

User Guide

Questions, feedback or requirement can be sent to
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We are glad for collaboration to explore the clinical application of super-resolution ultrasound imaging.

**This User Guide was written based on the SRUS version 2.0.
Updates in new versions can be found at the end of this document.**

Installation

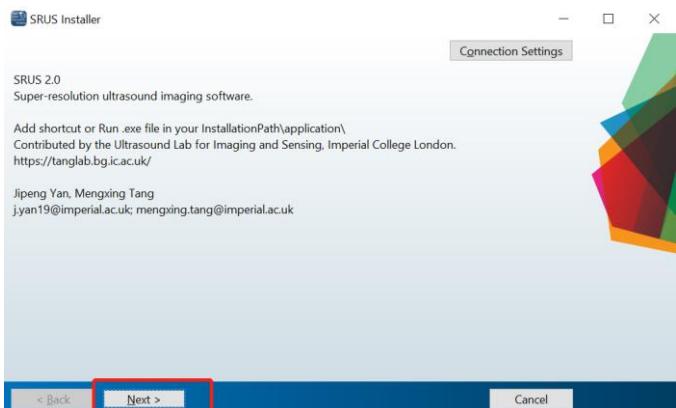
The software was tested using the following system hardware/software:

- Windows 10
- CPU: AMD Ryzen 9 5900 Processor
- GPU: Nvidia Geforce RTX3080
- RAM: 128 Gb

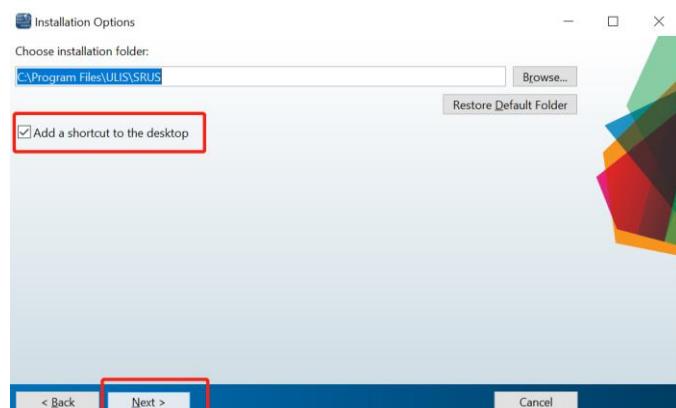


Preparing for installation. This may take a few minutes...

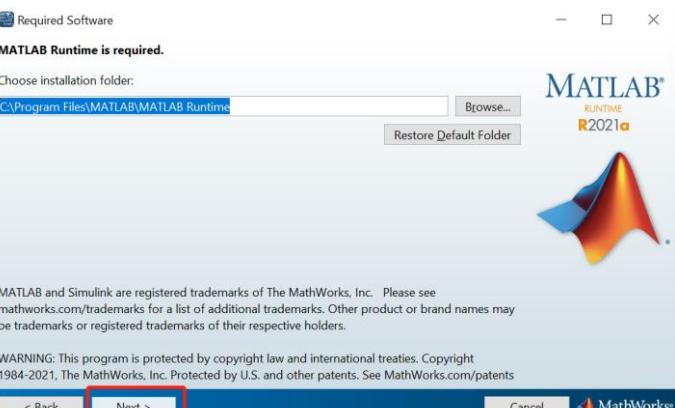
Wait the preparation



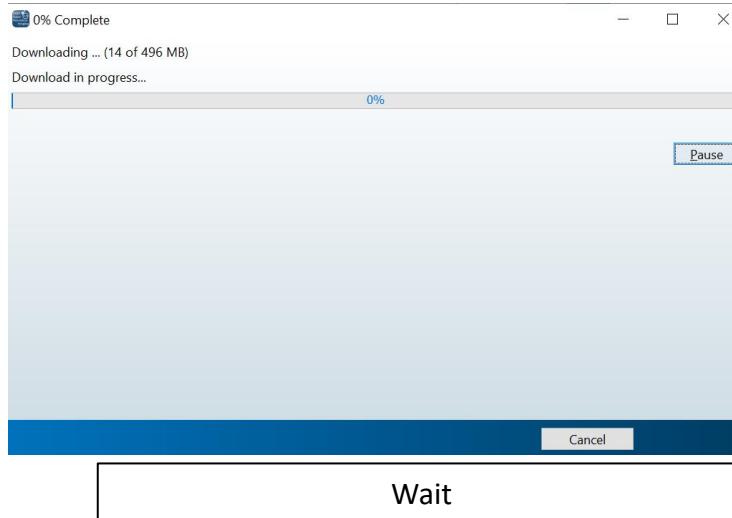
Click "Next"



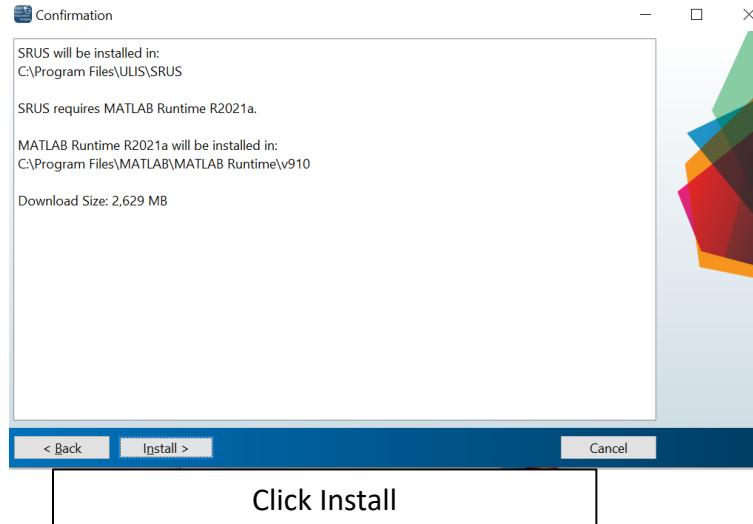
Add shortcut and Click "Next"



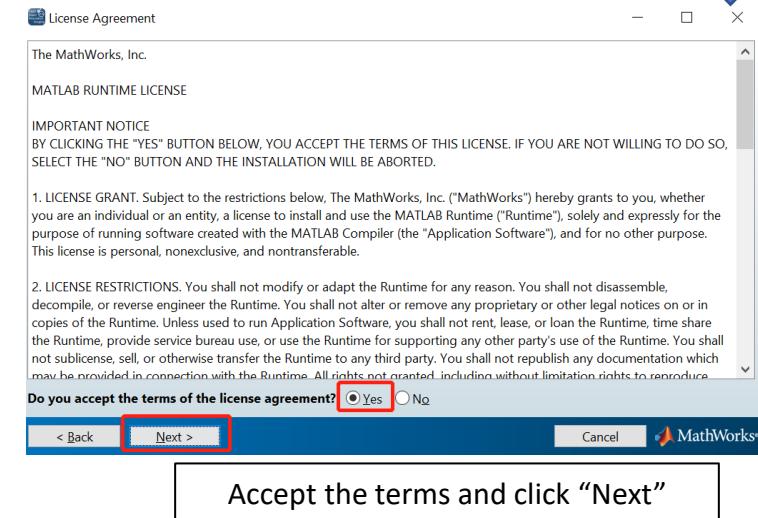
Click "Next"



Wait



Click Install



Accept the terms and click "Next"

PS: 1) Runtime installation happens when it is the first time for the PC to install the software.

2) Run .exe as administrator. Otherwise, error might happen if the user wants to install the software in the system disk.

Interface

When Starting, software tries to load previously saved parameters from the file in 'InstallationPath\application\'. If there is no such a file, the app will use default parameters.

MENU

Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing

Data information

Square pixel Axial Res(m) 0 Measure
Lateral Res(m) 0
Frame Rate 0 fps

Processing Frame

From To

Double-Column data

Get Midline Data Columns Double Single
CEUS at Left Right Crop Data

Run All With Preset Parameters

Run Motion Correction with Preset Parameters Run SR processing with Preset Parameters

Motion Correction

Motion Type Rigid Non-rigid
Do Motion Correction

Discard Frame Discard

Press Load Data button or Load Setting Parameters.
Mandatory Variables in .mat Data file:
contrast_image or C - CEUS image sequence.

TextArea for how to use software

Page for loading data and motion correction



Load&MoCo SR Processing Post-Processing

Background Reduction

Local Thresholding Global Thresholding

Threshold 0~1 Remove

Localisation

Localisation Unc... 25 um SR Ratio 10 Generate SR map

Subregions: Horiz... 1 Vertical 1 Estimate PSF

Localisation Method Dec... ▾ Multi-Thread Test Parameters

Sparsity Coefficient 0.01 Region Map Ratio 4 Localisation (All)

Tracking

Max Blood Flow Speed 0.02 m/s Reference Image ... Track Bubbles

Track Length 0 >mm 4 >Fra... Filter Tracks

Draw SR images

Start Frame 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 Interp Tracks

End Frame 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 Format -jpeg

Speed Color Limit 0.02 m/s Density
Density with Direction
Flow
Separated Direction

Density Color Limit 10 Preview

Image Blurring Factor 1 Plot and Save SR images

Press Load Data button or Load Setting Parameters.
Mandatory Variables in .mat Data file:
contrast_image or C - CEUS image sequence.

Page for Background removal, super-localization, tracking, and Plotting SR images

Load&MoCo SR Processing Post-Processing

Draw ROI for Parameter Calculation

Base Im... CEUS MIP ▼ SR Image Density ▼ Overlap Image

Draw Mask (In) Draw Mask (out) Draw Mask (Adjust)

Calculate Parameters

Generate Animation

Interp Movement Off On Generate Video

Background Off On

Press Load Data button or Load Setting Parameters.
Mandatory Variables in .mat Data file:
contrast_image or C - CEUS image sequence.

