VXRE Reconstruction Software Manual

Version 1.7.8

3D INDUSTRIAL IMAGING

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VXRE 3D CT Reconstruction Software

VXRE Reconstruction software reconstructs 3D volume using multiple 2D X-ray projection images with geometry information. The basic reconstruction process is based on FDK filtered back-projection algorithm for 3D Cone-beam CT. Major features are like the following.

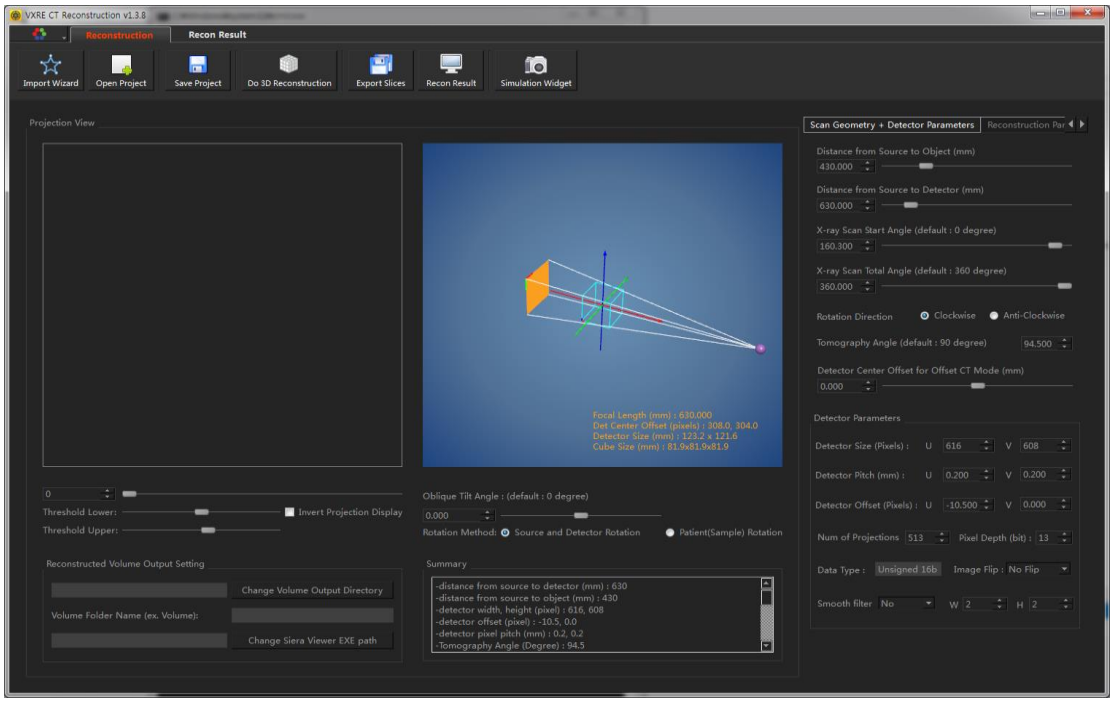
- Hardware Requirements
- Install and Launch VXRE
- Import Wizard
  - Projection Files, Geometry Parameter Setting, Volume Cube Setting
- 3D Cone Beam CT Reconstruction
  - FDK-filtered back projection
- Export Slices
- Main UI
  - Projection View, CT Geometry View, Recon Result View
- Basic Features
  - Noise Reduction and Dark/Bright field correction
  - Outside FOV Boundary Artifact Correction
  - Offset CT Mode
  - Oblique CT Mode
- Advanced Features
  - CT Value Calibration (Hounsfield Calibration)
  - CT Geometry Correction (Detector Offset/Tilt angle)
  - Custom Geometry XML Generation
  - RAR (Ring Artifact Reduction)
  - MAR (Metal Artifact Reduction for Dental CT)
- Appendix
  - Project file format
  - Command line & UDP remote commands

- Hardware Requirements

	Minimum Requirements	Recommended
OS	Windows Vista,7,8 (64bit)	Windows 7,8,8.1 (64bit)
CPU Memory	At least 2 GB (at least twice as big as the data size)	At least 6 GB (at least three times as big as the data size)
Graphics Card (GPU)	Graphics cards compatible with DirectX 10 or higher	Graphics cards compatible with DirectX 11 and Nvidia CUDA with GPU memory at least twice as big as the data size
CPU	Intel i3 Dual Core or higher	Intel i5 Quad Core or higher
HDD	At least 2GB free space	At least 2GB free space

Install and Launch VXRE

- Download latest VXRE install package and unzip the file.
- Click 'Setup_VXRE_V_x.x.x.official.exe' file, then installation process will begin.
- After the installation is done, click VXRE icon on the desktop to launch the VXRE software.



