

# *HREM-Filters Pro/Lite*

## *User's Guide*

*DigitalMicrograph Plugin  
for  
Image Filter Functions*

*Pro: Commercial Software  
Lite: Free Software*

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# 1. Introduction

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HREM-Filters Pro/Lite is a plug-in for use in Gatan's DigitalMicrograph for Windows v.3.8 or later. However, we will recommend you to use the latest version.

This HREM-Filters Pro/Lite User's Guide is written to provide information on the basic functions of the HREM-Filters Pro/Lite software, a procedure for installation of the Plug-In, some general tips on operation. This Guide assumes the user is familiar with image manipulation using DigitalMicrograph as well as Windows operating system.

**Note:** HREM-Filters Lite is free software, so anyone can use this software without a license. However, HREM Research Inc. does not renounce a copyright of this software.

## Technical Support

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HREM Research Inc.

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Fax: (81) 493-35-3919

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DigitalMicrograph is a trade mark of Gatan Inc.

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## 2. Installation

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This chapter describes hardware and software requirements to run the HREM-Filters Pro/Lite plug-in and an installation procedure of the plug-in.

### 2.1 Requirements

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The HREM-Filters Pro/Lite plug-in runs under DigitalMicrograph environment, and the software and hardware requirements are similar to those for DigitalMicrograph itself.

#### 2.1.1 Hardware requirement

The HREM-Filters Pro is commercial software and thus requires a license key (a USB dongle), while the HREM-Filters Lite is free software and thus requires no license key.

#### 2.1.2 Software requirement

The following is a list of the software requirements necessary to run the HREM-Filters Pro/Lite plug-in:

- **DigitalMicrograph for Windows (version 3.8 or later).**
- **USB Key Driver (only required for HREM-Filters Pro)**

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## 2.2 Software Installation

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The following modules should be installed. Please consult the ReadMe file for installation. The following modules should be placed in the folder “PlugIns” on the same level of the DigitalMicrograph.

- **HREM-Filters Pro or HREM-Filters Lite Plug-in (.gtk and .dll)**
- **HREM Mouse Tool Plug-in (Free-ware available at [www.hremresearch.com](http://www.hremresearch.com))**
- **IPU Plug-in (only required for HREM-Filters Pro; Free-ware available at [www.hremresearch.com](http://www.hremresearch.com))**
- **USB Key Driver (only required for HREM-Filters Pro)**

**Note:** The PlugIns folder should exist under a normal installation of the DigitalMicrograph.

### **Installing HREM-Filters Pro or HREM-Filters Lite Plug-in**

HREM-Filters Pro or HREM-Filters Lite (.gtk and .dll) can be installed by drag-and-drop copy to the folder “PlugIns” on the same level of the DigitalMicrograph.

### **Installing HREM Mouse Tool Plug-in**

This is a free plug-in. Please download the plug-in from the Scripts/Plugins page and install it according to the ReadMe file.

### **Installing IPU Plug-in**

This is a free plug-in. Please download the plug-in from the Scripts/Plugins page and install it according to the ReadMe file. This plug-in is required by HREM-Filters Pro in order to extend Fourier transform capability. However, anyone can use the IPU Plug-in to calculate Fourier transform of an arbitrary sized image.

When the DigitalMicrograph is launched after placing the plug-ins the PlugIns folder, HREM-Filters Pro/Lite menu (Filters) commands will be appeared under “Filters” menu and the Mouse tool will be appeared as an addition to the standard tools.

### **Installing Key Driver**

The user key driver should be installed by following the instructions given by the key driver installer (**only required for HREM-Filters Pro**). The key driver installer comes with HREM Filters Pro, or you can find it on our web site.

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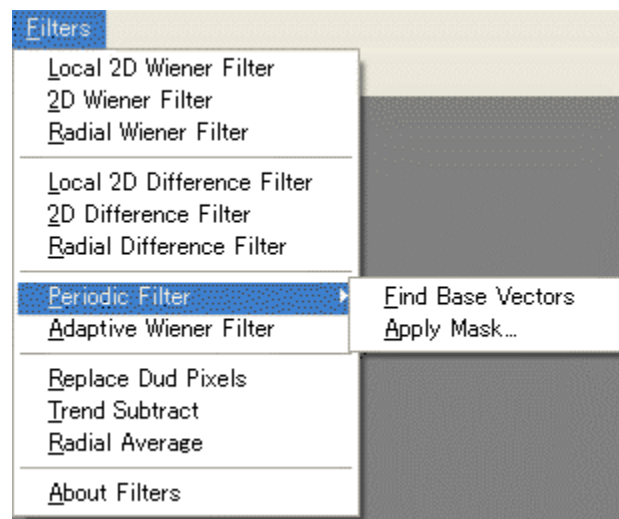
## 3. Getting Started...

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Using the HREM-Filters Pro/Lite is very simple. All the operations are menu driven, and process the front *active* image. This chapter briefly explains each command.

