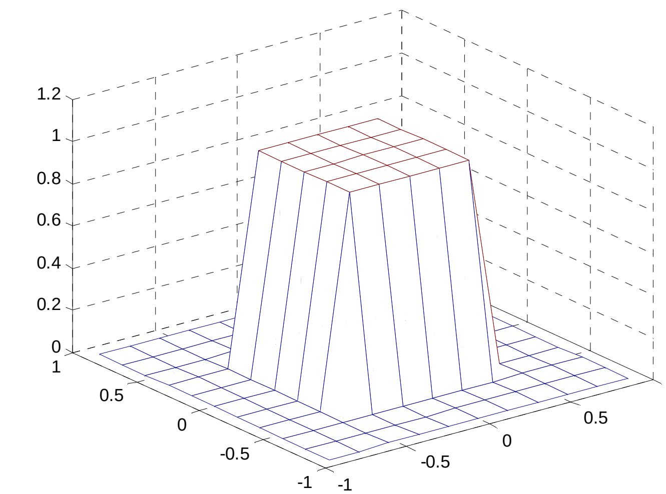
FIR Filter Design Using Windowing Method

FIR Filter Design Procedures

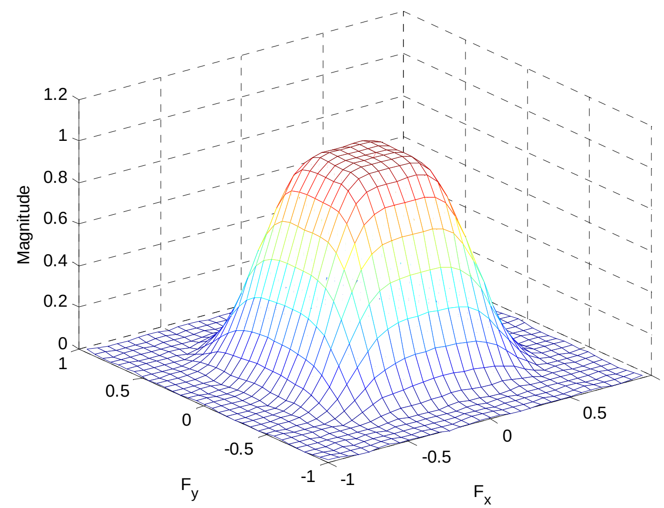
The windowing method involves multiplying the ideal impulse response with a window function to generate a corresponding filter.



Flow Diagram of Design Process for FIR filter



Desired Two-Dimensional Frequency Response



Actual Two-Dimensional Frequency Response

the windowing method has the ability to produce a filter whose frequency response approximates a desired frequency response, in addition, this response will depend on window type.

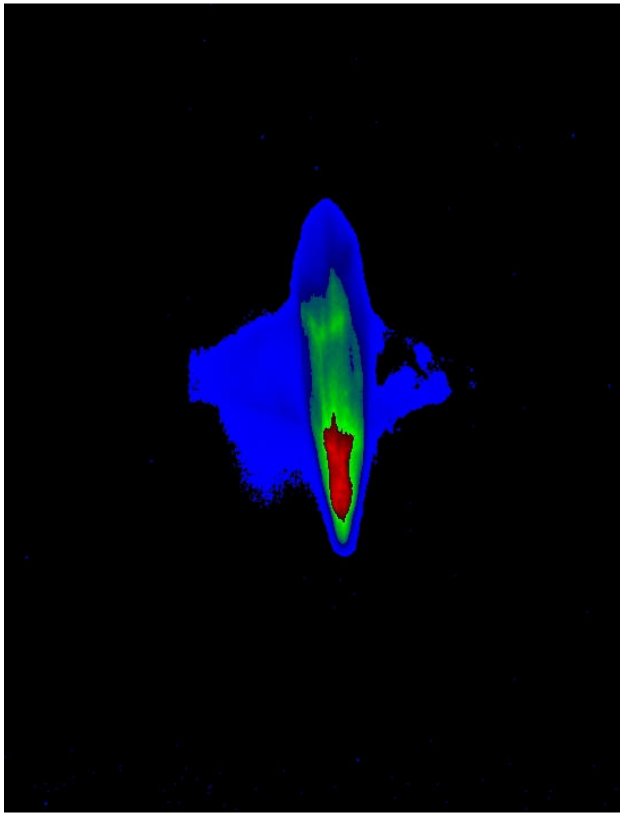
the Hamming windowing function have Minimum Stop-band Attenuation (dB) equal to 54, and Transition Bandwidth 6.64 f_N / N.

FIR Filter ↔ Digital Image Processing

Quality of noise reduction using FIR filter

Numerical example; RGB image

Source Image



FIR Filter ↔ Digital Image Processing

Quality of noise reduction using FIR filter

Numerical example; RGB image

Source Image

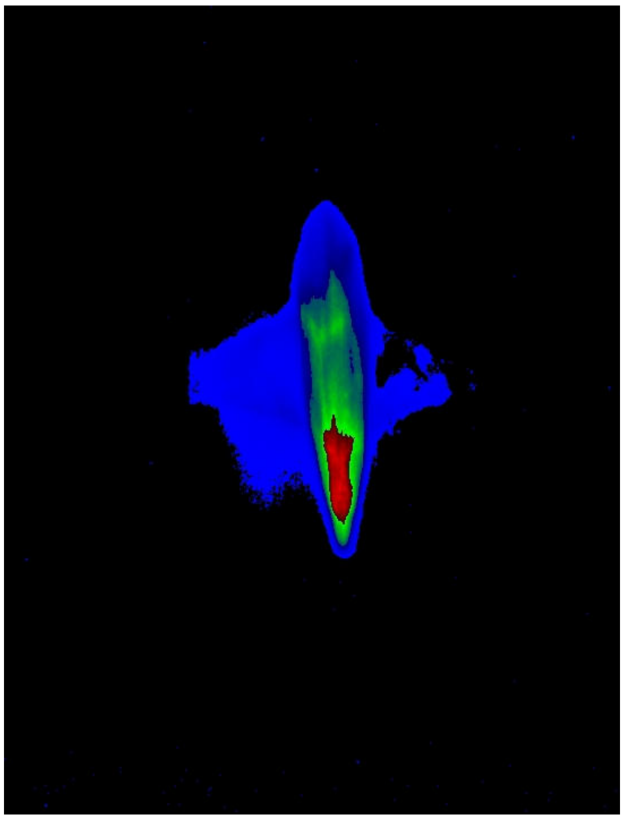
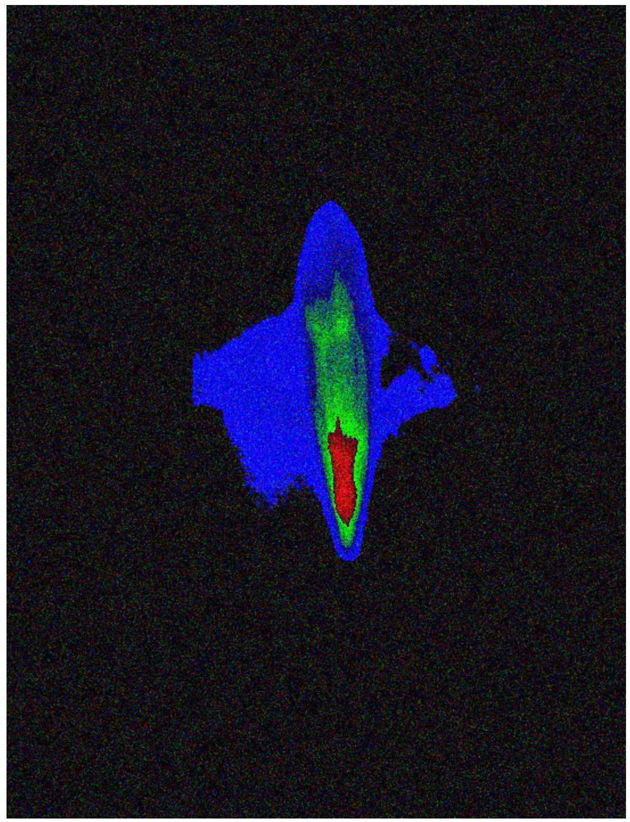