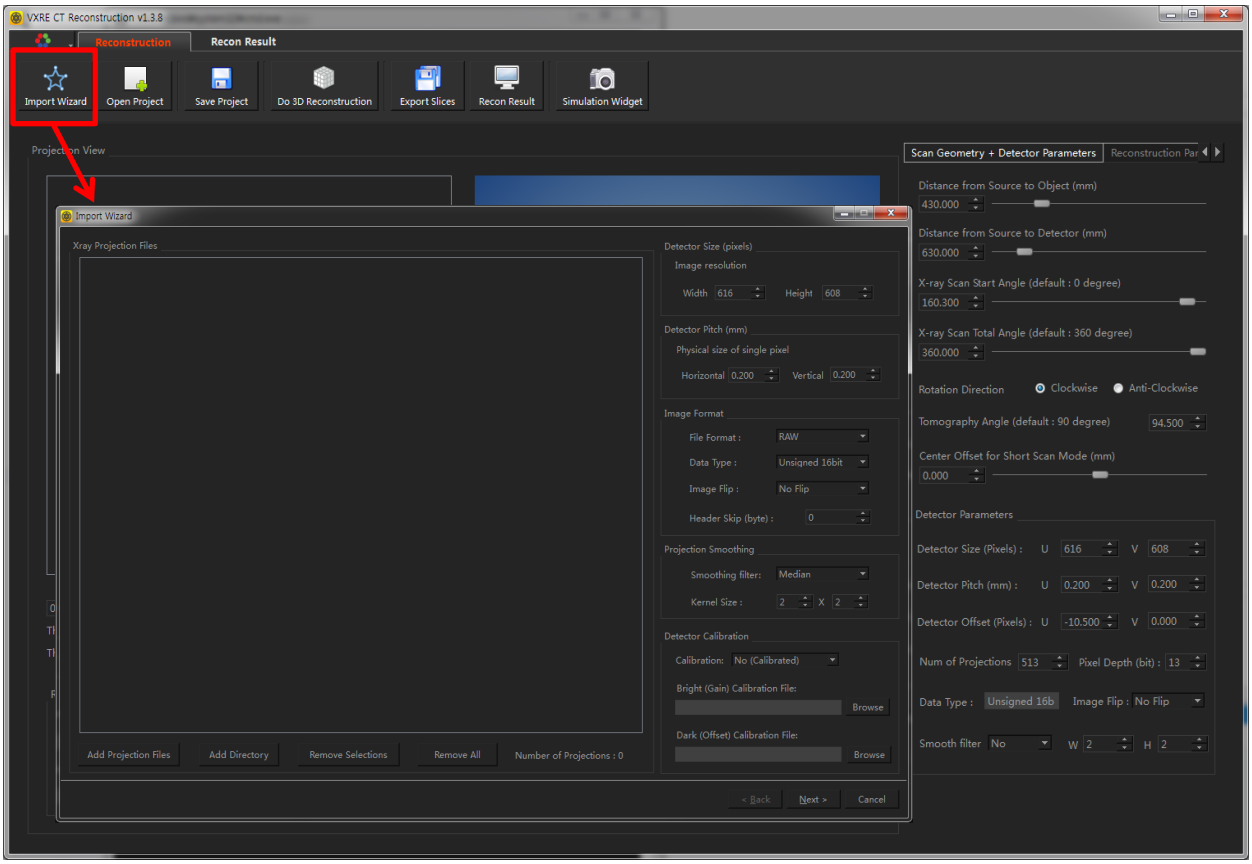
- **Click VXRE icon on desktop.**

● Import Wizard

– For the CT reconstruction, various parameter values (input file information, CT geometry parameters and volume cube information) should be set for correct reconstruction process.

– Parameter setting can be done by two different ways. By using import wizard (this section) or by using project file. For the latter method, please refer to ‘Project file format for reconstruction parameters’ section in this manual.