### 3.1 HREM-Filters

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Filters Pro/Lite Menu.

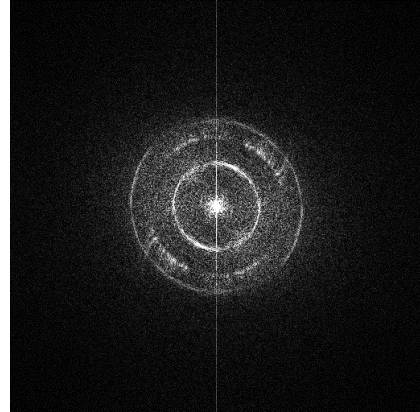
Local 2D Wiener, 2D Wiener, Local 2D Difference and 2D Difference Filters and Apply Mask... are available only for Filters *Pro*. The same commands that are available for *Lite* may be so optimized as *Pro*, and take more time than *Pro* version.

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We will use the following image of crysotile, a clay minerals, taken by Prof. Kogure, Univ. of Tokyo. This is not an ideal crystal showing a simple translational symmetry, and thus clearly shows a power of Filters Pro.



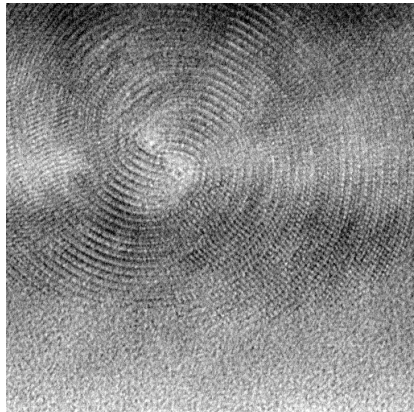
Original Image (crysotile)



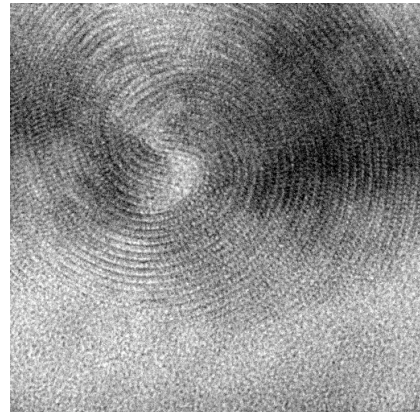
Fourier transform

### 3.1.1 Radial Wiener/Difference Filter

A background in Filter is estimated by radial average of Fourier transform of the whole area.



Radial Wiener filtered image

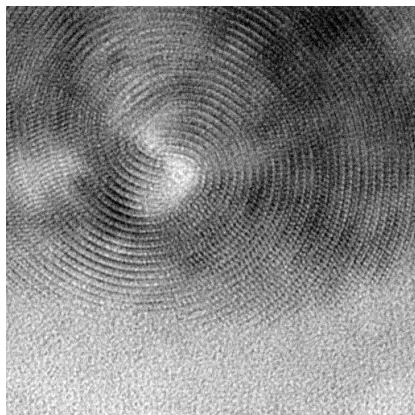


Residual of the original image

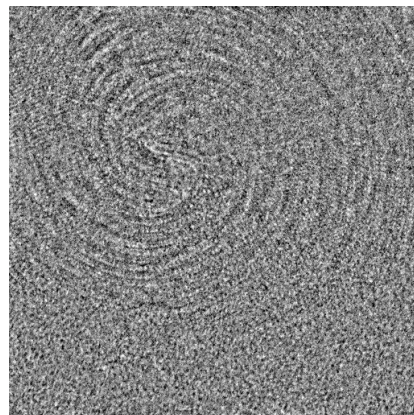
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### 3.1.2 2D Wiener/Difference Filter (Pro Only)

A smoothed two-dimensional trend of Fourier transform of the whole area is used as a background in Filter.



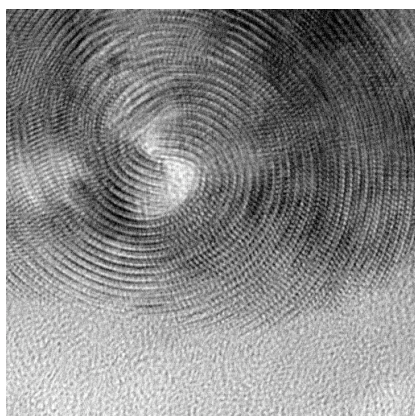
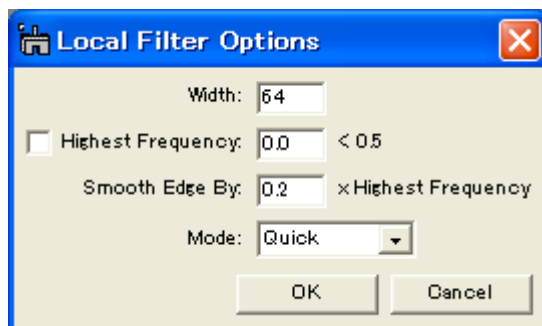
2D Wiener filtered image