Image with Random Noise,
Compatibility with source image = **85.44 %**



FIR Filter ↔ Digital Image Processing

Quality of noise reduction using FIR filter

Numerical example; RGB image

Source Image

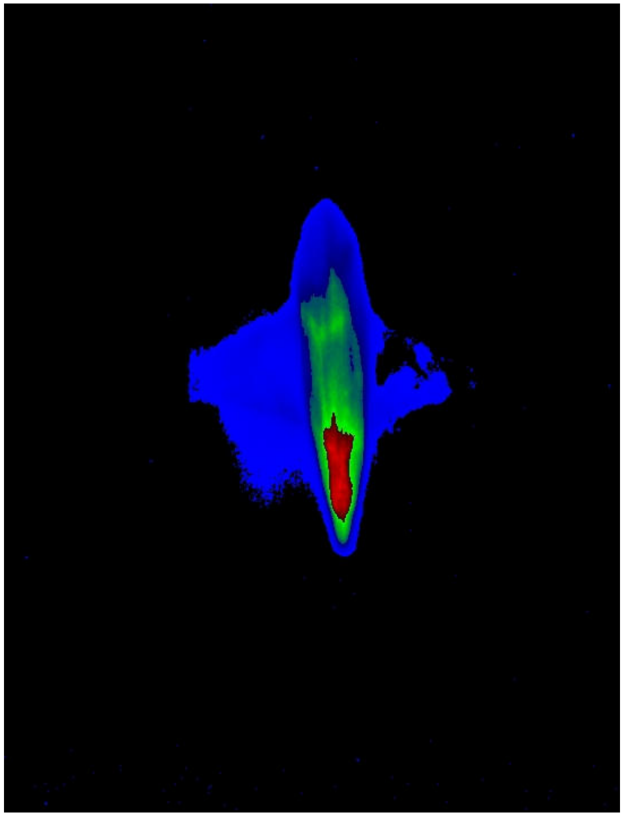


Image with Random Noise,
Compatibility with source image = **85.44 %**

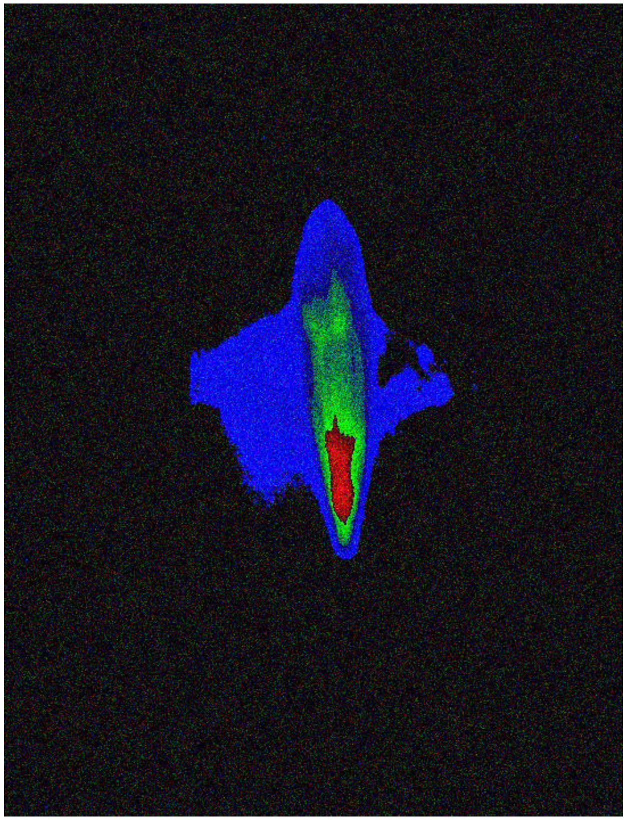
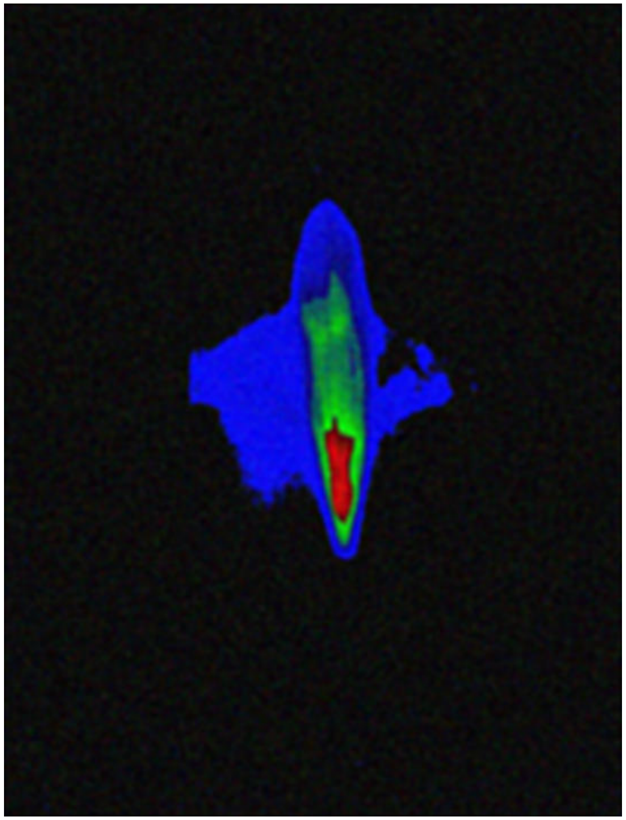


Image After FIR Filter,
Compatibility with source image= **98.82 %**



FIR Filter ↔ Digital Image Processing

Quality of noise reduction using FIR filter

Numerical example; RGB image

Source Image

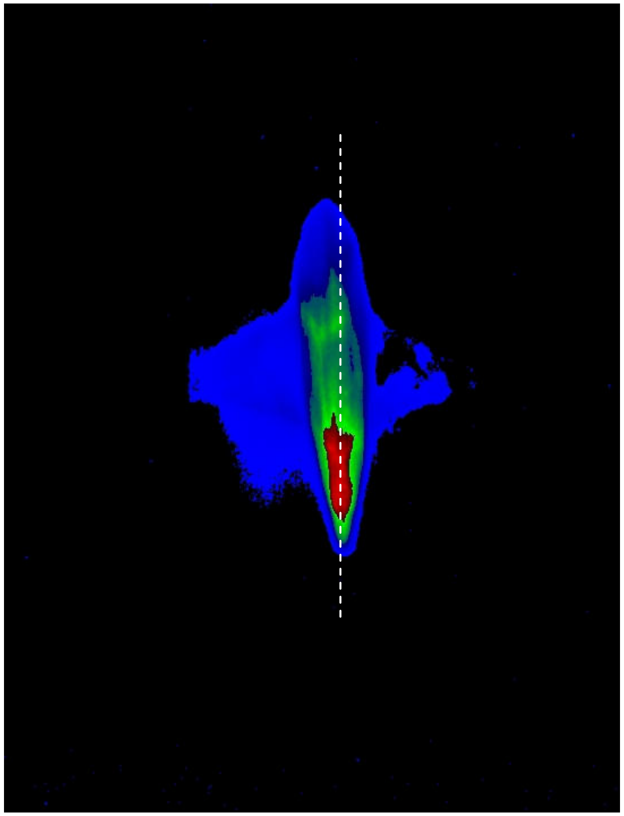


Image with Random Noise,
Compatibility with source image = **85.44 %**

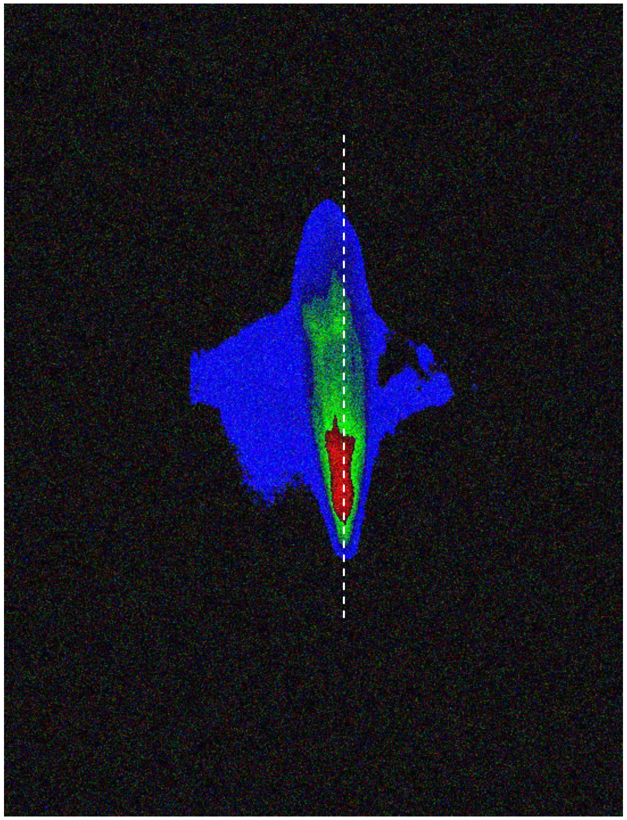
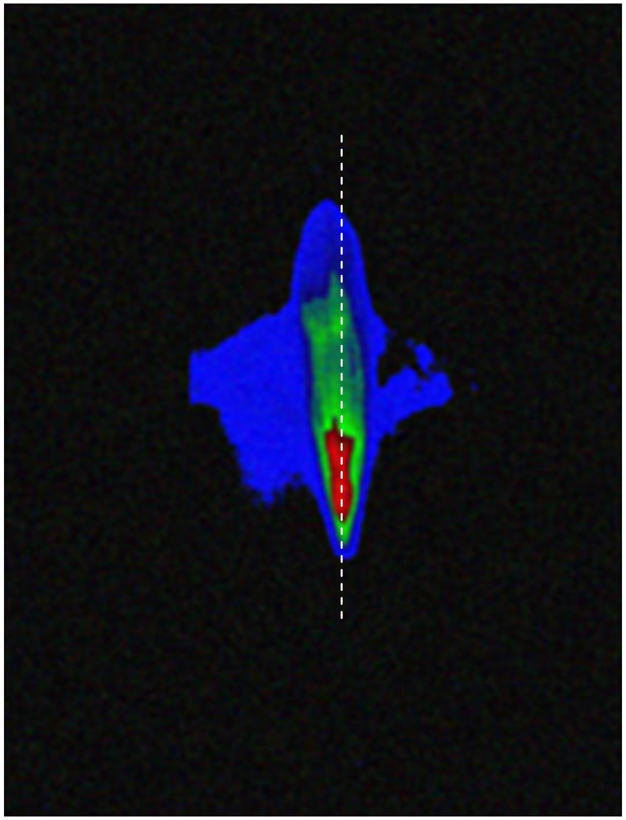