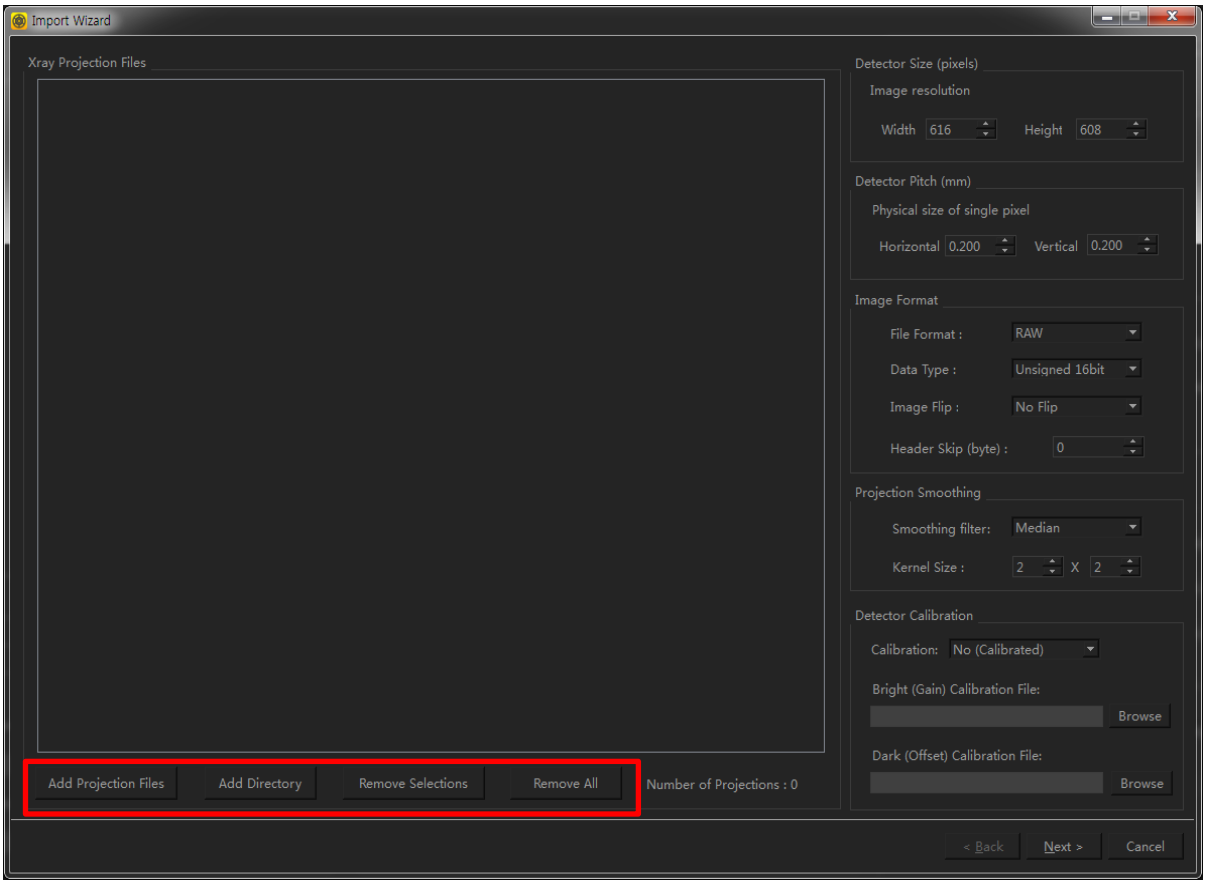
– By using import wizard, user can set many parameters step-by-step process. For launching import wizard window, please click ‘Import Wizard’ button in the top toolbar.



Import Wizard

Use Import Wizard to easily set input Projection Files, CT Geometry and Volume Cube Information.