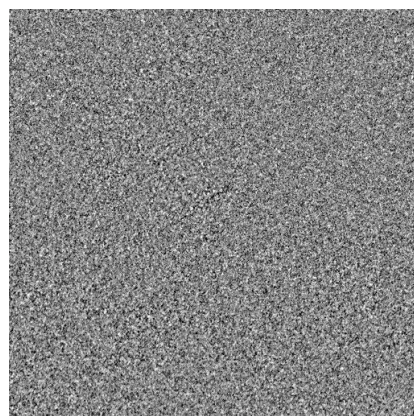
Residual of the original image

### 3.1.3 Local 2D Wiener/Difference Filter (Pro Only)

A background in Filter is locally estimated by smoothed two-dimensional trends of Fourier transform of finite areas. The size of the area is controlled by the **Size** parameter below.



Local 2D Wiener filtered image



Residual of the original image



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## 3.2 Other Filters

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### 3.2.1 Periodic Filter

DigitalMicrograph has a set of mask tools for Fourier filtering. However, it is not easy to set up a set of base vectors using a Periodic Mask tool for a Periodic Filter. The commands under this menu will work the Periodic Mask tool of DigitalMicrograph.



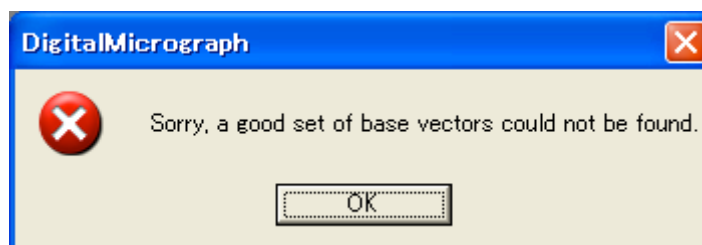
How to use “Periodic Filter”:

1. Specify any lattice points on the base vector directions by using the Periodic Mask tool.
2. Choose “Find Base Vectors” command when the masked image is at the front.
3. Adjust a mask size using the Periodic Mask tool.
4. Apply a mask using “Apply Mask...” command under the Process menu or Periodic Filter menu.

#### 3.2.1.1 Find Base Vectors (Using Periodic Mask tool)

This command will find a precise base vectors for a Periodic Filter.

1. Select any lattice points on two base vector directions by using the Periodic Mask tool.
2. (Optional) Put a Point ROI on one spot, when you want to use the spots on the lines passing through the Point ROI to find the base vectors.
3. Choose this command when the masked image is at the front, then true base vectors along the specified direction will be estimated precisely based on a least-square technique. Please note that user has to specify a set of correct directions to cover all the lattice points.
4. Make sure the base vectors are correct. If the command fails to find the correct base vectors, you will get a following message:

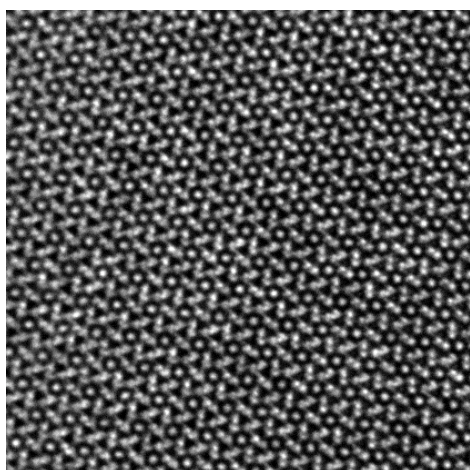


Then, you may want to try other set of lattice points using the Periodic Mask tool. Before trying another lattice points, you may also want to try with the Option (Step 2) using the same lattice points.

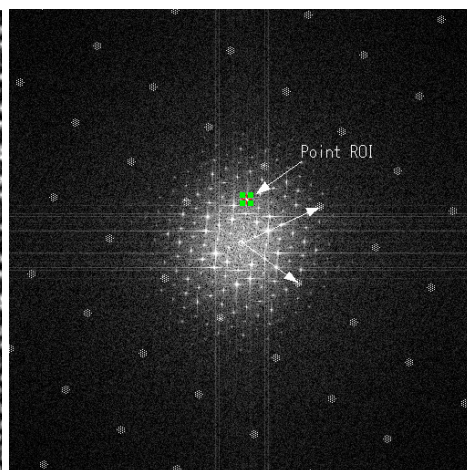
5. Adjust a mask size using the Periodic Mask tool.

When an image size is large, Filters Lite will take some time to get a result compared with Filters Pro.