Page for drawing ROI, Calculating Parameters,
and Generating animations

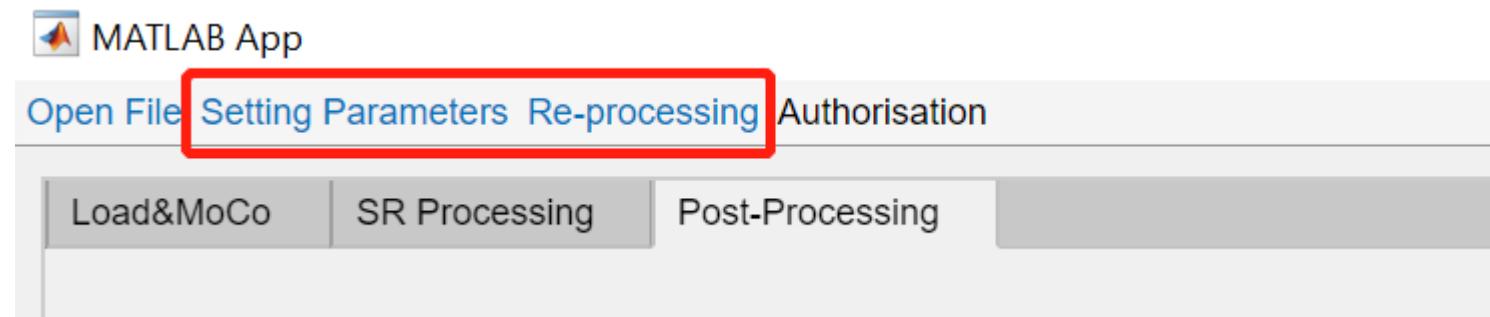


Authorisation

Software is free for research. Getting authorisation can help us know who is using the software.

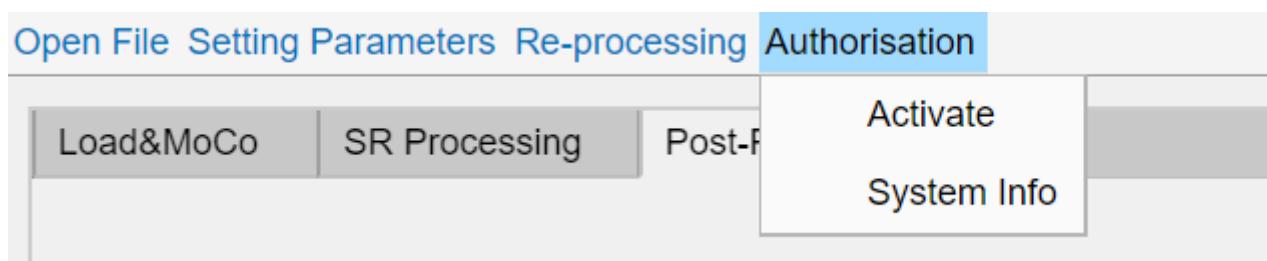
Limitation without authorisation

The user can still use the software without authorization, but below two modules are not available and plotted SR images will be with our Lab Logo.

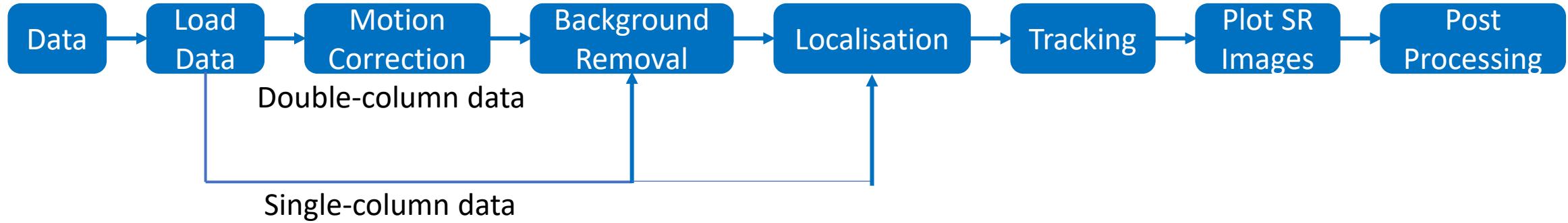


Steps to get authorization

1. Click authorisation and then system info to generate an identical file for your PC.
2. Send the generated file to us
3. You will get a “Key” from us.
4. Click activate and select the “Key” file.



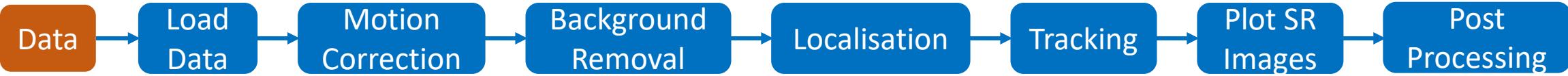
Please do not delete the key file after activation. When you move the key to another folder, you need to activate the software again by selecting the key in the new folder. The key is valid for **one year** and you can renew it by contacting us with your system info.



Operation Flow

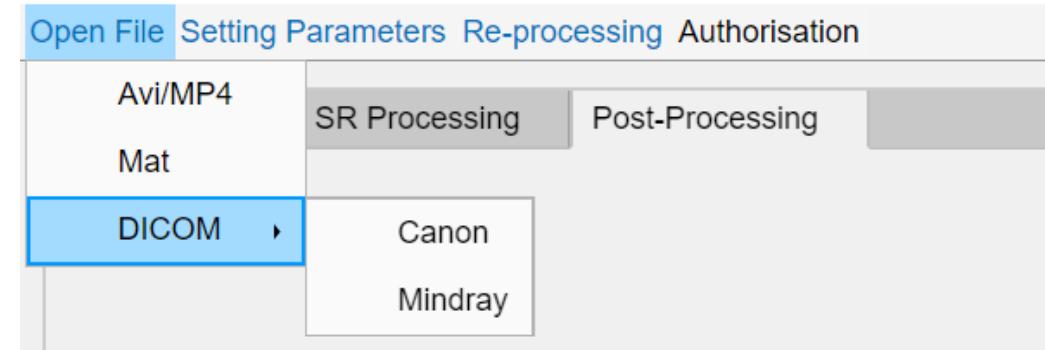
The operation on the software always follows from left to right and top to bottom. If changing parameters in one step, the user need to redo the processing after this step.

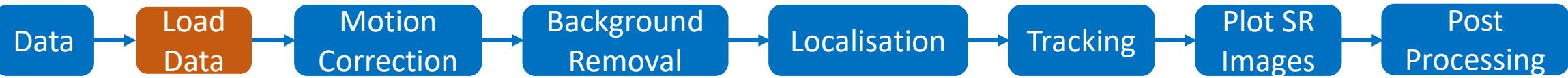
Single-column data should be motion corrected before being load by the software.



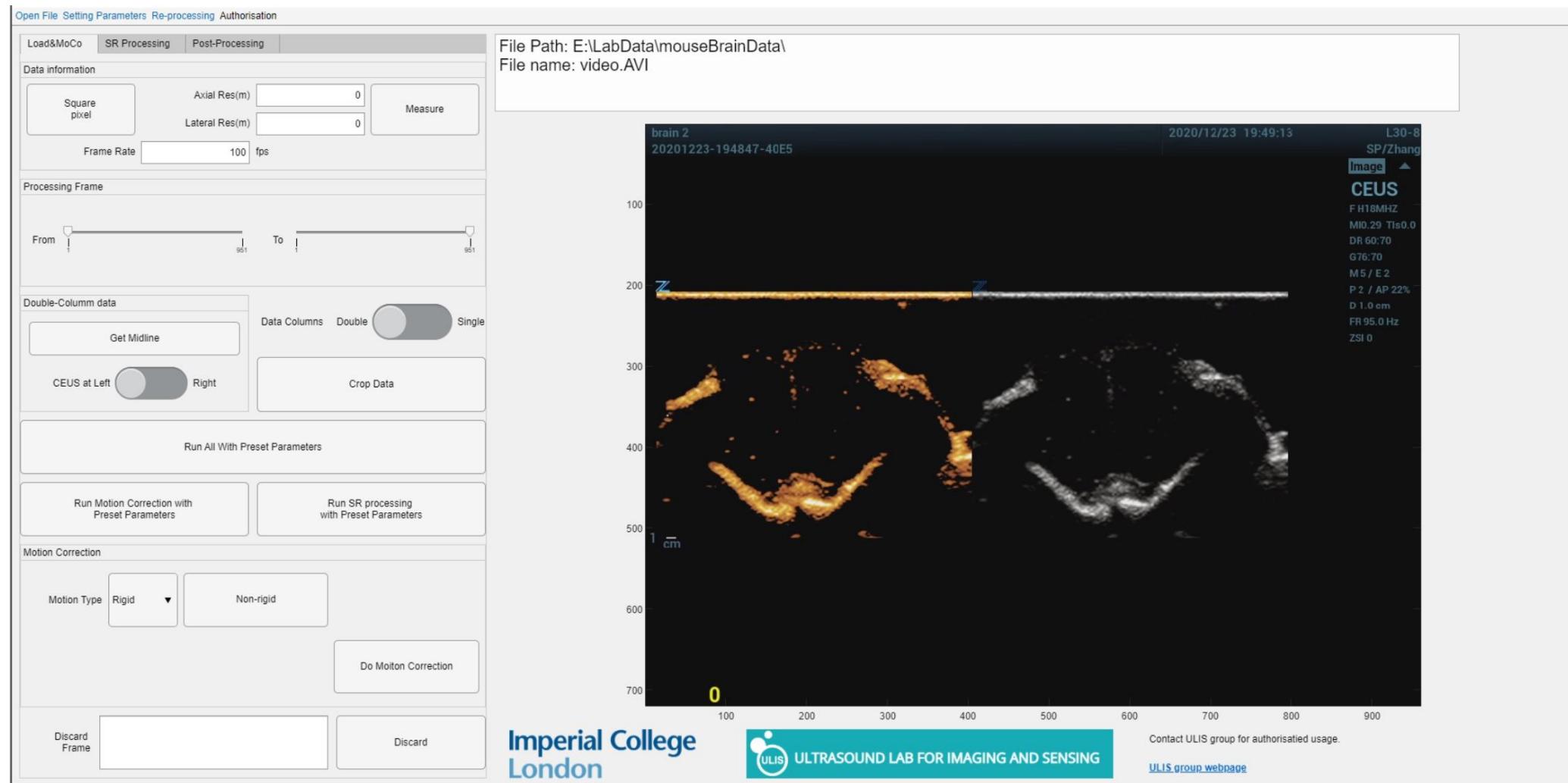
The user can click Open File and the find supported data type.