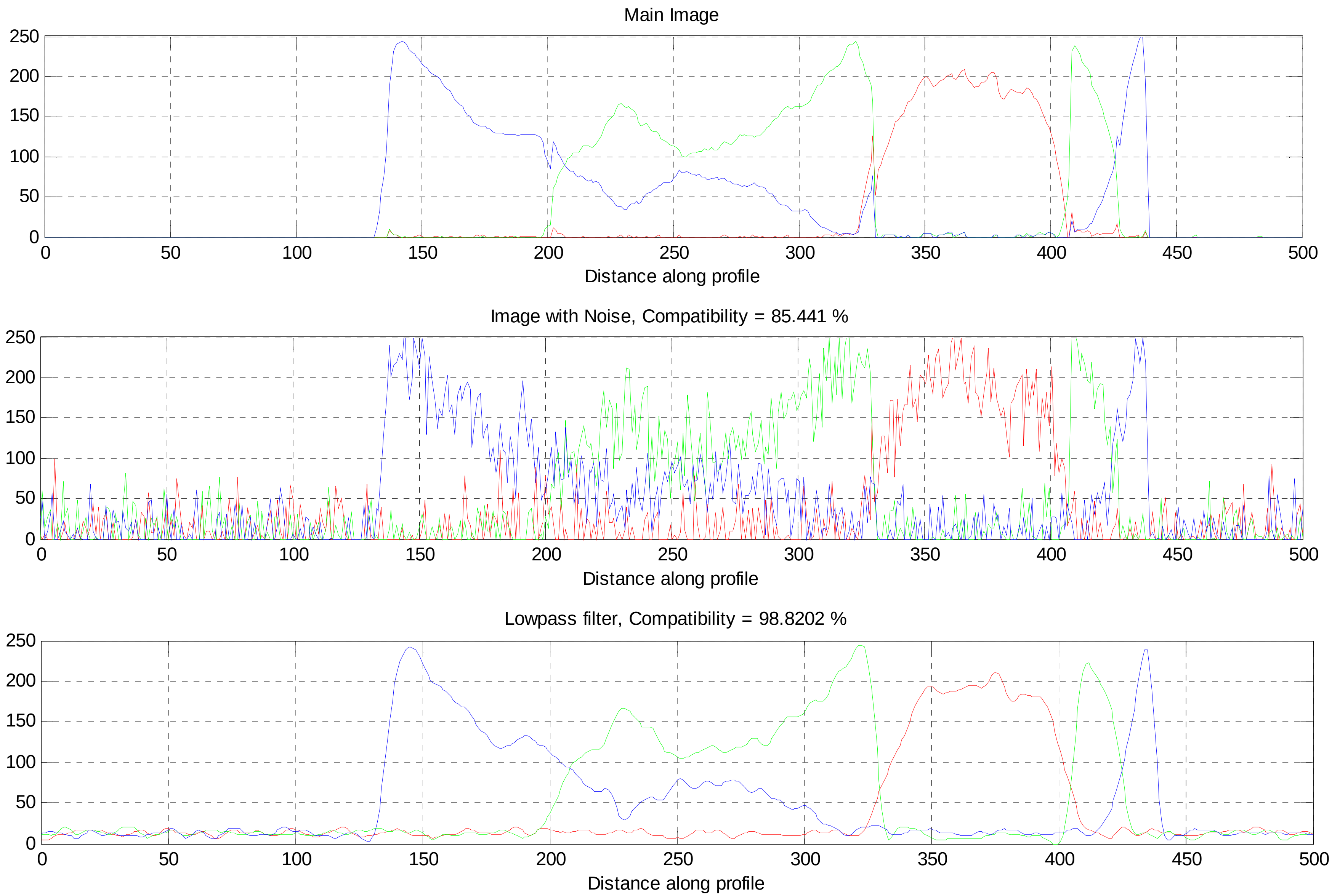
Image After FIR Filter,
Compatibility with source image= **98.82 %**



FIR Filter ↔ Digital Image Processing

Pixel-value cross-section along line segment,

computes the intensity values along a line path in an image, Numerical example; RGB image