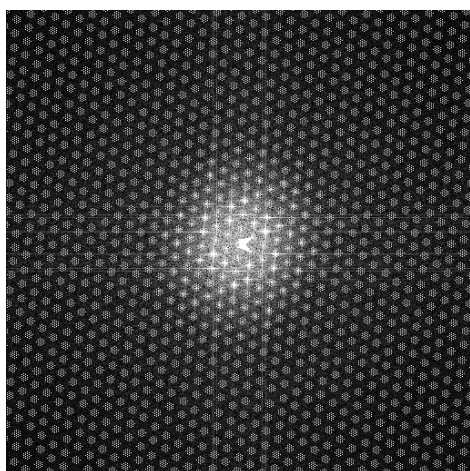




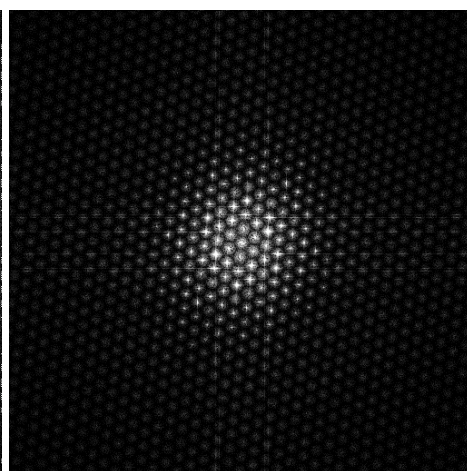
Original image (512x512) (Si<sub>3</sub>N<sub>4</sub>:  
Courtesy of C. Kisielowski)



Two lattice points on the base vector  
directions selected by using the  
Periodic Mask tool. Note an optional  
Point ROI.



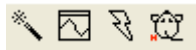
Base vectors and lattice positions  
estimated by using this command.



Mask applied by using the Apply Mask  
command of the Process menu.

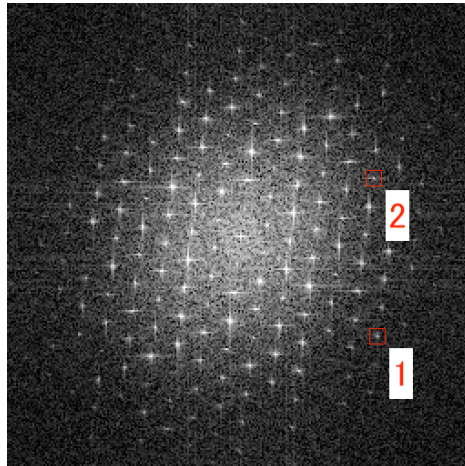
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### 3.2.1.2 Find Base Vectors (Using Mouse tool)

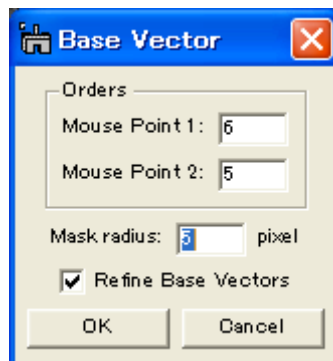


This command will find a precise base vectors for Periodic Filtering using the Mouse tool.

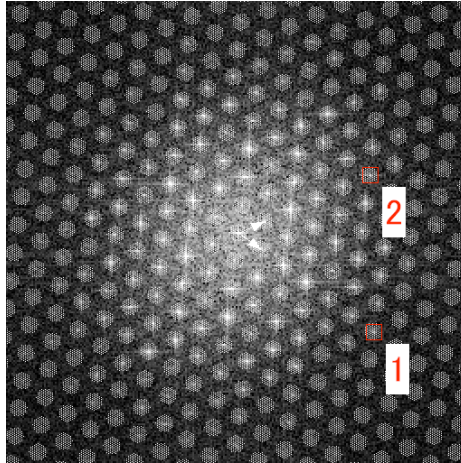
1. Select any lattice points on two base vector directions by using the Mouse tool.



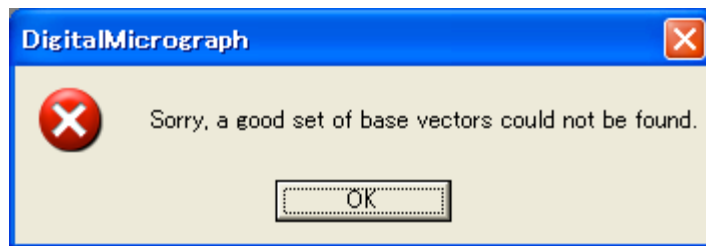
2. Choose this command when the masked image is at the front, then the following dialog will appear:



Here, you have to specify the order of the reflections specified by the Mouse tool. You can here specify the mask radius. If you check “Refine Base Vectors,” then true base vectors along the specified direction will be estimated precisely based on a least-square technique. Please note that user has to specify a set of correct directions to cover all the lattice points.



3. Make sure the base vectors are correct. If the command fails to find the correct base vectors,

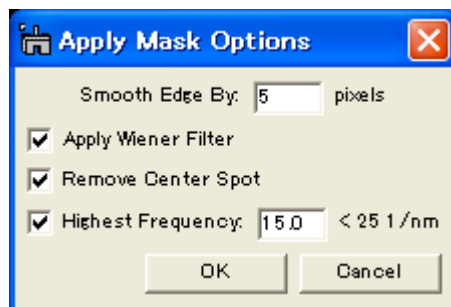


- Then, you may want to try other set of lattice points using the Mouse tool.
4. Adjust a mask size using the Periodic Mask tool.