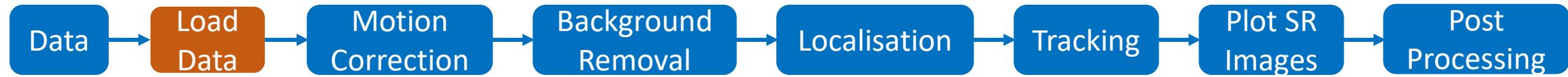
1. DICOM from other companies might be able to be loaded by one of the listed selections. If not, you can contact us.
2. Mat file can be data has been pre-processed by the user. The user can skip **Motion Correction** and/or **Background Removal** if the data has been processed through these steps. Requirements of the variable name in the Mat file can be found in the Software description file.
3. **All the folder names in the path should not have any ‘space’ and “special characters”.** Otherwise, the software cannot create a result folder in the same folder of the data. For example, the folder name should be ‘ClinicalData’ instead of ‘Clinical Data’



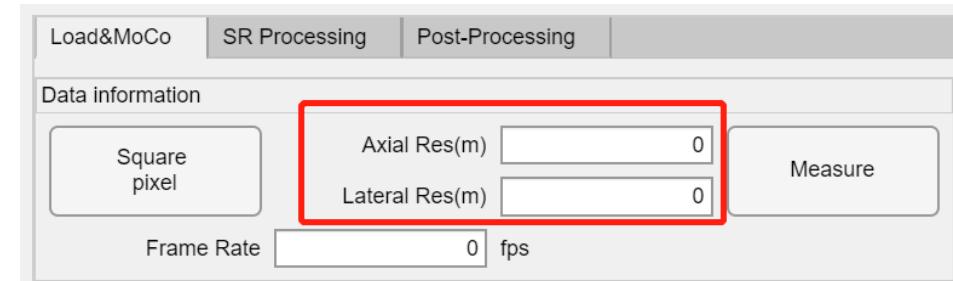


After opening file, data can be load and the user can see one frame of the image



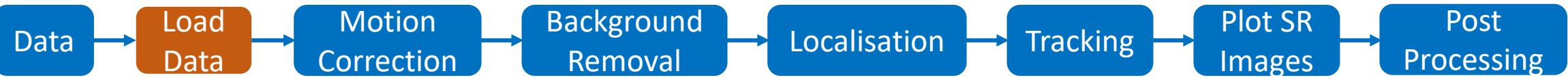


If pixel resolution cannot be read from file, they will be zeros and need the user to measure from the image or to be input by the user.



Sometimes, there is only a scale along the depth direction in the image. In this case, the pixel resolutions along the depth and lateral are generally same. The user can push the '**Square Pixel**' button down, only measure the pixel resolution along the depth and then get two resolutions.

The user should **check if the frame rate is right**. Frame rate read from the DICOM file might be different from the value used in acquisition. Some machines downsample the frame rate when saving the data. It is the frame rate of saved data that should be used. Frame rate read from MP4 and AVI files is the value of the saved video, which might also differ from that of data.



Click **Measure** button to measure pixel size from the image.

If the user want to measure pixel size again, **set the values as zeros** and Click **Measure** button

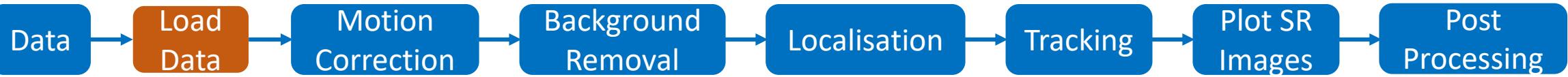
Select 1 cm in z direction

Discard Frame
Discard

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Select frames to be processed by dragging the **two sliders**

Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing Redo

Data information

Square pixel Axial Res(m) 3.3e-05 Measure

Lateral Res(m) 3.3e-05

Frame Rate 100 fps

Processing Frame

From 184 To 553

Is Line for defining resolution right? If right, click "Next", otherwise "Redo"

Next

brain 2
20201223-194847-40E5
2020/12/23 19:49:34 L30-8 SP/Zhang Image
CEUS F H18MHz MI0.29 Tis0.0 DR 60:70 G76:70 M 5 / E 2 P 2 / AP 22% D 1.0 cm FR 95.0/95.0 Hz ZSI 0

1 cm

0

Double-Column data

Get Midline Data Columns Double Single

CEUS at Left Right Crop Data

Run All With Preset Parameters

Run Motion Correction with Preset Parameters Run SR processing with Preset Parameters

Motion Correction

Motion Type Rigid Non-rigid

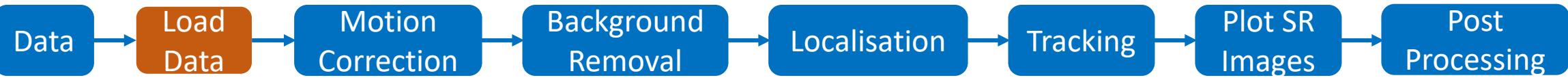
Do Motion Correction

Discard Frame Discard

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Crop Data: Double-column.

Left Panel: Control Interface

The interface includes the following sections:

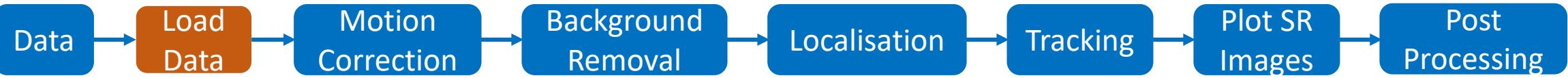
- Load&MoCo**: Includes fields for Axial Res(m) (3.3e-05), Lateral Res(m) (3.3e-05), and Measure button.
- Processing Frame**: Sliders for "From" (1 to 951) and "To" (1 to 951).
- Double-Column data**: A toggle switch between "Double" and "Single". Below it are buttons for "Get Midline" (with a red arrow pointing to it), "CEUS at Left" (with a red arrow pointing to it), and "Crop Data" (boxed with a red border).
- Run All With Preset Parameters**, **Run Motion Correction with Preset Parameters**, and **Run SR processing with Preset Parameters**.
- Motion Correction**: Motion Type dropdown (Rigid or Non-rigid) and Do Motion Correction button.
- Discard Frame** and **Discard** buttons.

Right Panel: Ultrasound Image

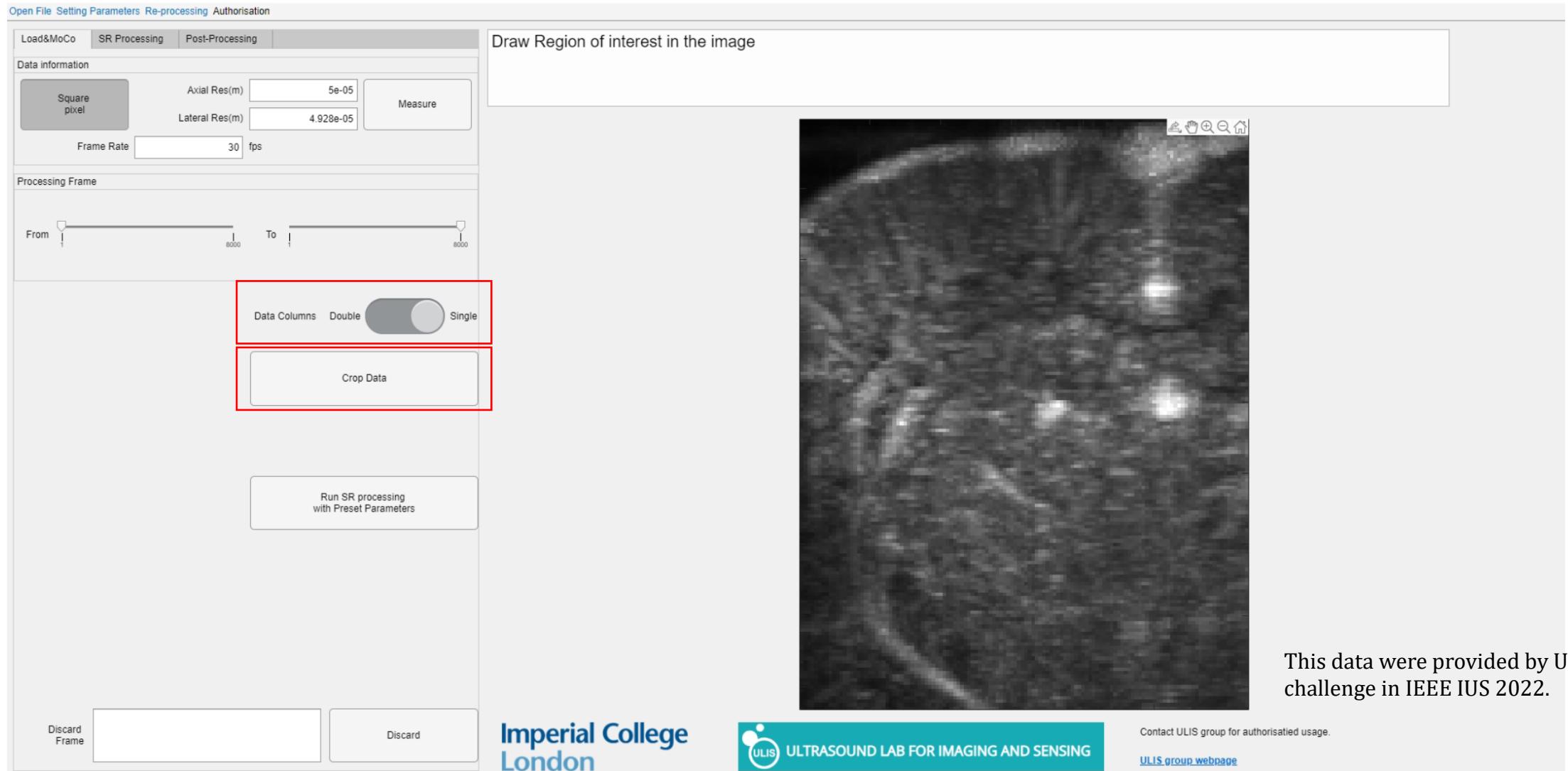
The image shows a grayscale B-mode ultrasound scan of a brain (labeled "brain 2" and "20201223-194847-40E5"). The image is labeled "Draw Region of interest in B-mode image". The top right corner displays acquisition parameters: 2020/12/23 19:49:20, SP/Zhang, Image, CEUS, F H18MHZ, M10.29 T1s0.0, DR 60:70, G76:70, M 5 / E 2, P 2 / AP 22%, D 1.0 cm, FR 95.0/95.0 Hz, ZSI 0. A scale bar indicates 1 cm. A blue arrow points to the "Crop Data" button in the control interface.