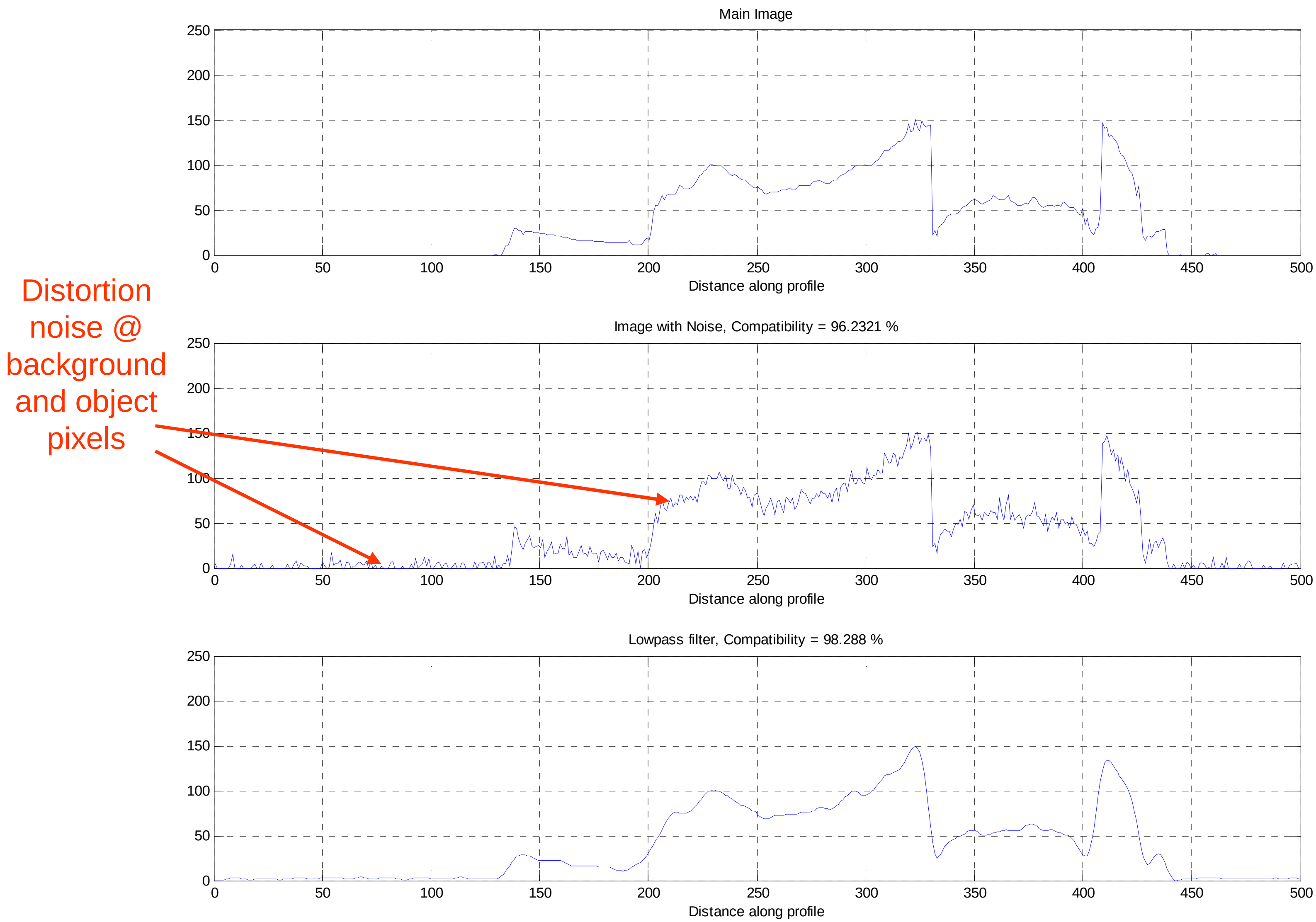


FIR Filter ↔ Digital Image Processing

Pixel-value cross-section along line segment,

computes the intensity values along a line path in an image

Numerical example (1); grayscale image

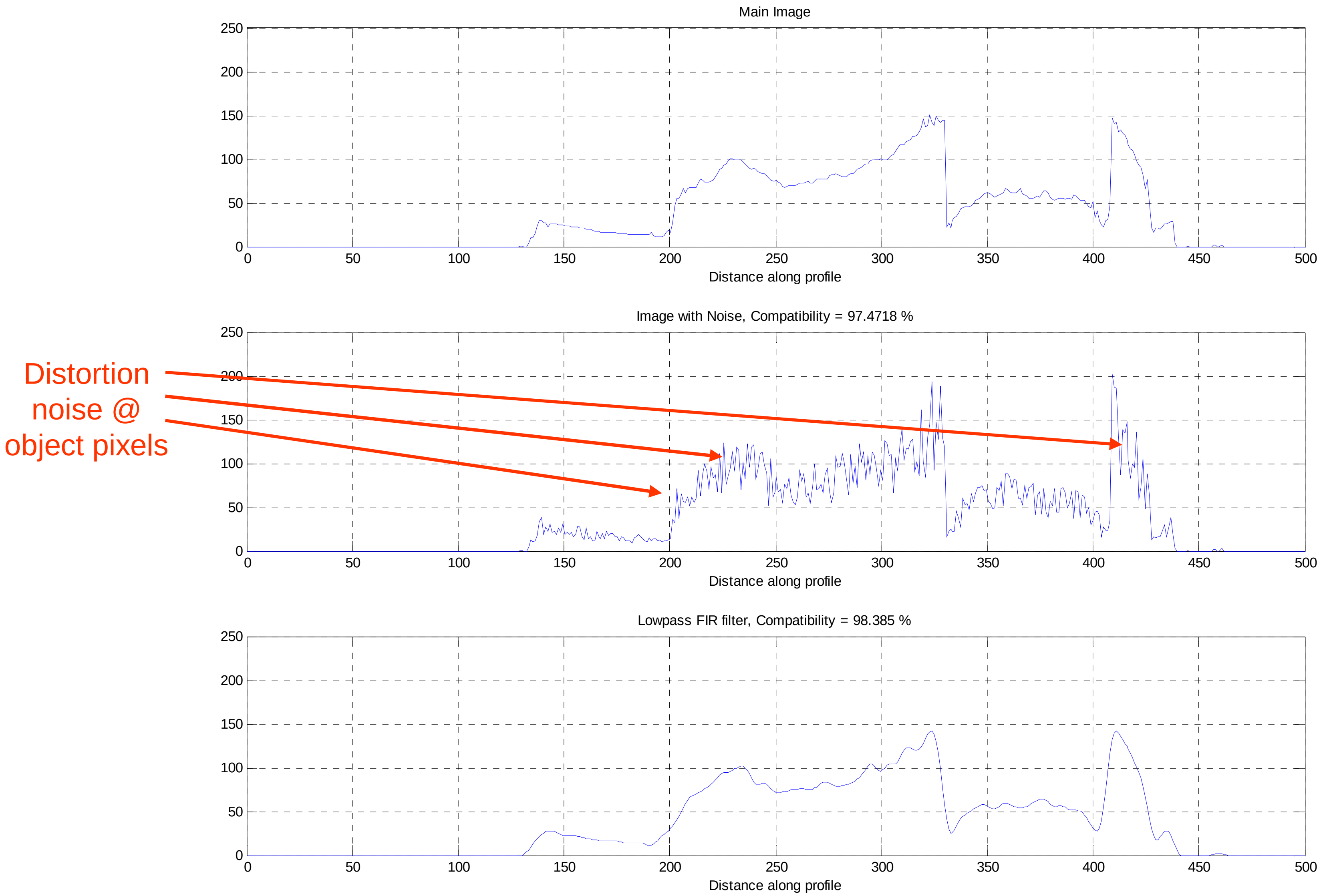


FIR Filter ↔ Digital Image Processing

Pixel-value cross-section along line segment,

computes the intensity values along a line path in an image

Numerical example (2); grayscale image



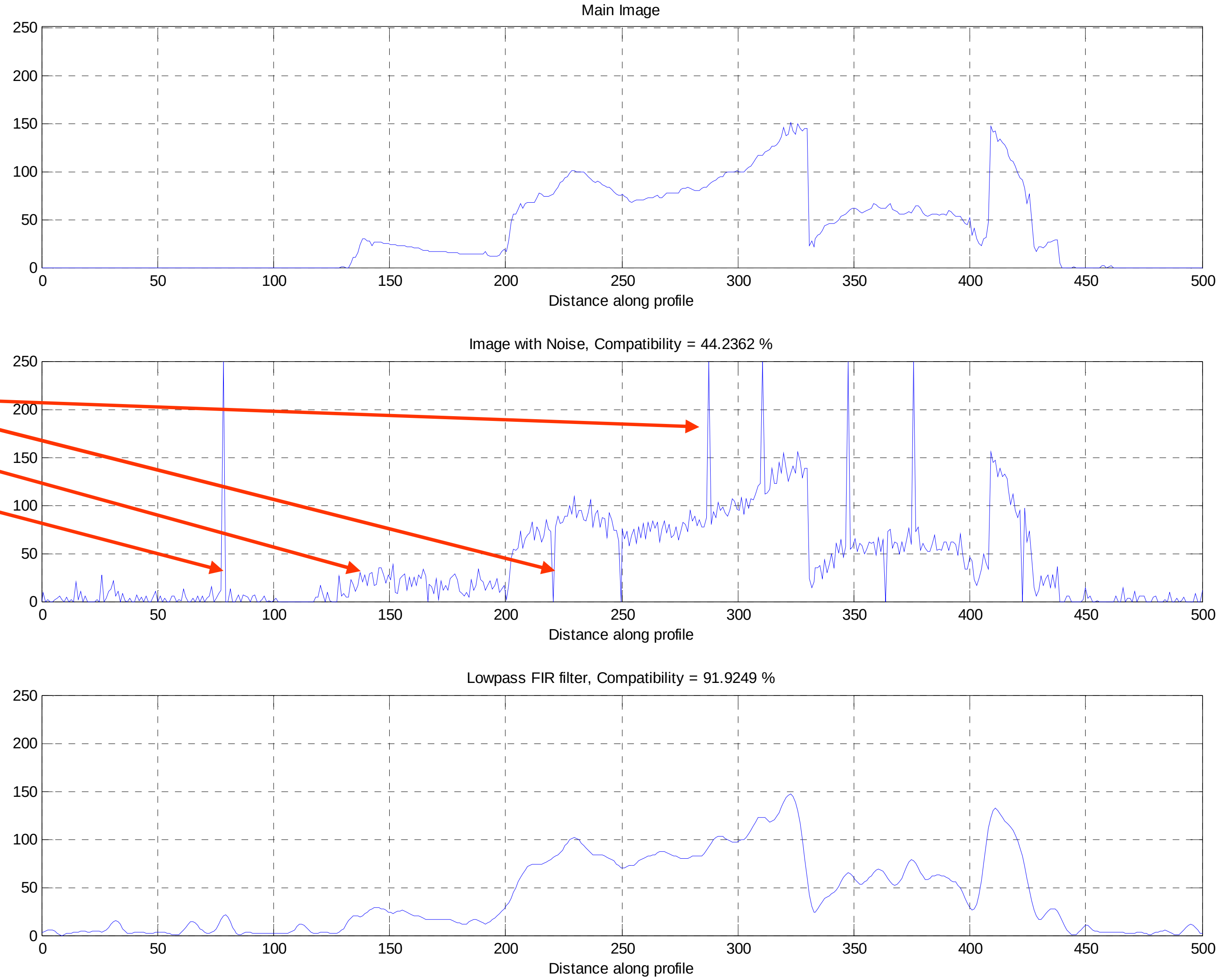
FIR Filter ↔ Digital Image Processing

Pixel-value cross-section along line segment,

computes the intensity values along a line path in an image

Numerical example (3); grayscale image

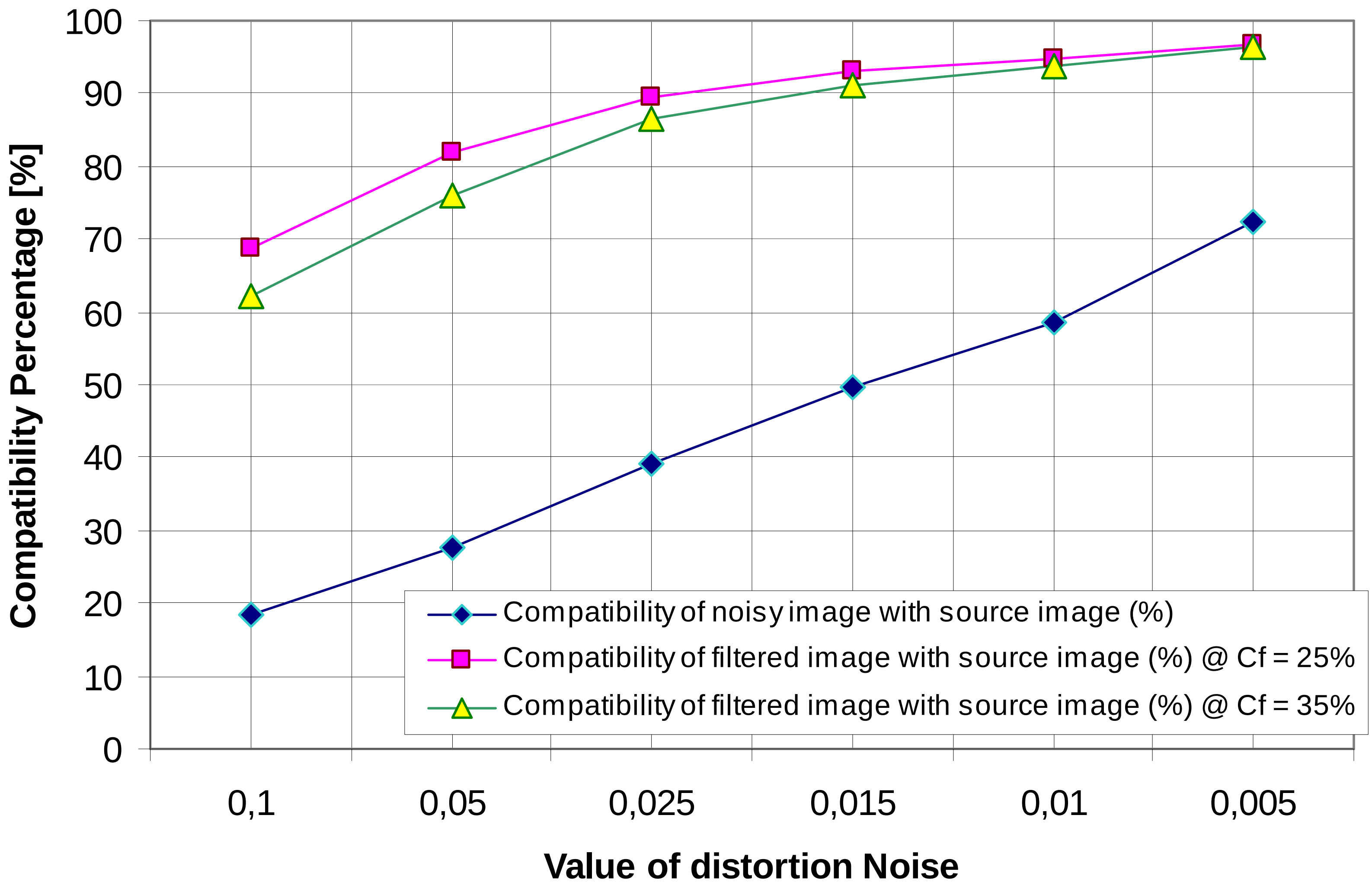