When an image size is large, Filters Lite will take some time to get a result compared with Filters Pro.

### 3.2.1.3 Apply Mask...(Pro Only)

This is an extended version of the command “Apply Mask...” under the Process menu of DigitalMicrograph. There are several options that will reduce random noise from the final filtered image.

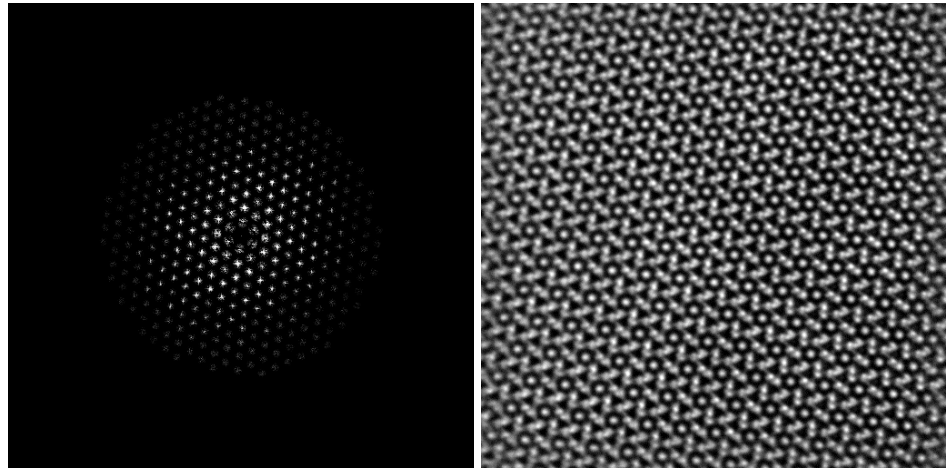


Apply Wiener Filter: Amplitude of the spot is modified by a Wiener estimate

$$F \Rightarrow \frac{|F|^2 - |F_b|^2}{|F_b|^2} F$$

where  $F_b$  is average amplitude around each spot.

- 
- Remove Center Spot: Amplitude around the center spot is set to zero except the origin single point.
- Highest Frequency: Amplitude beyond this value is set to zero.  
If the image is calibrated, the highest frequency should be given in an absolute scale, where the maximum frequency is 0.5/(sampling interval).  
If the image is not calibrated, the highest frequency should be given in a relative scale, where the maximum frequency is 0.5.



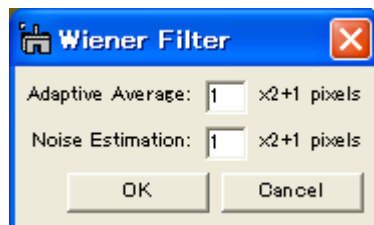
Mask applied by using the extended Apply Mask command.

Filtered image.

### 3.2.2 Adaptive Wiener Filter

This command applies a linear filter (local average) to an image *adaptively* according to the local image variance. The sizes of a local average and local variance can be controlled by “Adaptive Average” and “Noise Estimation”, respectively. If the variance is large, the filter performs less smoothing, while the variance is small, the filter performs more smoothing.

The adaptive filter is more selective than a simple local average filter, preserving edges and other high-frequency parts of an image.





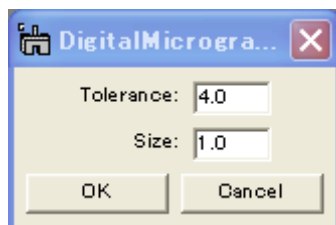
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## 3.3 HREM-Filters Utilities

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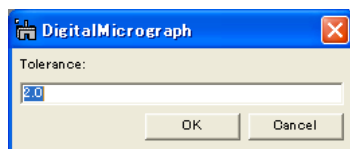
### 3.3.1 Replace Dud Pixels

This command will remove dud image points due to bad pixels of a CCD camera or due to uncontrollable x-ray or cosmic ray. The values of the dud pixels will be replaced by a local mean. This is an automatic version of **Zapper** tool of DigitalMicrograph's standard tools.



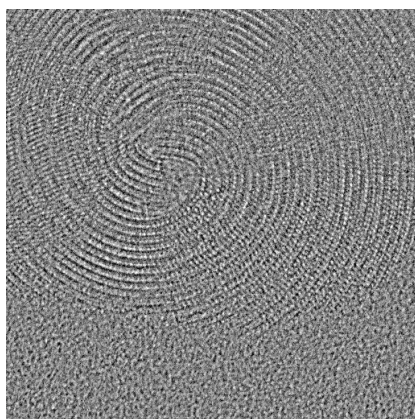
The size of a cluster of dud points can be controlled by the **Size** parameter. The **Tolerance** controls a degree of singularity in terms of a local standard deviation. This will work ideally for small isolated clusters.