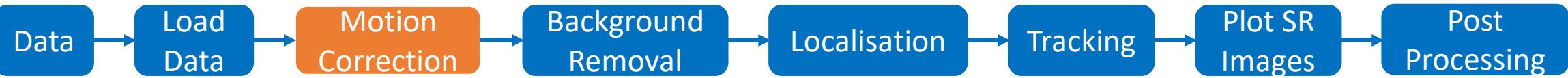
Bottom Navigation

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Crop Data: Single-column.





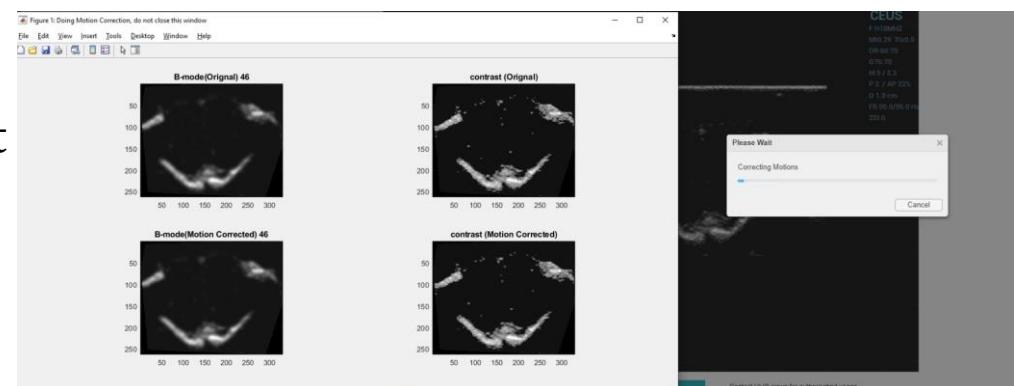
Motion correction components only work when there are B-mode data.

Set motion correction parameters:

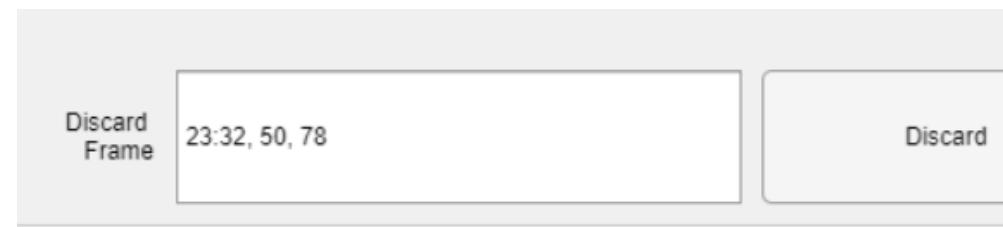


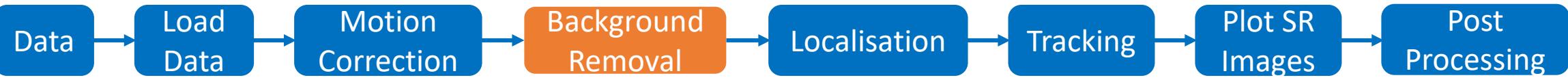
Click 'Do motion correction' button and wait.

If motion is still obvious after motion correction, the user can **cancel** the processing and adjust parameters for motion correction. If still not work, the user has to abandon data or contact us for help.



User can discard part of frames that are not rightly corrected by inputting the frame number and click **Discard**. The right example means frames from 23 to 32 and frame 50 and 78 will not be used in the following processing,





Input the number and click **Remove** button. Higher the number, less noise and less signal.

Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing

Background Reduction

Local Thresholding Global Thresholding

Threshold 0.3 0~1 Remove

Localisation

Localisation Uncertainty 25 um SR Ratio 10 Generate SR map

Subregions: Horizontal 1 Vertical 1 Estimate PSF

Localisation Method Decon... Multi-Thread Test Parameters

Sparsity Coefficient 0.01 Region Map Ratio 4 Localisation (All)

Tracking

Max Blood Flow Speed 0.02 m/s Reference image Track Bubbles

Track Length 0 >mm 4 >=Fra... Filter Tracks

Draw SR images

Start Frame 0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 Interp Tracks

End Frame 0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 Format -djpeg

Speed Color Limit 0.02 m/s Density Density with Direction Flow Separated Direction Preview

Density Color Limit 10 Plot and Save SR images

Image Blurring Factor 1

Background noise has been removed.

Contrast-mode Image - Frame #2001

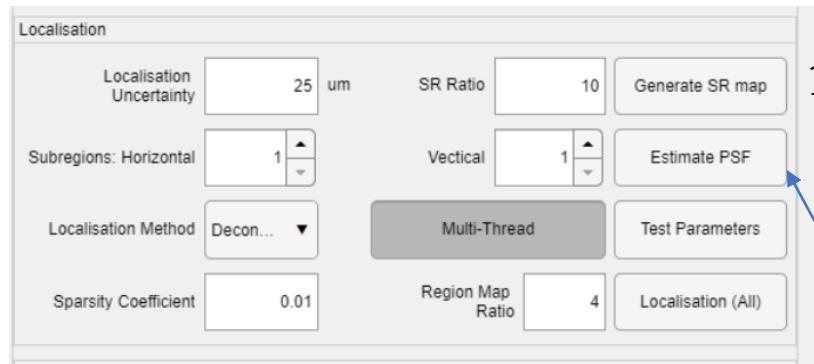
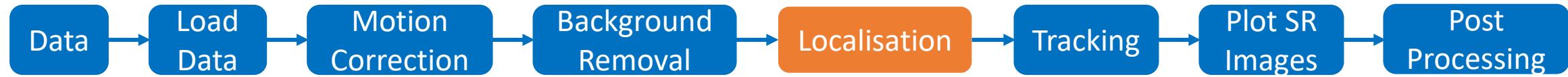
Depth 1 2 3 4 5 6 7 8

Lateral 1 2 3 4 5 6

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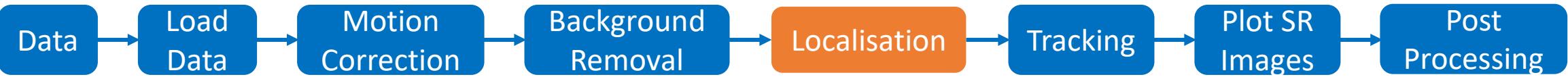
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1. Input localization uncertainty and SR ratio and click **Generate SR map** button.

2. Use Default\Last PSF or estimate PSF from the data by clicking **Estimate PSF** button.
Estimated PSF will be saved in the result folder.
If there is a PSF file in the result folder, click **Estimate PSF** button will load the file;
If the user want to estimate new PSF, the user should remove the PSF File from the folder
and then click **Estimate PSF** button.



Estimate PSF

Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing

Background Reduction

Local Thresholding Global Thresholding

Threshold 0~1 Remove

Localization

Localization Uncertainty 25 um SR Ratio 10 Generate SR map

Subregions: Horizontal 2 Vertical 2 Estimate PSF

Localization Method Decon... Multi-Thread Test Parameters

Sparsity Coefficient 0.01 Region Map Ratio 4 Localization (All)

Tracking

Max Blood Flow Speed 0.02 m/s Reference Image Track Bubbles

Track Length 0 >mm 4 >Frame Filter Tracks

Draw SR images

Start Frame 1 Interp Tracks

End Frame 1 Format -jpeg

Speed Color Limit 0.02 m/s Density
Density with Direction
Flow
Separated Direction Preview

Density Color Limit 10 Plot and Save SR Images

Image Blurring Factor 1

Background noise has been removed.

Select an isolated MB in the red box. If not, click outside image.
0 of 10 have been selected.

If there is no bubbles in the region, just pick ten black/empty area.

PSF for different regions

Estimated PSF

Estimated PSF

Estimated PSF

Estimated PSF

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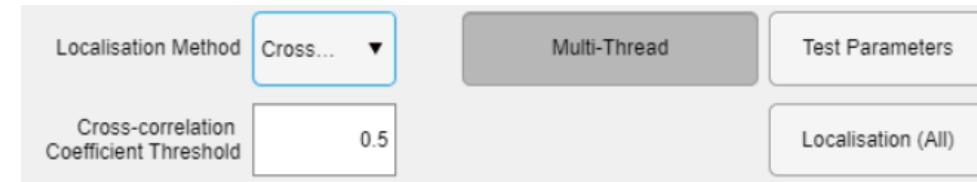
Select localization method: cross-correlation usually gives a faster computation but worse performance at high bubble concentrations