Complex noise @ background and object pixels



FIR Filter ↔ Digital Image Processing

Quality of noise reduction using FIR filter

Numerical example; grayscale image



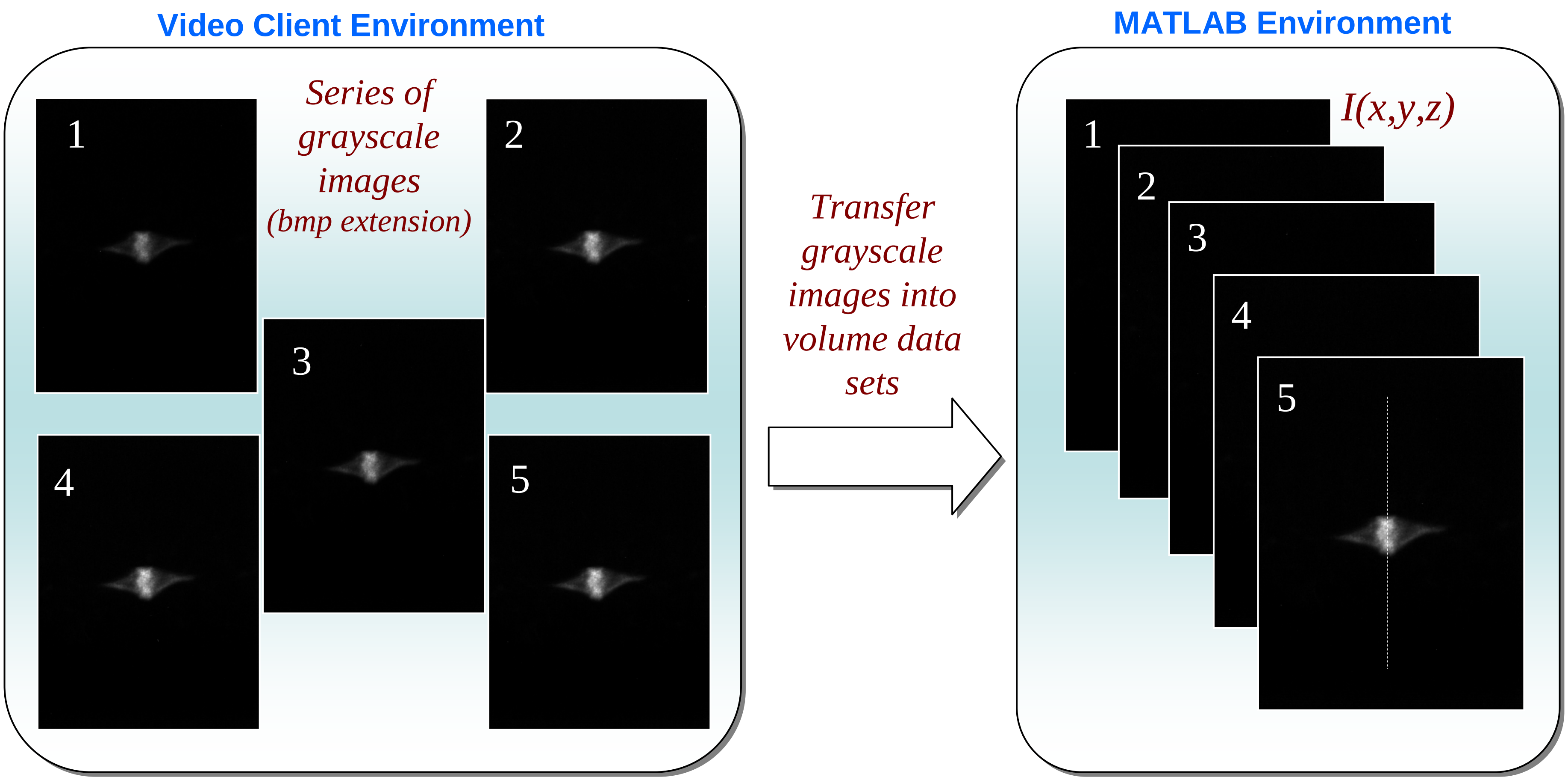
*Numerical parameters are normalized; they correspond to operations with images with intensities ranging from 0 to 1.

C_f is the cutt-off frequency.

Definition of 3-D Images

3-D volumetric images:

3-D (or volume) images are represented by a stack of 2-D images as *I(x,y,z)*, where *z* refers to the slice number.



Volume data sets are characterized by multidimensional arrays of scalar or vector data. These data are typically defined on lattice structures representing values sampled in 3-D space.