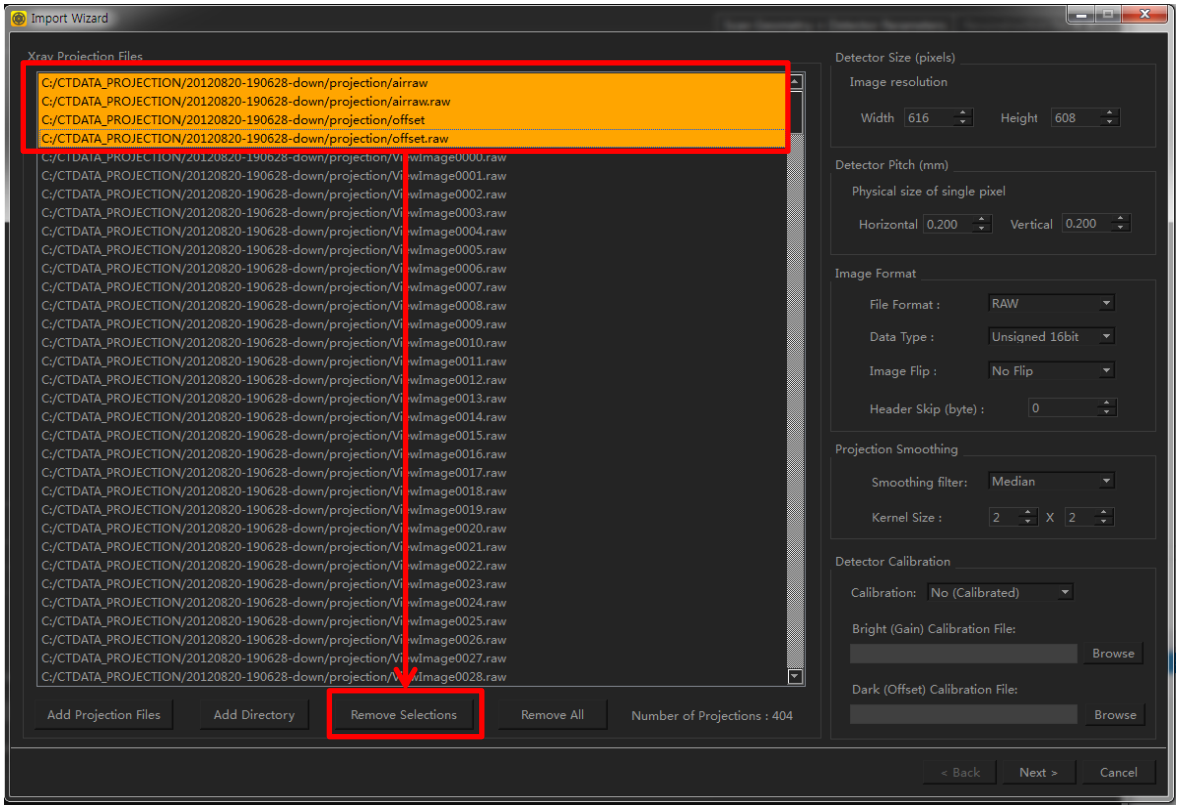
- Import Wizard 1: Setting input projection files (Step1)



❖ Setting Input Projection Files

1. Click the Import Wizard button to open the Import Wizard window.
2. Click 'Add Projection Files' or 'Add Directory' button to open the Opening Files window.
3. Select X-ray Projection images or a folder name.

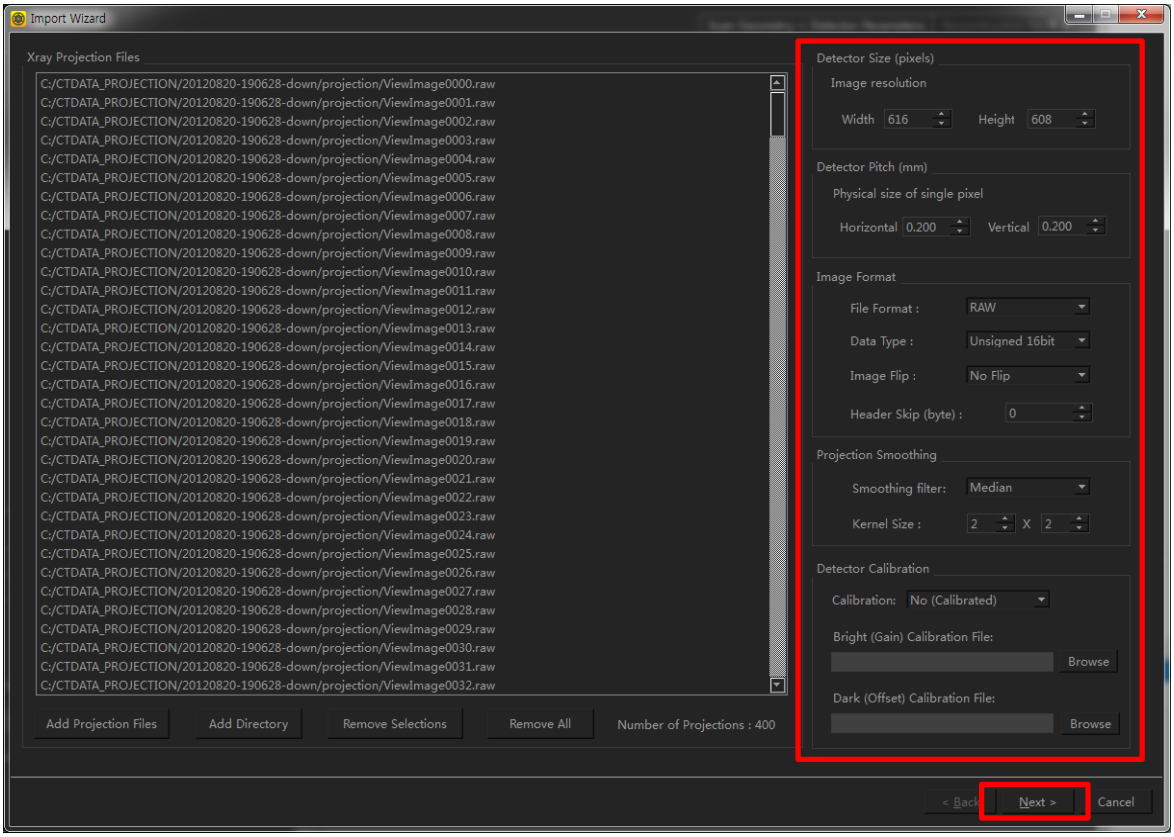
- Import Wizard 1: Setting input projection files (Step2)