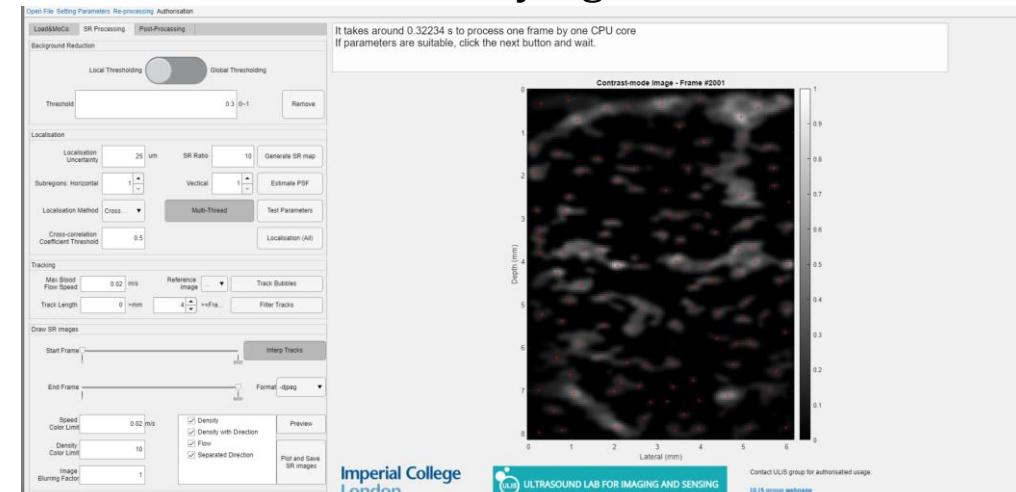
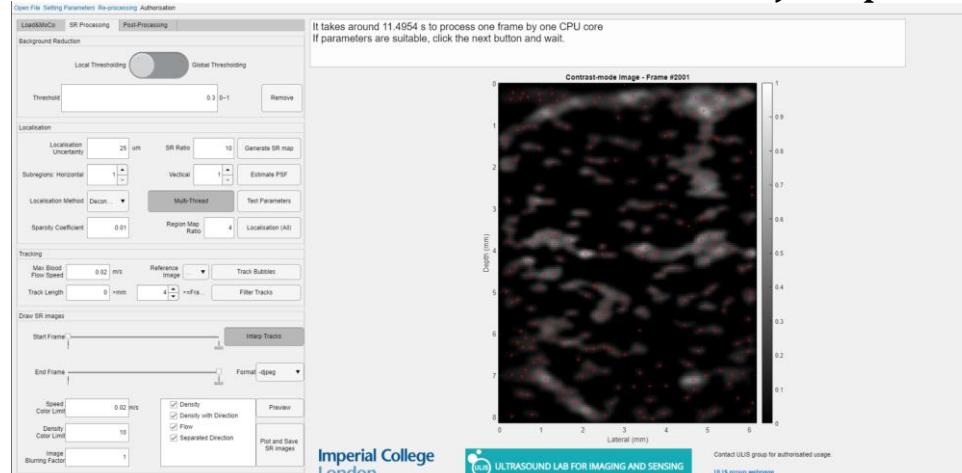
Deconvolution parameters



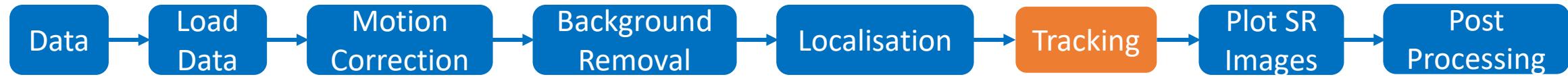
Cross-correlation parameters



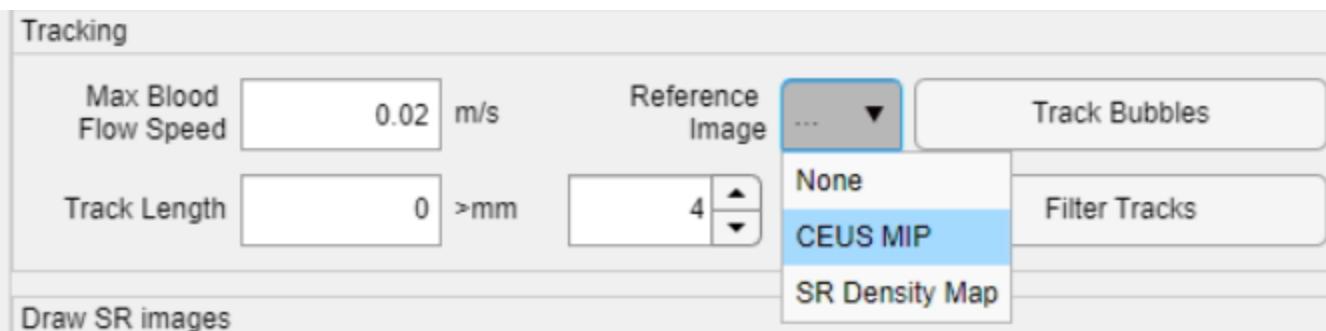
Click **Test Parameters** button and adjust parameters if the localisation is not satisfying

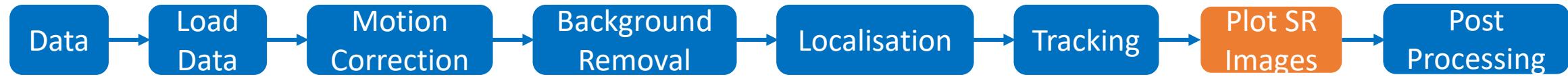


Click **Localisation (All)** button to process all the frames

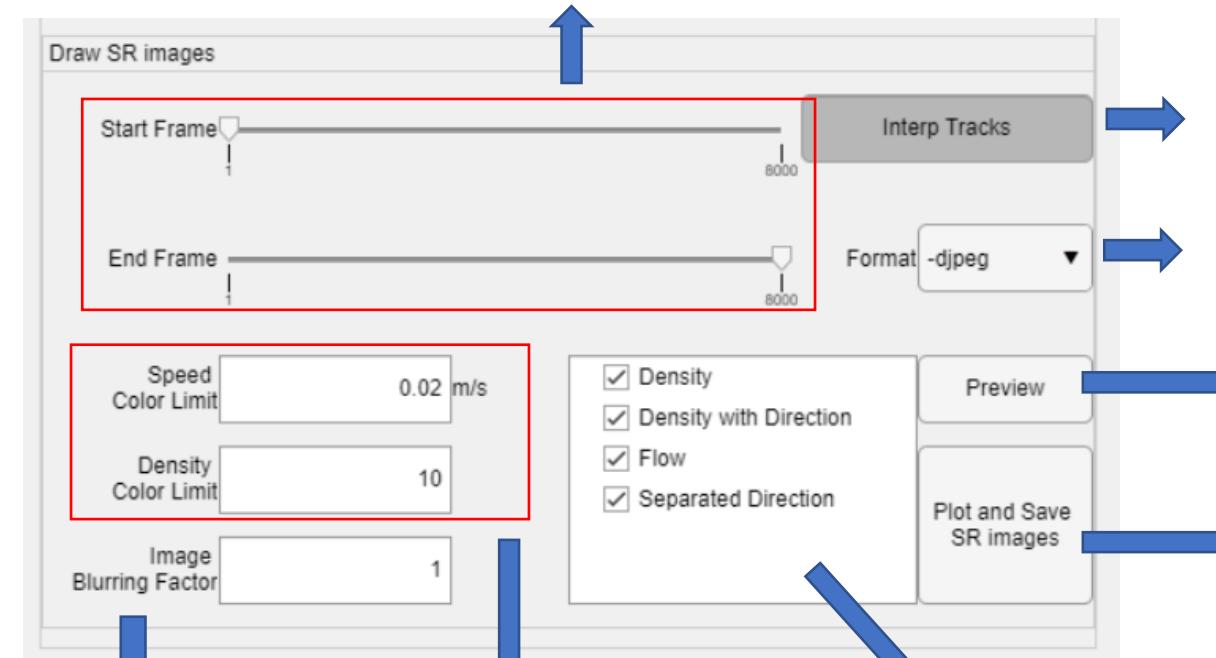


Set max blood flow speed; chose the reference image and click **Track Bubbles** button.
After finishing tracking, set filters and click **Filter Tracks** button





Use sliders for Start and End frames to select the temporal range the user want to reconstructed for SR images and quantified in post-processing.



Suggest to press this button down to enhance reconstructed vessel saturation.

Format of saved SR images

Click to preview SR density map to adjust dynamic range and blurring

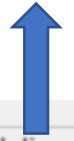
Click to generate all maps.

Dynamic range of SR images

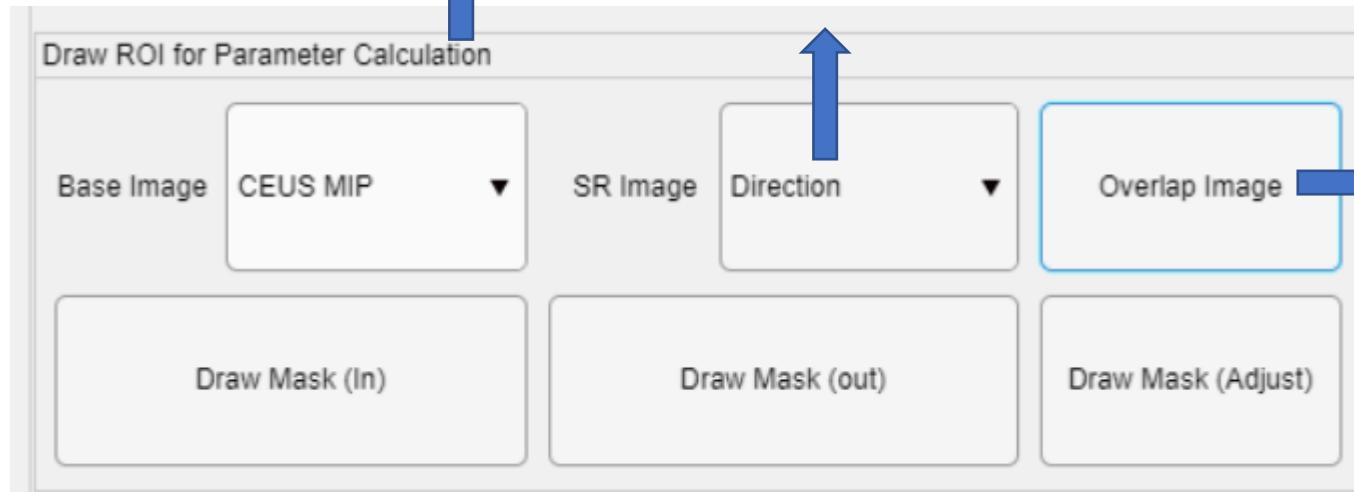
Control of blurring (>0)

Select what maps to be generated. It is suggested to select at least the first three one to have all the functions and metrics in the post-processing

Select the image at bottom: CEUS MIP or B-mode. B-mode is not available for single column data.