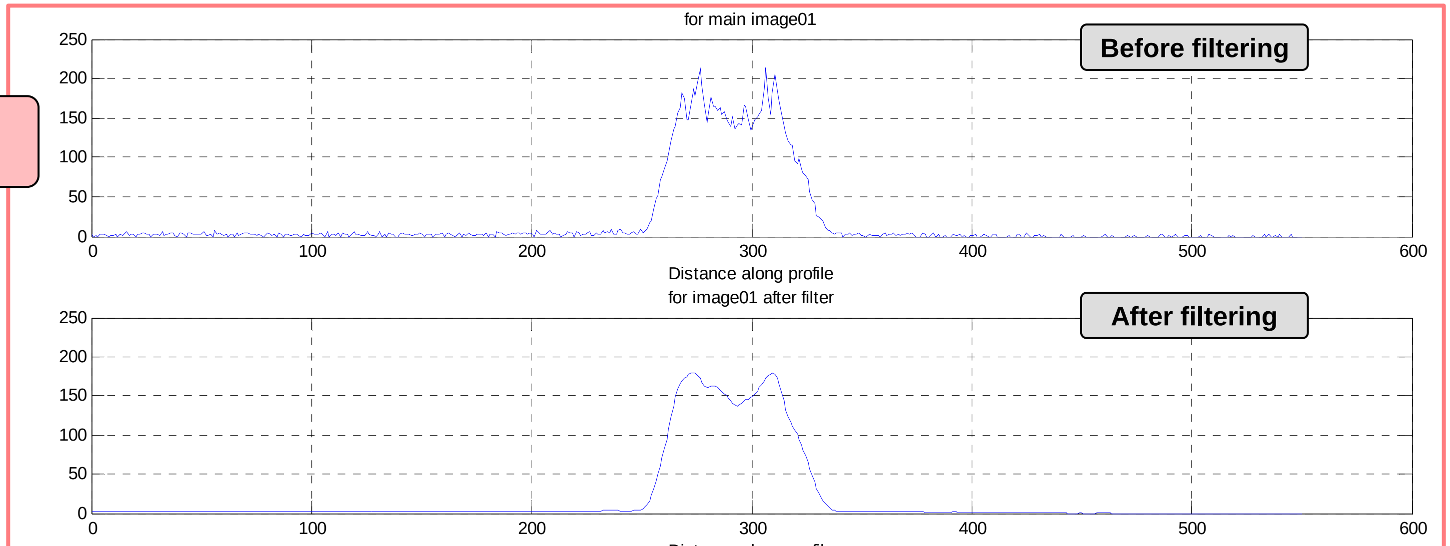
FIR Filter ↔ Multidimensional Filtering

Pixel-value cross-section along line segment,

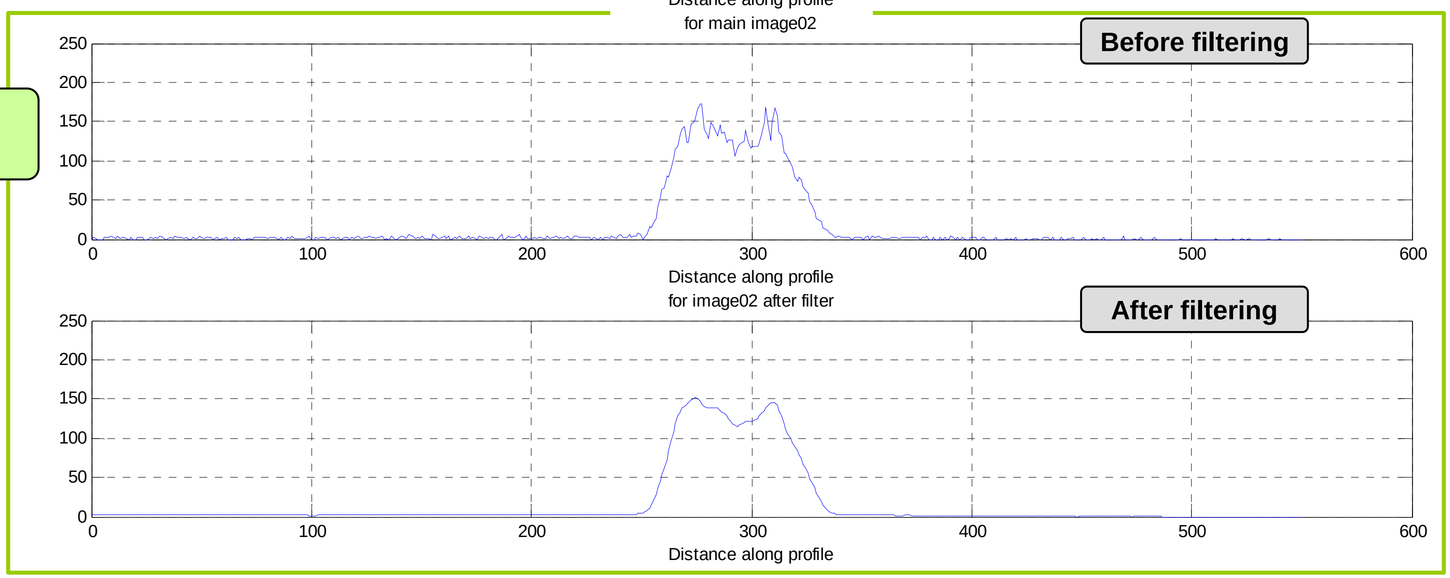
computes the intensity values along a line path in an image