For a long connected dud image pixels, an area that includes the dud pixels may be indicated by a **ROI** tool manually. Then, the dud pixels will be replaced by a local mean, when a pixel differs from the local mean by a specified **tolerance** times the variance of the area.



### 3.3.2 Trend Subtract

This command will remove a smoothed trend of an image, and makes a structural detail to be recognized more clearly. When an image size is large, Filters Lite will take some time to get a result compared with Filters Pro.



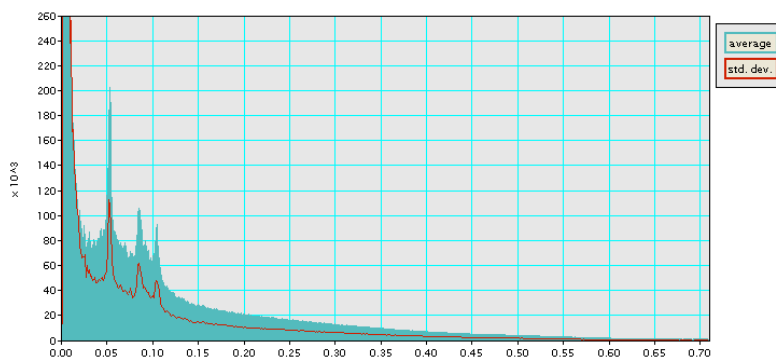
Trend Subtracted image

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### 3.3.3 Radial Average

This command will calculate an average profile over the pixels on the same radial distance from its image center. If the image is complex number such as a Fourier transform of an image, a modulus will be averaged.

This command will also calculate a standard deviation profile, although the profile is hidden by default. You can see the standard deviation profile by choosing “Show std. dev.” on a context menu that will appear by clicking a right mouse button on the “std. dev.” legend.



Radial average profile (Standard deviation profile is set to “show.”)

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## 4. Filter Description

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### 4.1 Fourier Transform

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An observed signal  $F_o$  in Fourier transform may be written as a sum of a true signal  $F_c$  due to a crystal part and a background  $F_b$  due to a non-crystal part:  $F_o = F_c + F_b$ . If we assume the true signal and the background are mutually independent, then we may be able to write  $|F_o|^2 \approx |F_c|^2 + |F_b|^2$ .

### 4.2 Wiener Filter

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The Wiener filter seeks a solution that minimizes the summed square difference between the true signal  $F_c$  and its estimate  $\hat{F}_c$  resulting

$$\hat{F}_c = \frac{|F_c|^2}{|F_c|^2 + |F_b|^2} F_o \approx \frac{|F_o|^2 - |\hat{F}_b|^2}{|F_o|^2} F_o = \frac{|F_o|^2 - |\hat{F}_b|^2}{|F_o|} e^{i\phi_o},$$

where  $\phi_o$  is the phase of the observed signal  $F_o$  and  $\hat{F}_b$  the estimate of the background. Here, we assume  $F_c$  and  $F_b$  are independent.

If  $|F_o| - |\hat{F}_b| \leq 0$ ,  $\hat{F}_c$  is set to zero.

### 4.3 Difference Filter

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The Difference filter (the background subtraction filter) is simply given by

$$\hat{F}_c = (|F_o| - |\hat{F}_b|) e^{i\phi_o},$$

where  $\phi_o$  is the phase of the observed signal  $F_o$  and  $\hat{F}_b$  the estimate of the background. If  $|F_o| - |\hat{F}_b| \leq 0$ ,  $\hat{F}_c$  is set to zero.

Reference: R. Kilaas, *J. Microscopy* 190 (1997) 45-51.



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## 4.4 Background Estimation

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In order to use either filter we have to estimate a background contribution  $\hat{F}_b$ . A radial average background has been commonly used. Here, we propose new backgrounds.

### *1. Radial Background*

Normally, the background is estimated as a radial average of the Fourier transform of the whole image assuming that the contribution from amorphous (non-periodic) materials varies slowly.

Reference: L.D. Marks, *Ultramicroscopy* 62 (1996) 43-52; R. Kilaas, *J. Microscopy* 190 (1997) 45-51.

### *2. Two-Dimensional Background*

A radial background will not work, when structure information appears at the same distance from the origin in Fourier space. Thus, we developed a novel approach based on P-spline fitting to estimate a smoothed two-dimensional background in Fourier space.

Reference: P.H.C. Eilers et al., *Computational Statistics and Data Analysis* 50 (2006) 61-76.

### *3. Local Two-Dimensional Background*

When an orientation of periodic structure is different locally, the background estimated for the whole image is not adequate. Thus, a set of two-dimensional backgrounds in Fourier space is estimated by dividing an image into local small areas.