❖ Setting Input Projection Files

4. If you want to delete unwanted files, select them by mouse drag and click 'Remove Selections' button.

- Import Wizard 1: Setting input projection files (Step3)



❖ Setting Input Projection Files

5. Set detector image resolution and pitch values. (e.g. 1024x1024, 0.2mm x 0.2mm)

6. Set detector image format. (e.g. Raw file format, 16bit data type)

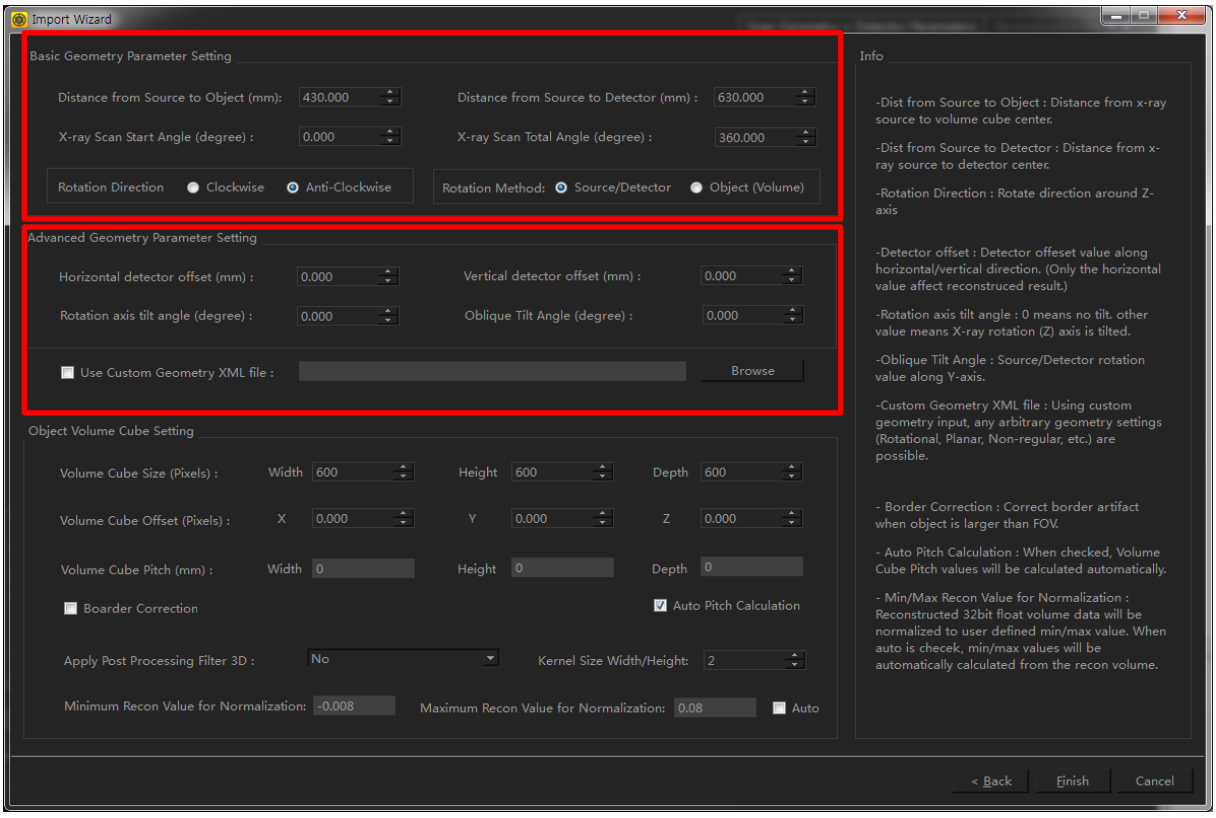
7. Set Projection Smoothing filter (If the projection image has noise, apply median filter.)

8. Set Detector Calibration images.

→ Set Bright (Gain) image and Dark (Offset) image file path.