Numerical example ; grayscale image

Slice 01



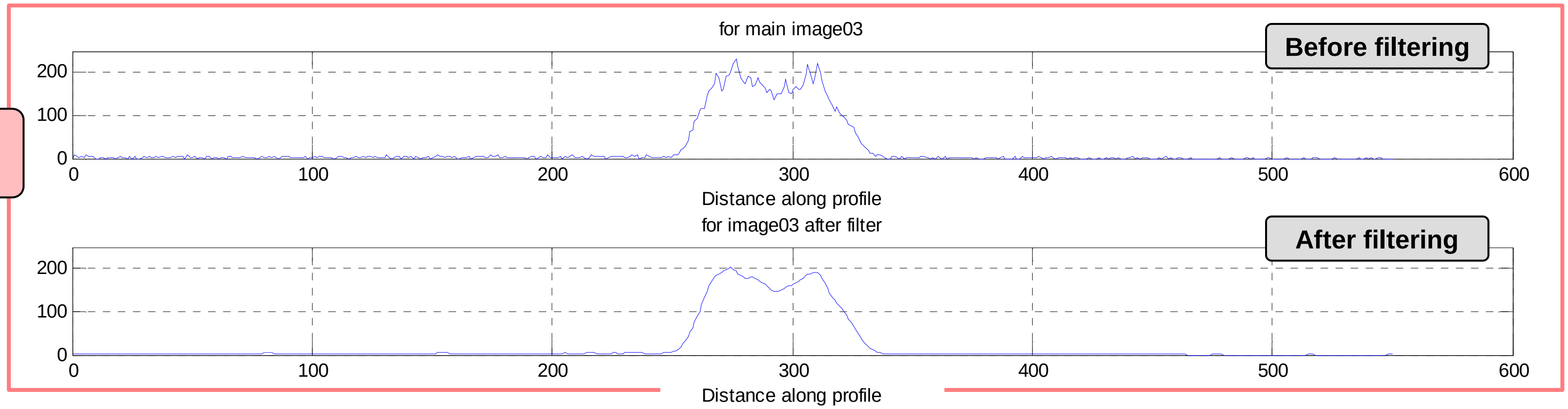
Slice 02



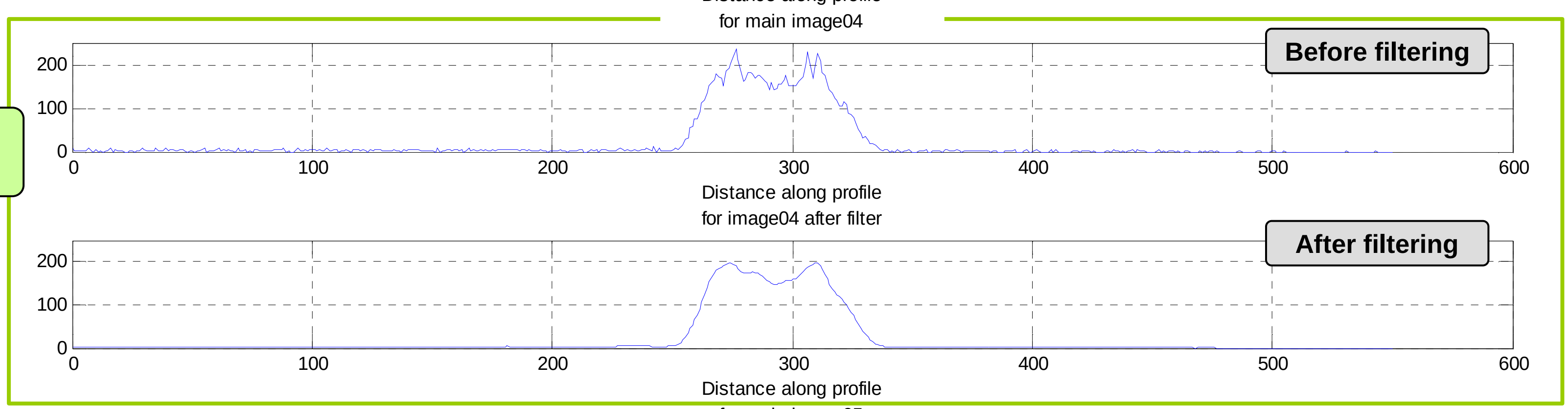
FIR Filter ↔ Multidimensional Filtering

Pixel-value cross-section along line segment

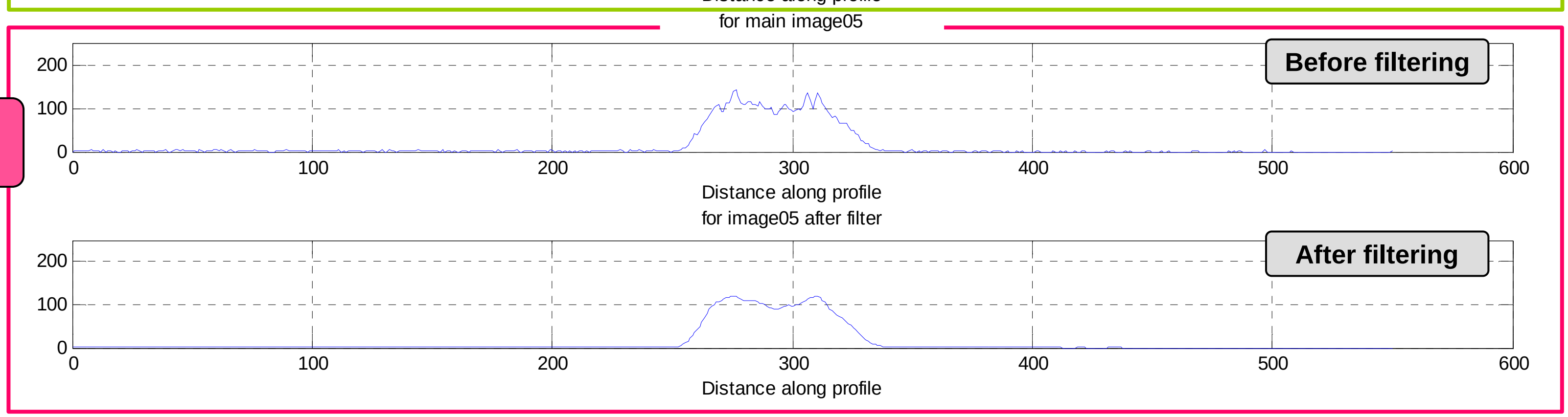
Slice 03



Slice 04

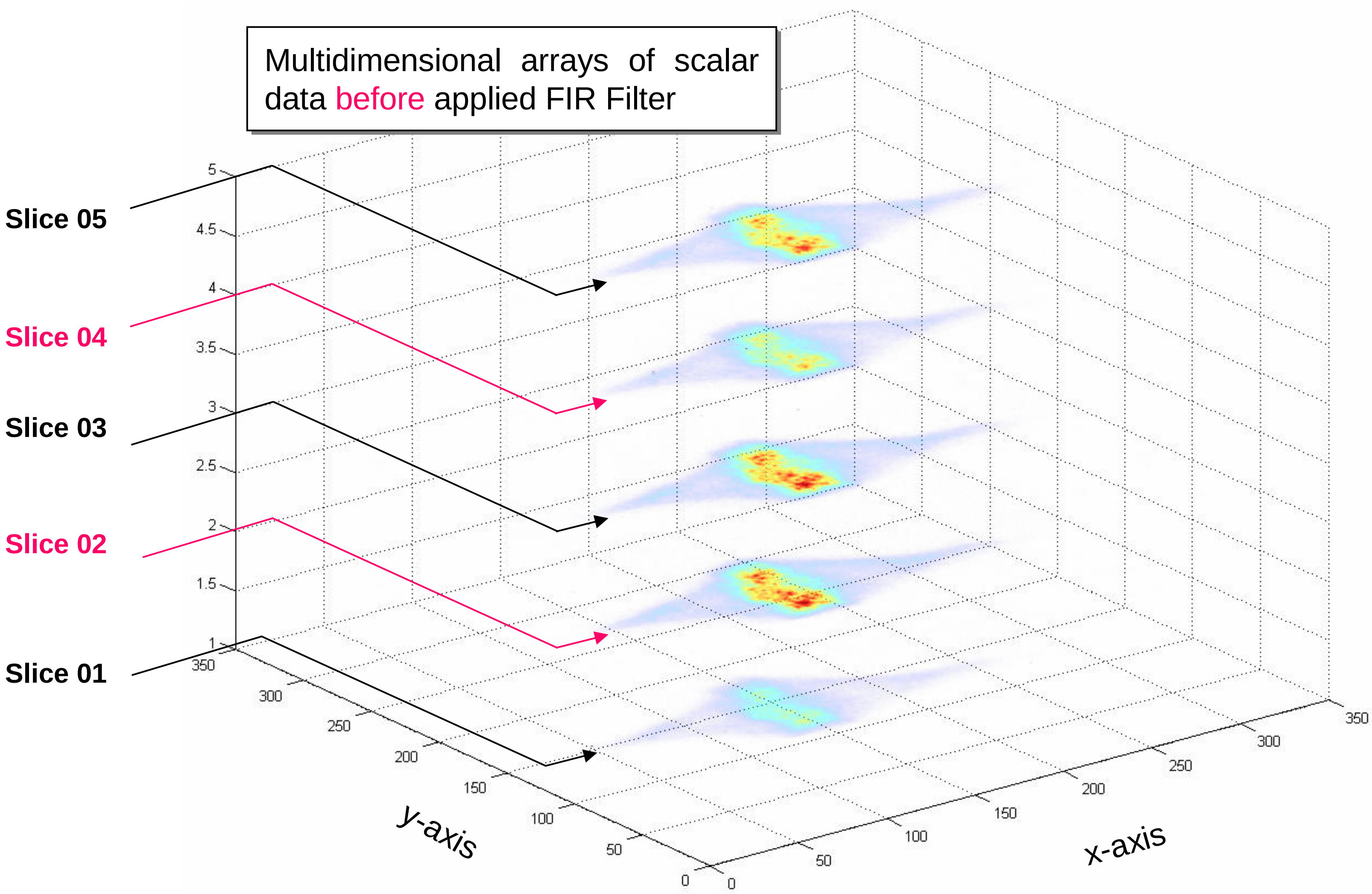


Slice 05



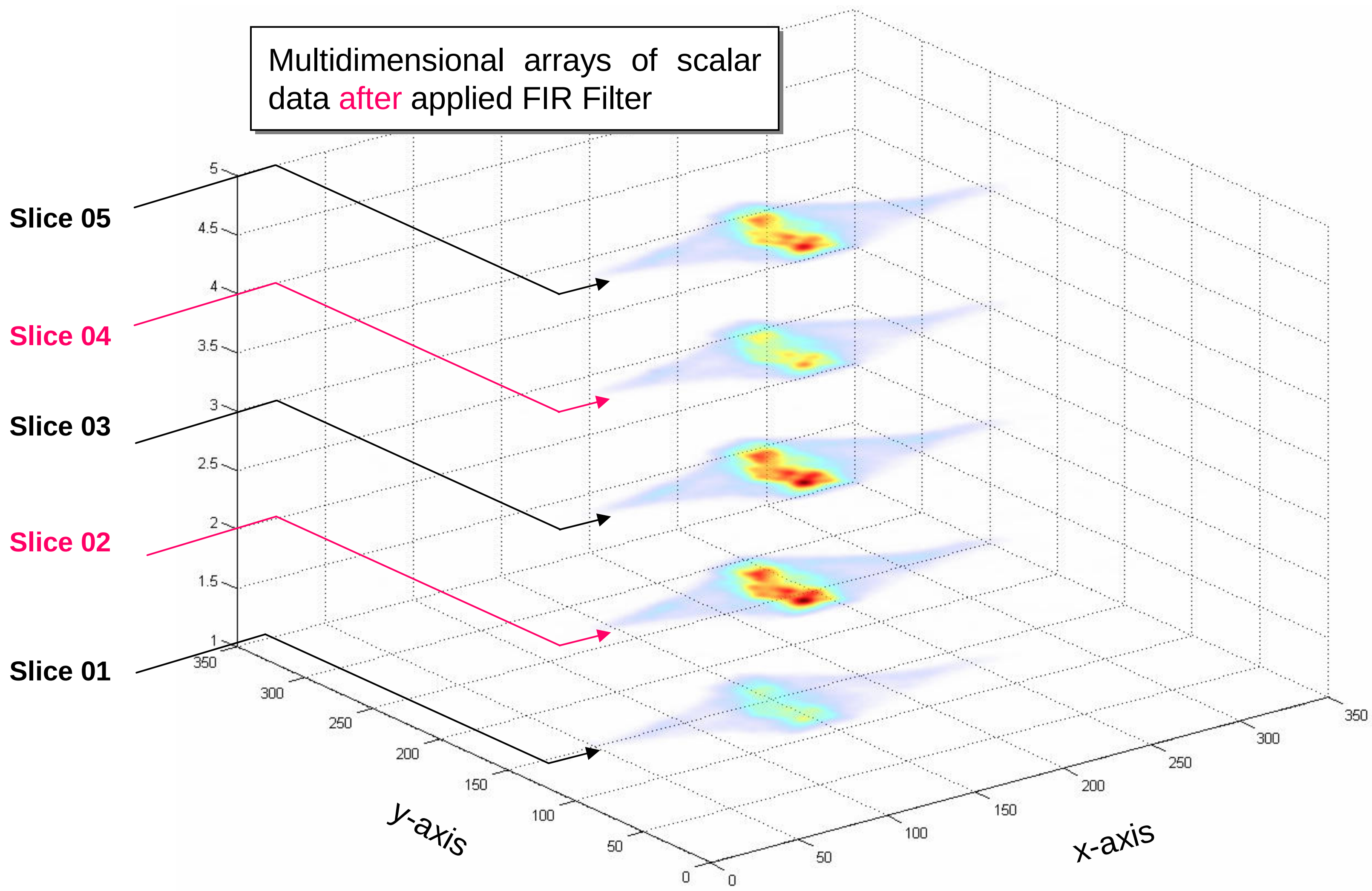
FIR Filter ↔ Multidimensional Filtering

To further investigate, how the FIR filter of our synthetic image looks, we can generate a 3-D view of our accumulator arrays using Volume Visualization.



FIR Filter ↔ Multidimensional Filtering

After FIR filter, the ripples in projected beam disappeared and the desired intensity distribution was approximately achieved , as shown in the following 3-D view of our accumulator arrays using volume visualization.