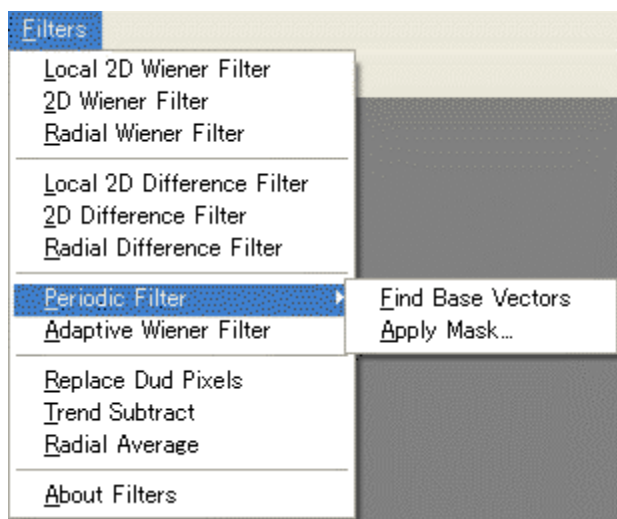
### *4. Periodic Mask Background*

A periodic mask is frequently applied to a Fourier transform of a lattice image. We may be able to modify a simple periodic filter to a Wiener type filter, where a background is estimated for each diffraction spot from a surrounding area of each mask.

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# Quick Reference Guide

## The HREM-Filters Main Menu



The commands in the HREM-Filters menu are described below.

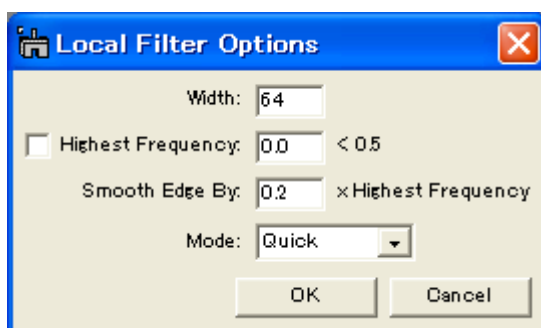
Command	Description
Local 2D Wiener Filter	Calculates a Wiener filtered image using 2D local backgrounds
2D Wiener Filter	Calculates a Wiener filtered image using a 2D background
Radial Wiener Filter	Calculates a Wiener filtered image using a radial background
Local 2D Difference Filter	Calculates a Difference filtered image using 2D local backgrounds
2D Difference Filter	Calculates a Difference filtered image using a 2D background
Radial Difference Filter	Calculates a Difference filtered image using a radial background
Periodic Filter (see sub menus)	Commands for Periodic Filter <ul style="list-style-type: none"><li>● Find Base Vectors</li><li>● Apply Mask</li></ul>
Adaptive Wiener Filter	Performs a linear filter (local average) adaptively according to the local image variance.
Replace Dud Pixels	Replaces dud pixels with a local average automatically according to the local image variance.
Trend Subtract	Subtracts an image trend (global background)
Radial Average	Calculates a radial average and std. deviation of a Fourier transform

The components of the dialog are described below.

## **HREM-Filters Menu**

### **Local 2D Filter Menu – Local Filter Options Dialog**

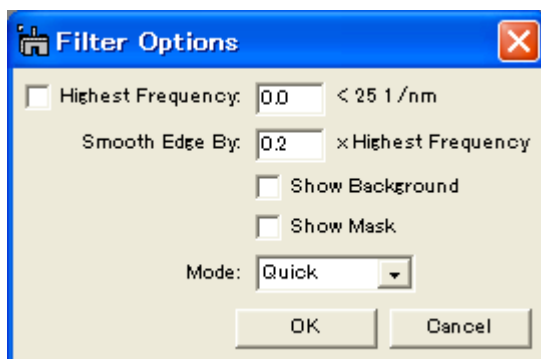
Dialog



Component	Description
Width	Width and height of the local area.
Highest Frequency	Highest frequency of a low-pass filter. The check box on the left controls an application of the low-pass filter. If an original image is calibrated in nm, this parameter should be given in 1/nm. If an original image is NOT calibrated, this parameter should be given in terms of Nyquist frequency, namely the highest value is 0.5.
Smooth Edge By	The width of smoothing of the high-pass filter edge in terms of the highest frequency of the filter.
Mode	The mode of 2D background estimation.

### **2D Filter Menu – Filter Options Dialog**

Dialog

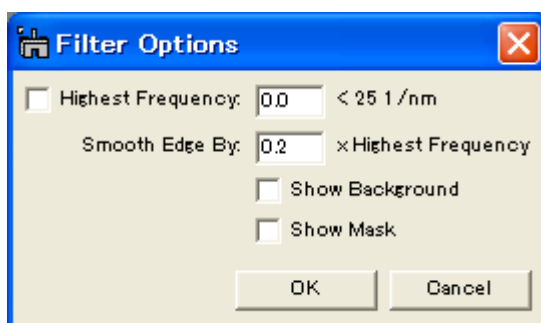


Component	Description
Highest Frequency	Highest frequency of a low-pass filter. The check box on the left controls an application of the low-pass filter. If an original image is calibrated in nm, this parameter should be given in 1/nm. If an original image is NOT

	calibrated, this parameter should be given in terms of Nyquist frequency, namely the highest value is 0.5.
Smooth Edge By	The width of smoothing of the high-pass filter edge in terms of the highest frequency of the filter.
Show Background	If checked, an estimated 2D background will be displayed.
Show Mask	If checked, an estimated Wiener/Difference mask will be displayed.
Mode	The mode of 2D background estimation.