9. Click 'Next' button.

- Import Wizard 2 : Setting geometry parameters



❖ Setting Geometry Parameters

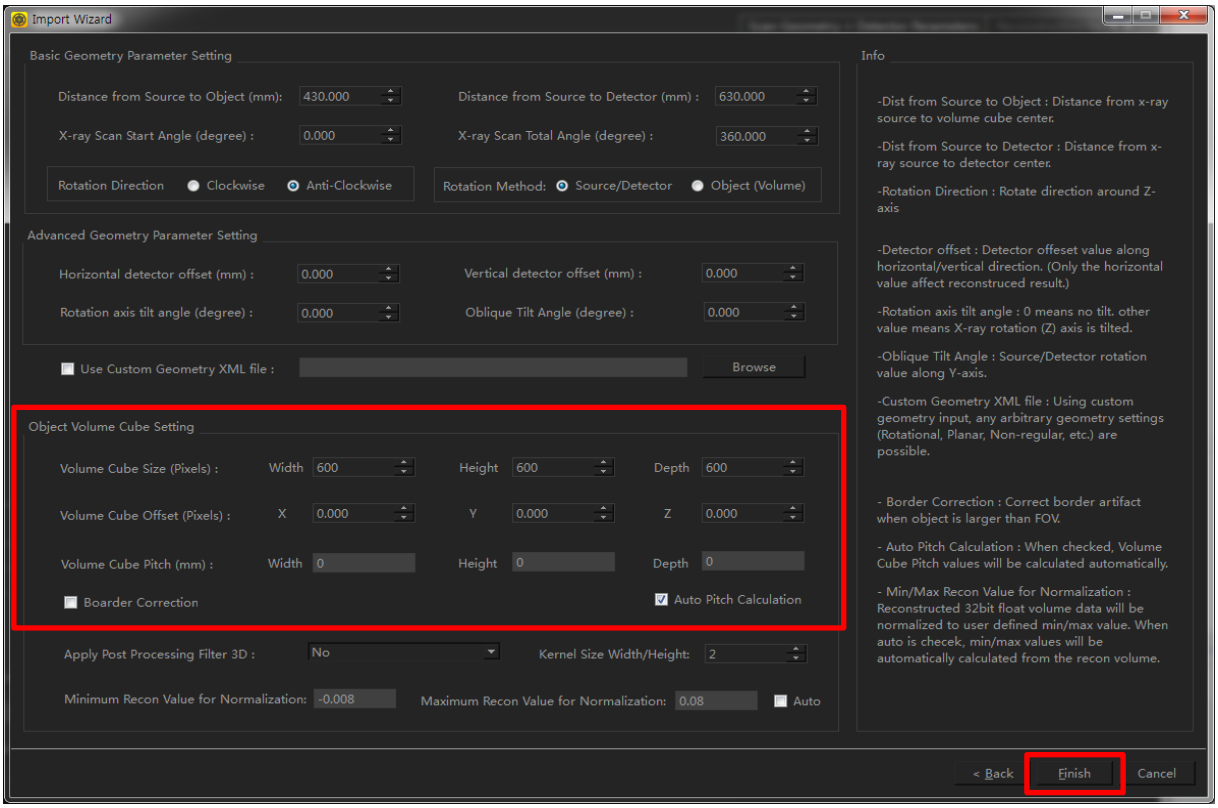
1. Set up basic geometry parameters:

- **Source to Object distance**
- **Source to Detector distance**
- **Rotation Direction (CW or CCW)**
- **Source/Detector rotation vs. Object rotation**