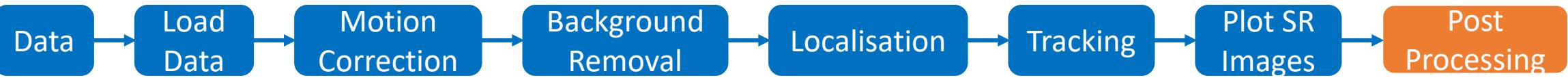


Select the image at top: SR density map or density map with direction.



Overlap two selected images.





Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing

Finish ROI

Draw ROI for Parameter Calculation

Base Image CEUS MIP ▾ SR Image Direction ▾ Overlap Image

Draw Mask (In) Draw Mask (out) Draw Mask (Adjust)

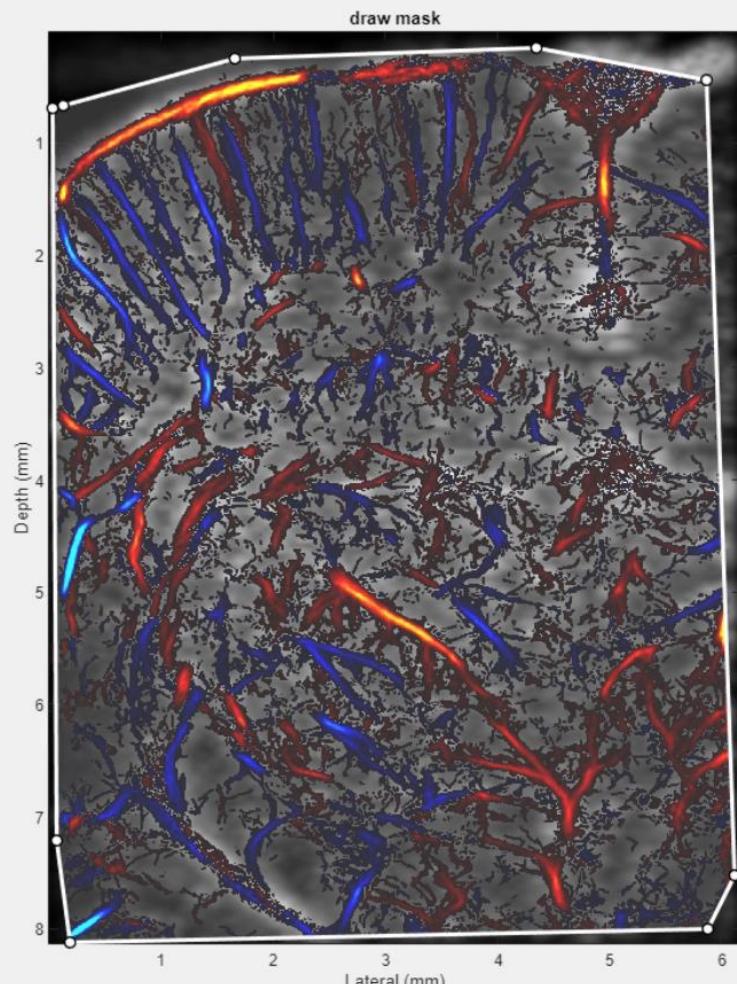
Calculate Parameters

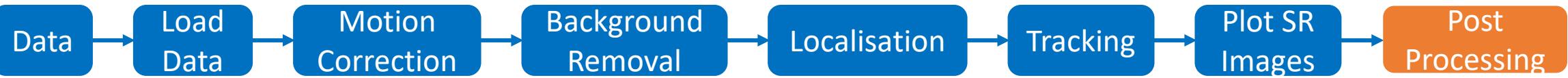
Generate Animation

Interp Movement Off On

Background Off On Generate Video

Remove wrong localisations at the edge of image.





Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing

Do you want to remove another area?, If yes, click Redo; If no, clike Next

Redo

Next

Draw ROI for Parameter Calculation

Base Image: CEUS MIP ▾ SR Image: Direction ▾ Overlap Image

Draw Mask (In) **Draw Mask (out)** Draw Mask (Adjust)

Calculate Parameters

Generate Animation

Interp Movement: Off On Generate Video

Background: Off On

Remove region of not interested
This step can be jumped or done for multiple time.

draw mask

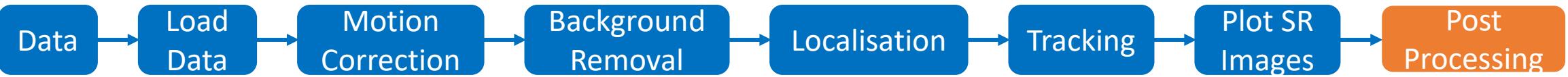
Depth (mm)

Lateral (mm)

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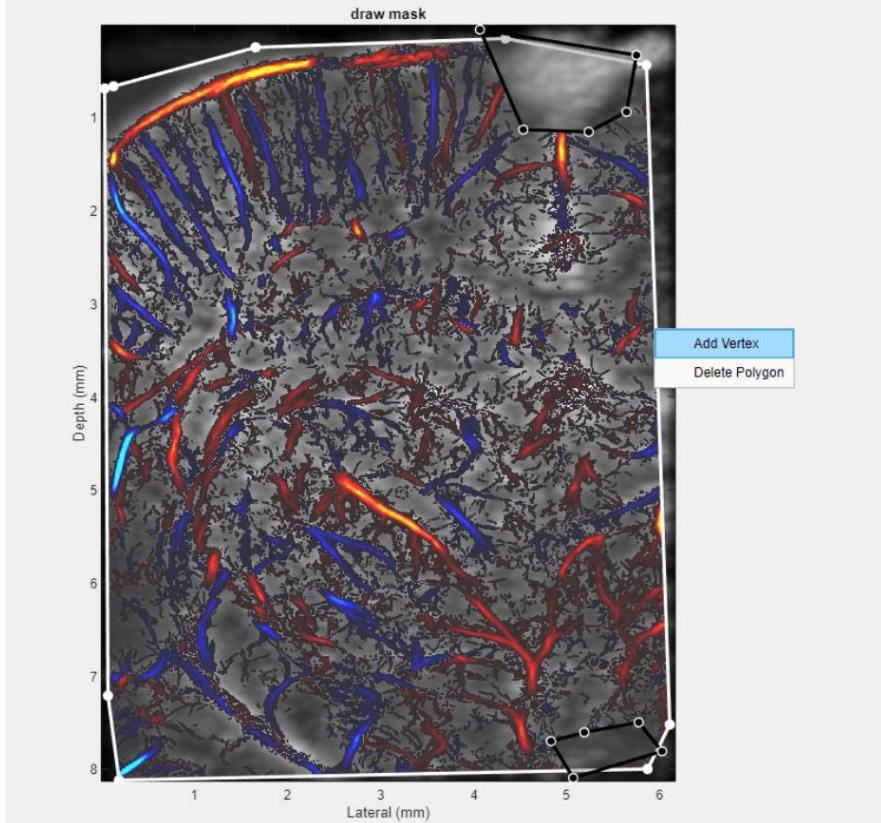
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The user can adjust ROI by dragging vertex or adding vertex.

After finishing, click **Draw Mask (adjust)** button to update the mask.



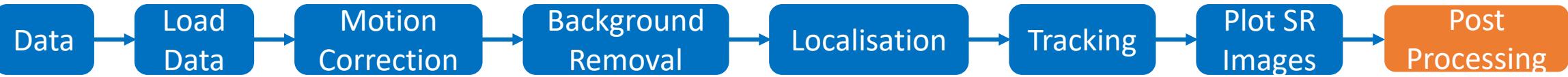
From GUI 2.1

Button: Draw Mask (adjust)

Replaced by

Button: Confirm Mask

If the user want to redo all the ROIs, click **Overlap** button and draw ROIs.



Click **Calculate Parameter** button, images within the masks will be generated and most of metrics will be automatically calculated.

Open File Setting Parameters Re-processing Authorisation

Load&MoCo SR Processing Post-Processing Done!

Draw ROI for Parameter Calculation

Base Image CEUS MIP SR Image Direction Overlap Image

Draw Mask (In) Draw Mask (out) Draw Mask (Adjust)

Calculate Parameters

Generate Animation

Interp Movement Off On

Background Off On

Generate Video

The user needs to select a steady range of below curve to calculate the fractal dimension, by drawing a line from the start to the end of the range with the mouse.

$d \ln I / d \ln r$, local dimension

Draw the steady range of the curve

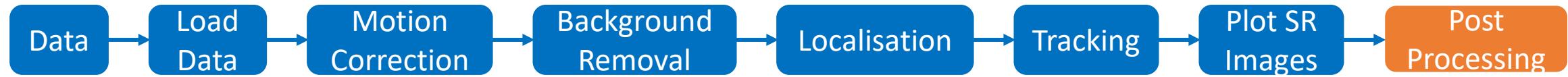
r, box size

When finishing, calculated parameters will be presented in the top-right area and saved in the result folder if the software is authorised.