### **Radial Filter Menu – Filter Options Dialog**

#### **Dialog**



<b>Option</b>	<b>Description</b>
Highest Frequency	Highest frequency of a low-pass filter. The check box on the left controls an application of the low-pass filter. If an original image is calibrated in nm, this parameter should be given in 1/nm. If an original image is NOT calibrated, this parameter should be given in terms of Nyquist frequency, namely the highest value is 0.5.
Smooth Edge By	The width of smoothing of the high-pass filter edge in terms of the highest frequency of the filter.
Show Background	If checked, an estimated 2D background will be displayed.
Show Mask	If checked, an estimated Wiener/Difference mask will be displayed.

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## **Periodic Filter Menu**

### **Distortion Correction Menu**

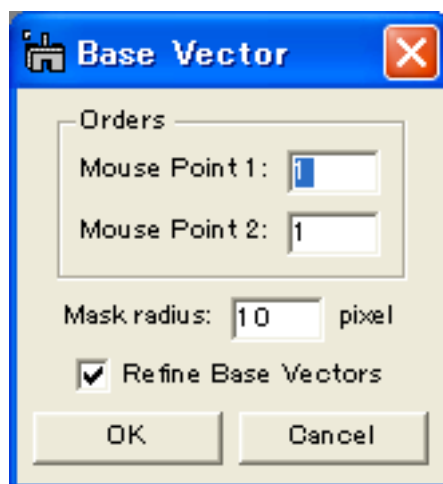


Option	Description
Find Base Vectors	Assists to find a precise base vectors for a Periodic Filter using the Periodic Mask tool, or using the mouse tool.
Apply Mask...	Apply a periodic mask with Wiener filter and/or low-pass filter.

## **Find Base Vectors – Base Vectors Dialog**

When two mouse points are placed on the two spots along the two base vectors, the dialog below will appear.

### **Dialog**

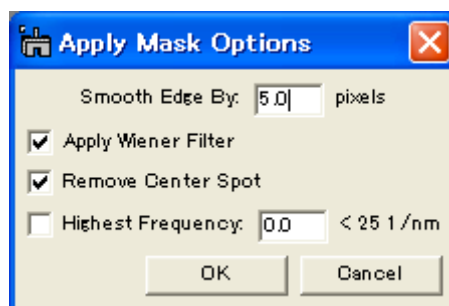


Option	Description
Mouse Point 1	The order (index) of the mouse point #1 for the base vector 1.
Mouse Point 2	The order (index) of the mouse point #2 for the base vector 2.
Mask Radius	The mask radius for each spot in pixels.
Refine Base Vectors	The base vector can be refined with a least-square fitting by checking this box. Use this capability except you intentionally want to use the mouse points without the least-square refinement.

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## **Apply Mask Menu - Apply Mask Options Dialog**

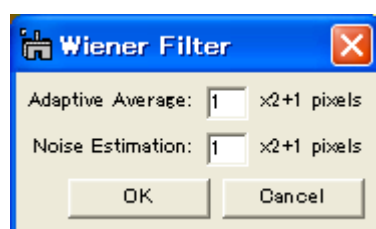
Dialog



Option	Description
Smooth Edge By	The width of smoothing of the high-pass filter edge in terms of the highest frequency of the filter.
Apply Wiener Filter	Wiener filter is applied to each spot by estimating the background for the spot.
Remove Center Spot	The whole mask area of the center spot will be removed (filtered out)
Highest Frequency	Highest frequency of a low-pass filter. The check box on the left controls an application of the low-pass filter. If an original image is calibrated in nm, this parameter should be given in 1/nm. If an original image is NOT calibrated, this parameter should be given in terms of Nyquist frequency, namely the highest value is 0.5.

## **Adaptive Wiener Filter - Wiener Filter Dialog**

Dialog

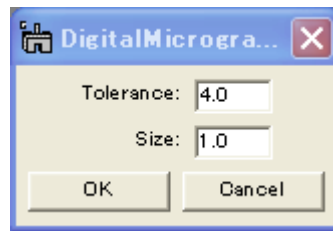


Option	Description
Adaptive Average	Defines an area of local average
Noise Estimation	Defines an area for local variance estimation

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## **Replace Dud Pixels Dialog**

Dialog



Option	Description
Tolerance	Controls a degree of singularity in terms of a local standard deviation
Size	The size of a cluster of dud points.