2. Set up advanced geometry parameters:

- **set detector offset (Horizontal detector offset value is important)**

- Import Wizard 3 : Volume cube setting

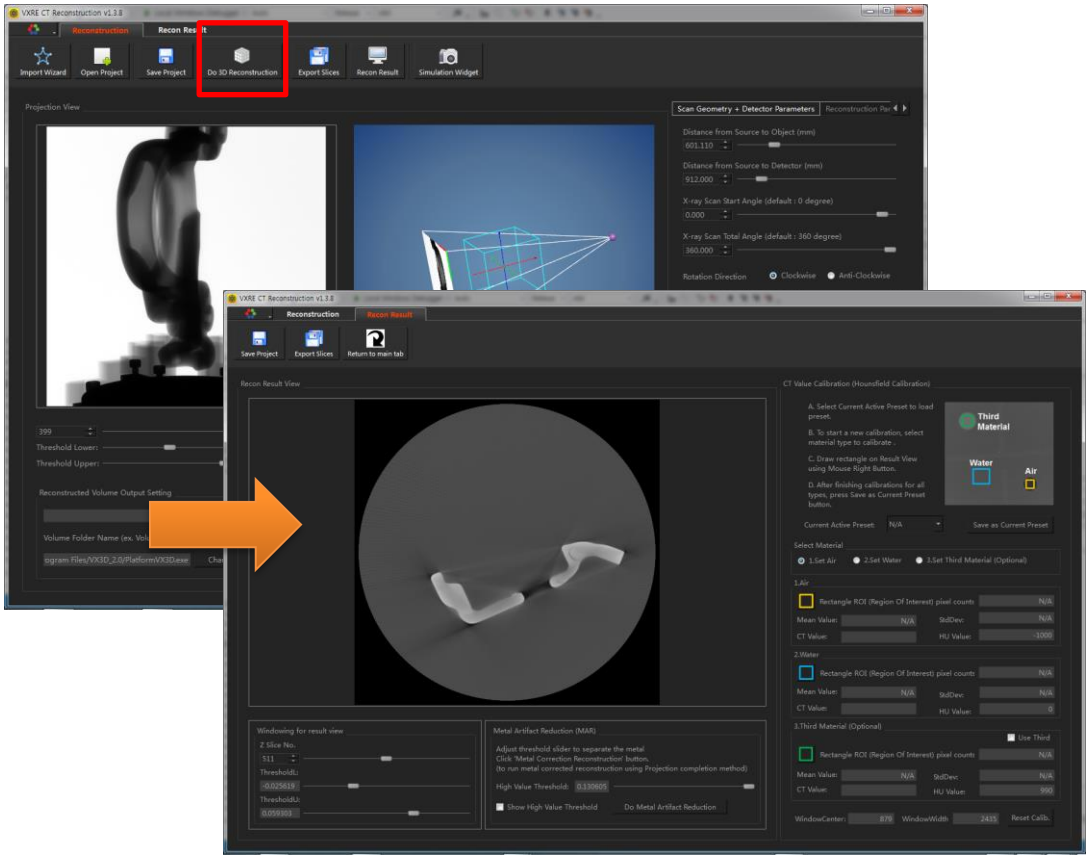


❖ Setting Volume Cube

1. **Set Volume Cube Size. (e.g. 600x600x600)**
2. **Set Volume Cube Pitch.**
   - **size of a single voxel in mm**
   - **Or set 'Auto Pitch Calculation' check box for automatic pitch calculation**
3. **Click 'Finish' button.**

● 3D Cone Beam CT Reconstruction

- To start CT reconstruction, click 'Do 3D Reconstruction' button in the top toolbar.
- Input projection (x-ray) images will be reconstructed as a 3D volume slices using FDK based filtered back-projection algorithm.
- When Nvidia graphics card is installed on the PC, the reconstruction process will be accelerated using CUDA technology.