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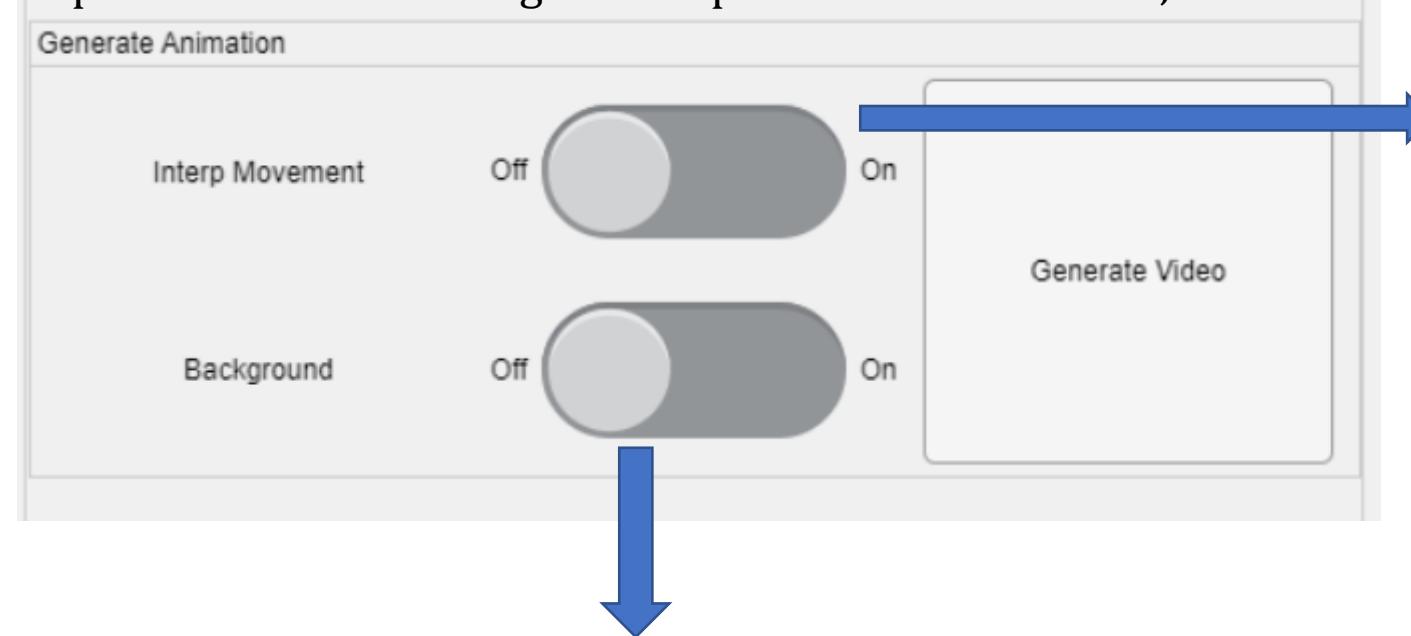
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Click **Generate Video** button to generate animations. Video can be found in the result folder. **Density map with direction has to be generated for this step.**

If this step is done before drawing ROI for parameter calculation, an animation will be generated for the whole image.
If this step is done after drawing ROI for parameter calculation, an animation will be generated with in the Mask.



If on (Suggested), put part of localised bubbles in one frame and move bubbles along interpolated tracked trajectories.

Otherwise, put part of localised bubbles in one frame and other parts of bubbles appear in sequence.

If on, density map with direction will be set as background.
Otherwise, no background.

Quick Run

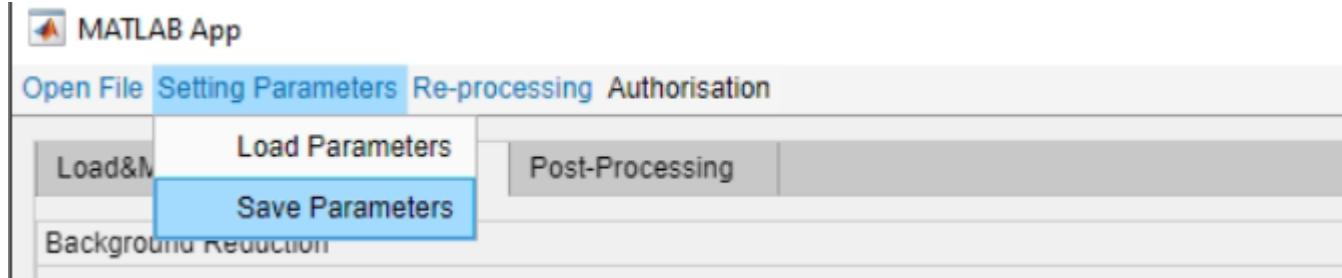
User can save the setting parameter and process the data with same experiment protocol without going through each step manually.

User can save setting parameters for processing by click **Save Parameters**.

User can save the file anywhere.

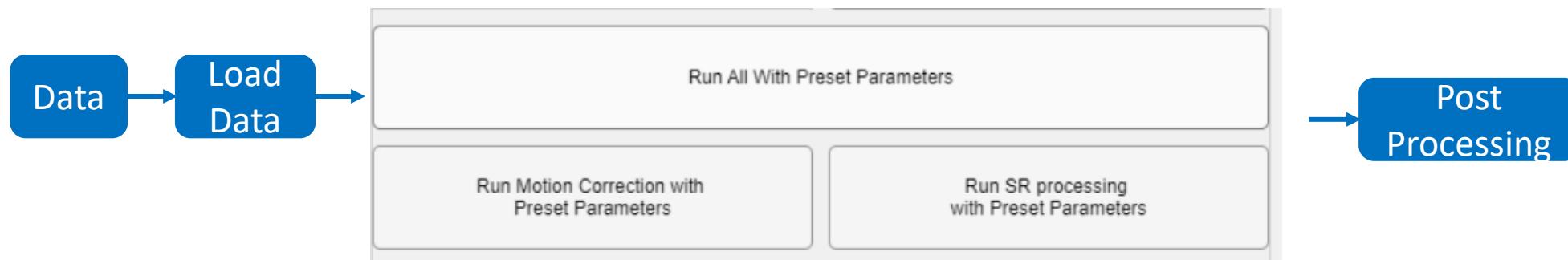
If the file is saved in Folder 'InstallationPath\application\' , the saved parameters will be default parameters for opening the software next time.

User can use **Load Parameters** to load parameters in any folder.



After loading and cropping the data, user can click

1. **Run all** to do all the processing automatically;
2. **Run Motion** correction to only do motion correction automatically;
3. **Run SR Processing** to only do motion correction automatically.



Re-Processing

Pre-process data with new parameters.

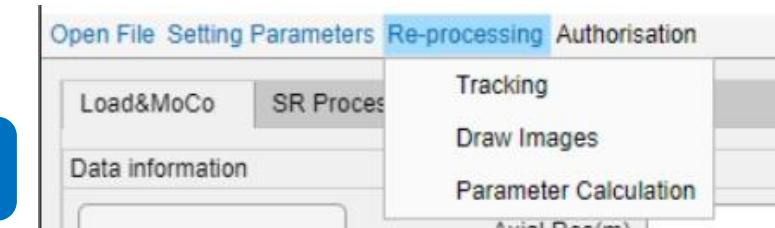
Re-process Localisation:

User can load motion-corrected data by Open File-Mat, and then do



Re-process Tracking:

User can click Re-processing - Tracking, load Localisation result File, and then do



Re-draw Images:

User can click Re-processing – Draw Images, load Tracking Result File, and then do



Re-Calculate parameters:

User can click Re-processing – Parameter calculation, load SR Maps File, then do



Updates in SRUS 2.1

GUI 2.0->2.1

Localisation 2.0->3.0

Plotting 2.0 ->2.1

Parameter Calculation 2.0 ->2.1

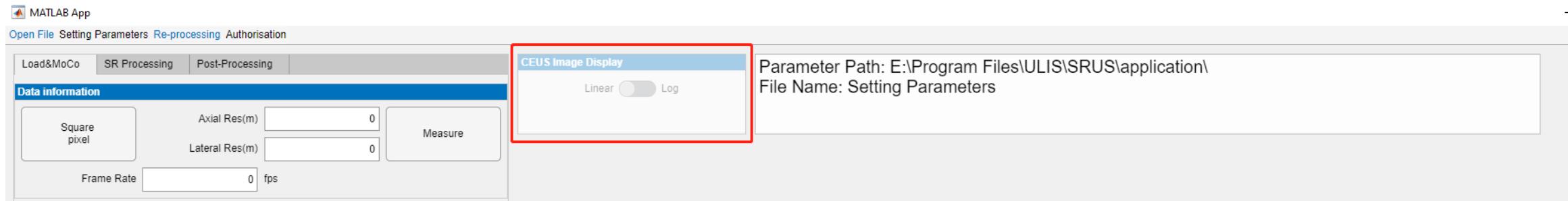
Localisation 3.0:

Normalized cross-correlation can be done with spatial-varying PSFs and computation was optimised for faster speed and less memory.

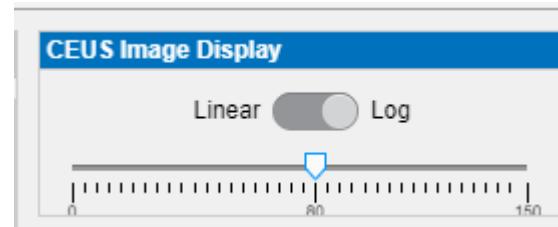
An additional filter is added in Deconvolution to remove noise.

GUI 2.1:

Add a new panel for choose display mode and change dynamic range (dB scale) if log (log compression) is chosen.



It is only enabled when Mat data is loaded. The display setting will take effect when CEUS images are plotted next time. With below setting, CEUS image will be displayed in log compression with dynamic range from -80 to 0 dB



Folder for files used to set the software is moved to the installation path of the software.

Plotting 2.1:

A flow magnitude map calculated by averaging speed of each passing bubble was added.

Parameter Calculation 2.1:

Selection for calculated parameters and if replotting images in ROI were added.

Updates in SRUS 2.2

GUI 2.1->2.2

Localisation 3.0->3.1

Plotting 2.1 ->2.2

GUI 2.2:

Unpressed:

Save Mat Files

Pressed:

Save Mat Files

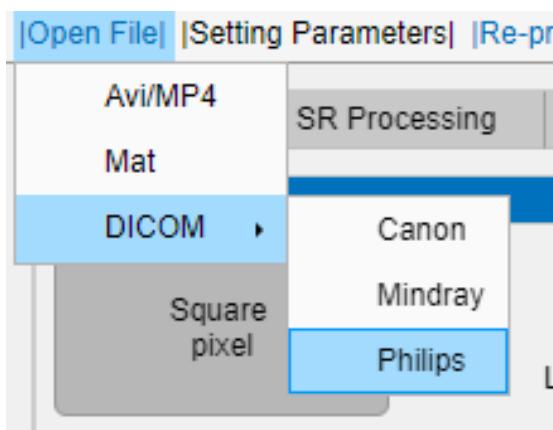
1. Add a state button at the middle button.

1) The button is default ‘Pressed’. In this case, processed results are saved in Mat files after ‘Motion correction’, ‘Localisation’, ‘Tracking’, and ‘Plotting’, each time of which might take much time.

2) The user can make the button unpressed to reduce consuming time when tuning the processing parameters.