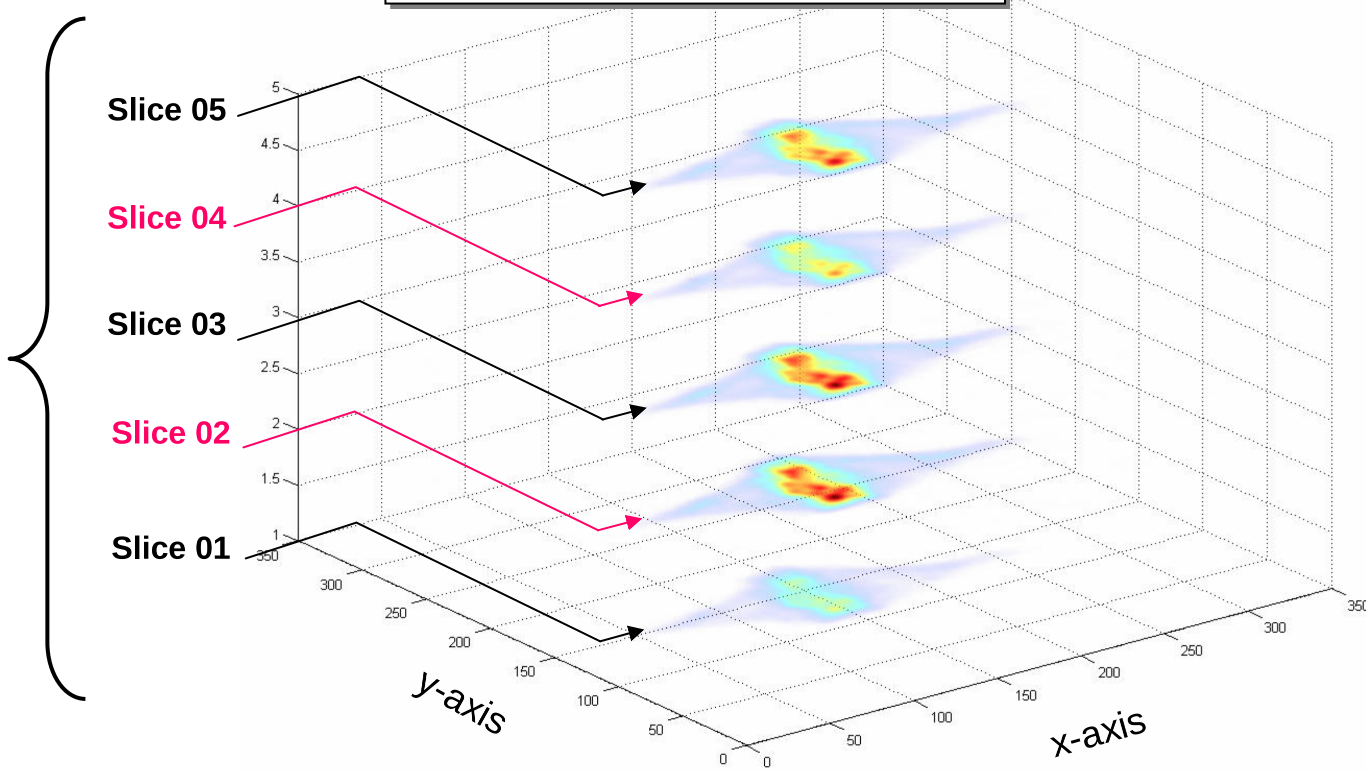


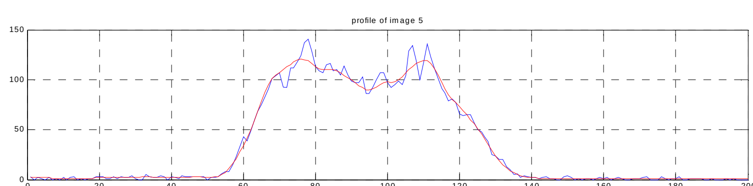
FIR Filter ↔ Multidimensional Filtering

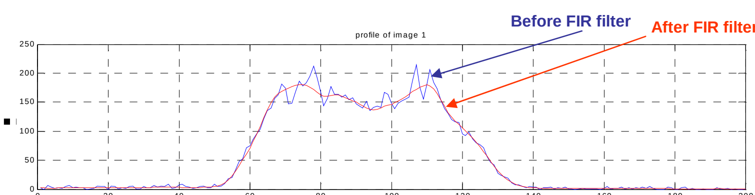
After low-level processing, the image and/or objects analysis and identification can be done by several methods and techniques depend on our requirements and applications.

Multidimensional arrays of scalar data after applied FIR Filter

Image analysis and region properties	
1	Area
2	Centroid
3	Bounding Box
4	Major Axis length
5	Minor Axis Length
6	Eccentricity
7	Orientation
8	Convex Hull
9	Convex Image
10	Convex Area
11	Euler Number
12	Equivalent Diameter
13	Solidity
14	Perimeter



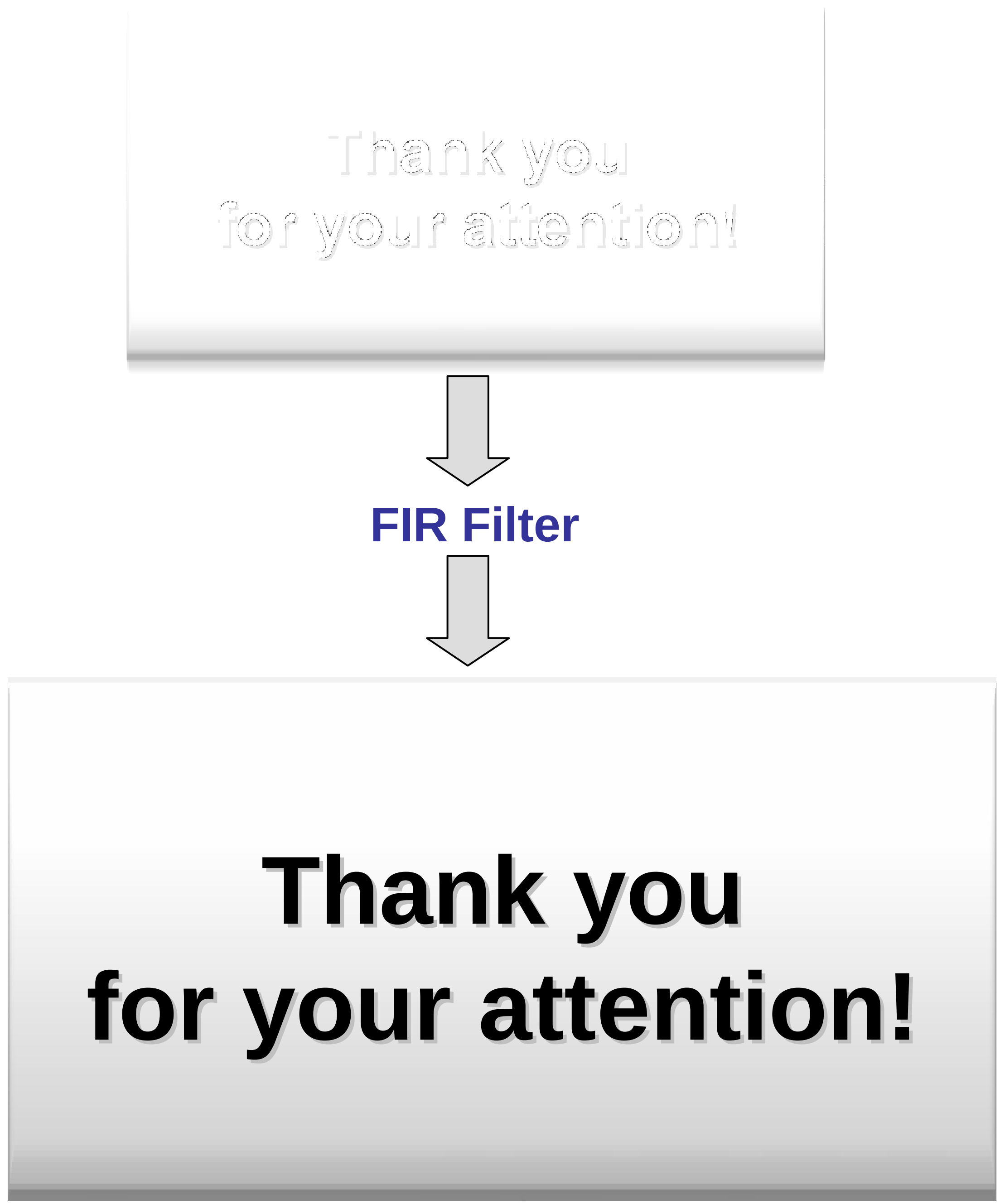




Conclusions and Future Works

1. **The noise reduction of RGB image (matrix → m-n-by-3 array) is more efficient with low-pass FIR filter rather than grayscale image (matrix → m-n array).**
2. **The FIR filter has real-time ability to filter N–slice(s) of projected images.**
3. **The FIR filter at C_f = 25% has suitable efficiency for digital noise reduction with respect to image structure.**
4. **This filter technique can be realized as;**
   - **(a) Declared function, and we can call it inside MATLAB.**
   - **(b) An option inside MATLAB-GUI, in addition with analysis operations.**

5. **Deep study should be done to find , what are the important features that should be extracted from the images.**


Thank you
for your attention!
FIR Filter
Thank you
for your attention!