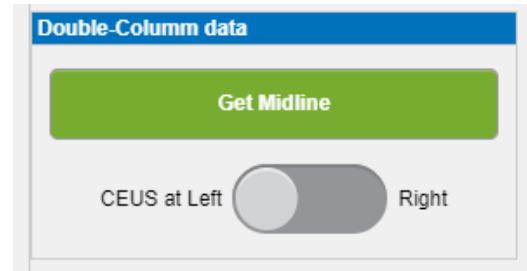
3) **The user is suggested to press the button again to save all Mat files, after fixing processing parameters.** Mat files can be re-processed by the software. ‘Batch Processing’ will be provided to deal with Mat files in the future.

2. Add “Philips” as a new option in the ‘Open File’ menu.

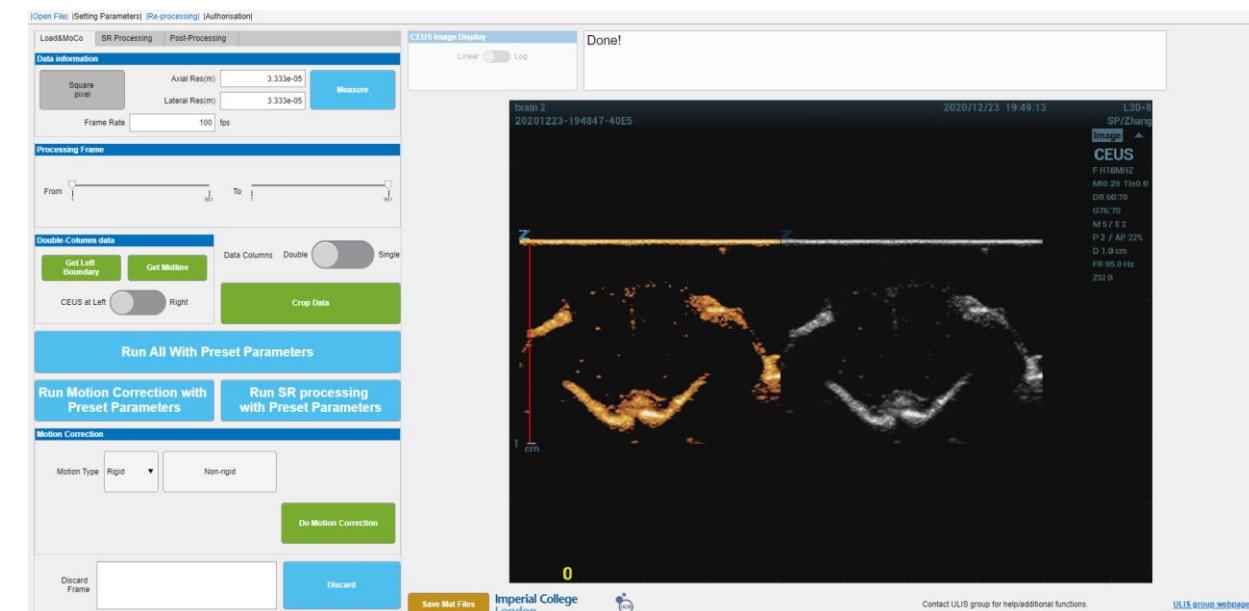


3. Add “Get left boundary”, to deal with some cases where the left edge of the ultrasound image is not the edge of the whole image.

GUI 2.1:



GUI 2.2:



Left edge of ultrasound image **is** the edge of the whole image.
The user **does not need** to click the “Get left boundary” button.

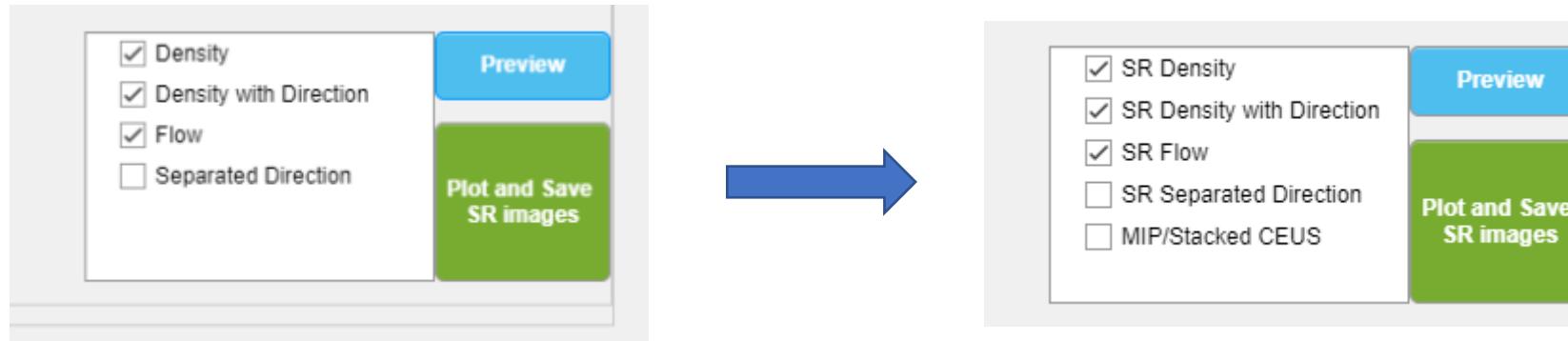
Left edge of ultrasound image **is not** the edge of the whole image.
The user **needs** to click the “Get left boundary” button.

Localisation 3.0->3.1

“Localisation (all)” works stable where there are blank (no signal) CEUS frames in the sequence.

Plotting 2.1 ->2.2

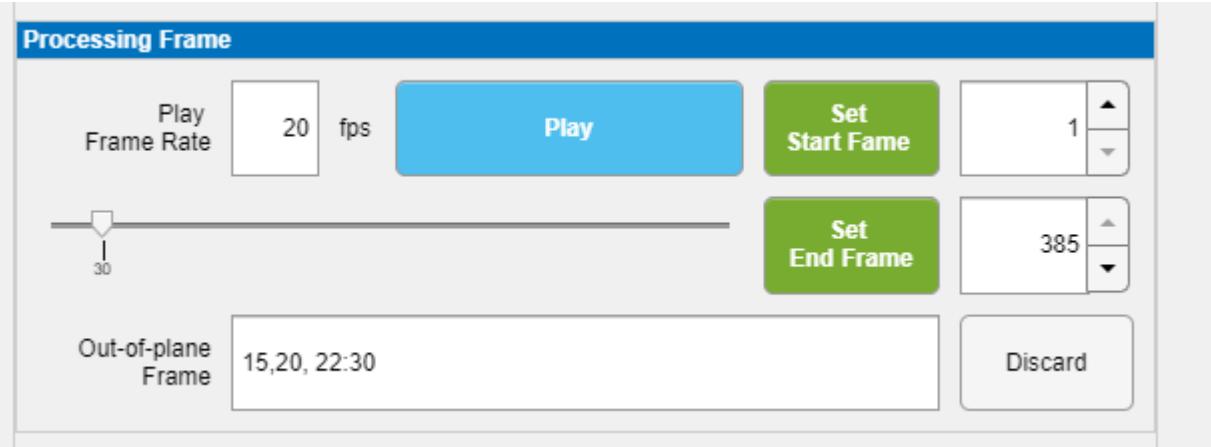
The user can choose if saving Maximum Intensity Projection (MIP) image and Averaged (Stacked) Image of CEUS Sequence.



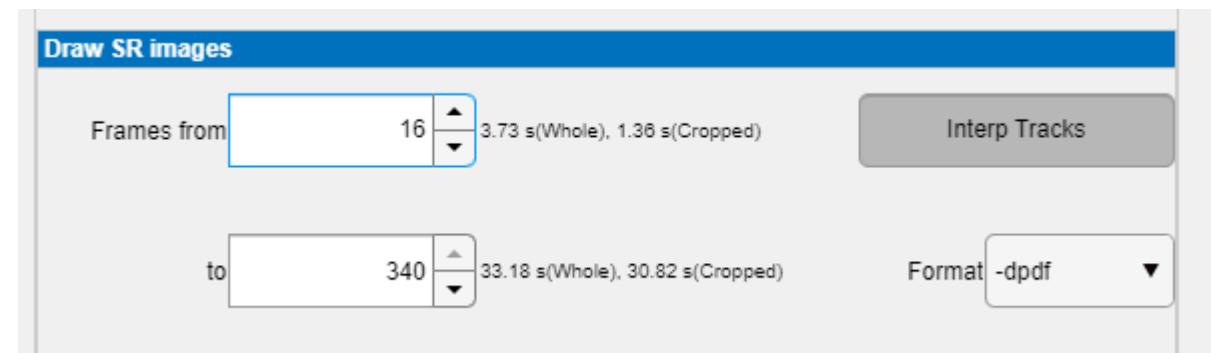
Updates in SRUS 2.3

GUI 2.2->2.3

GUI 2.3: Improve ‘Processing Frame’ and ‘Draw SR image’ sections to exactly select frames for processing



1. Add video player. The playing frame rate might not reach the set FPS with limited PC performance.
2. The user can set start and end frames exactly with the Spinners.
3. The user can discard out-of-plane frames before doing motion correction.



1. The user can use the Spinners to set frame ranges for plotting SR images.
2. Texts show the time corresponding to the frame. If the start frame in “Processing Frame” is set as 1, the time (whole) and time (cropped) are same; otherwise, the former is the time in the whole video sequence and the latter is the time in the cropped sequence.

GUI 2.3: the display range of the Arriving Time Map can be adjusted.

[Open File] [Setting Parameters] [Re-processing] [Authorisation]

Load&MoCo SR Processing Post-Processing

CEUS Image Display
Linear Log

Please adjust the time range of arriving time map and click Print.

Print

Draw ROI for Parameter Calculation

Base Image CEUS MIP ▾ SR Image Density ▾ Overlap Image

Draw Mask (In) Draw Mask (out) Confirm Mask

Metric Calculation

Velocity Distribution
 Vessel Density
 Vessel Diameter
 Tortuosity
 Arriving Time Map
 Fractal Dimension

Plot Image in ROI Off On

Calculate Parameters

Display Range Start (s) 9

Display Range End (s) 80

Generate Animation

Interp Movement Off On

Background Off On

Generate Video

Save Mat Files

Imperial College London

ULIS

Arriving Time

Depth (mm)

Lateral (mm)

80
70
60
50
40
30
20
10

Contact ULIS group for help/additional functions.

ULIS group webpage