❖ CT Reconstruction Process

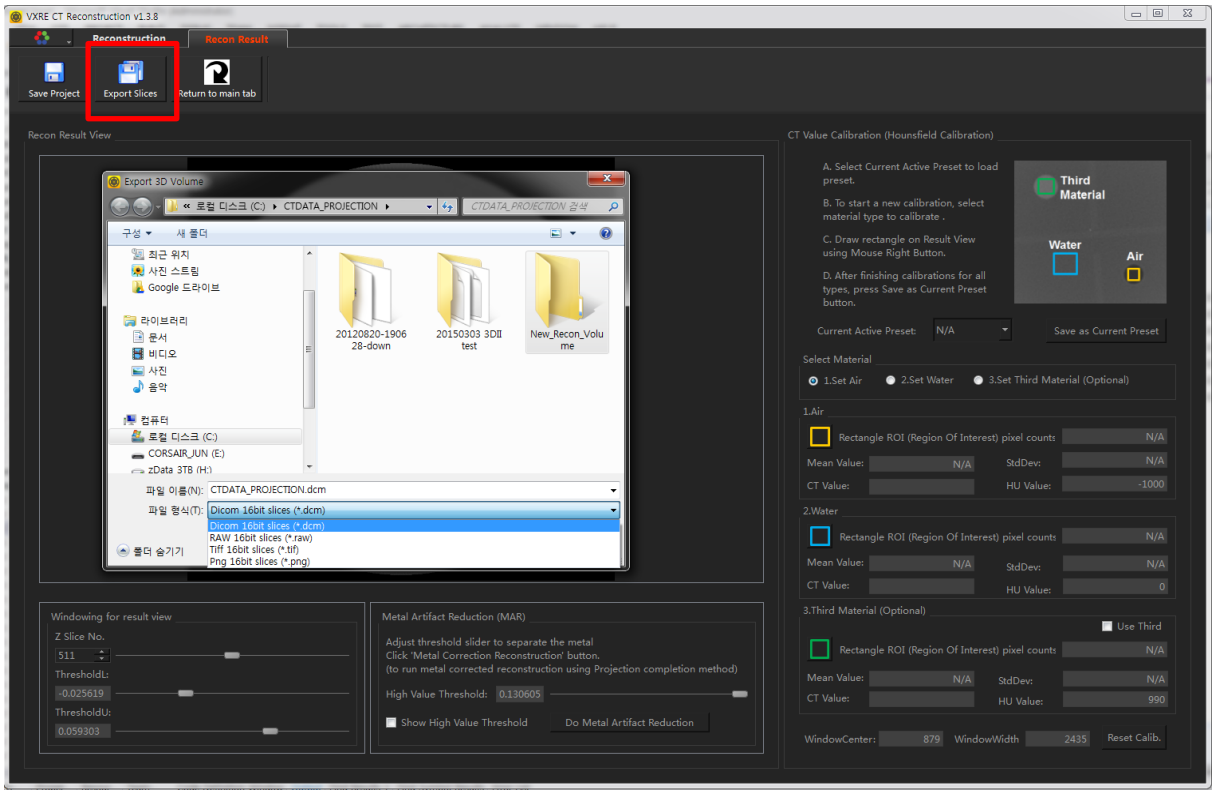
1. Click 'Do 3D Reconstruction' button

2. After the reconstruction process finished, recon result view tab will be activated.

● Export Slices

– After CT reconstruction, user can export (save) the reconstructed 3D volume data to slice files.

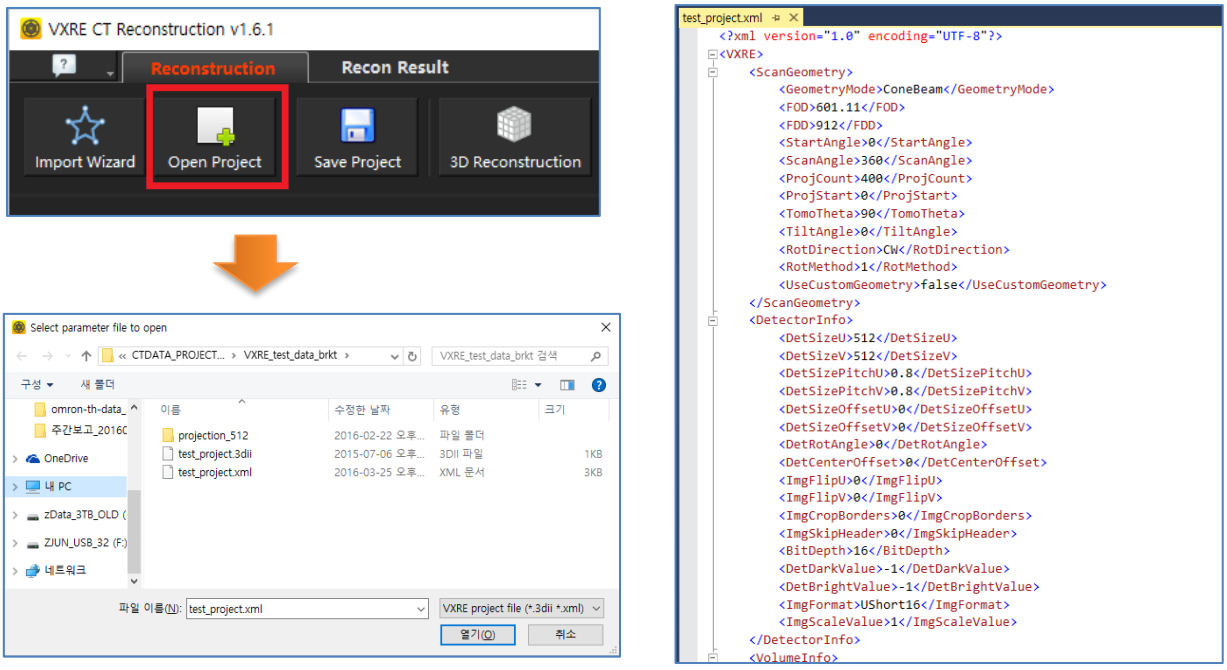
– Volume slices will be saved as 16bit and 4 different types are supported (Dicom DCM, RAW, TIFF, PNG format).



❖ Export Slices

1. **Click 'Export Slices' button.**
2. **Create New folder where the volume slices will be saved.**
3. **Select file format and click 'save' button.**

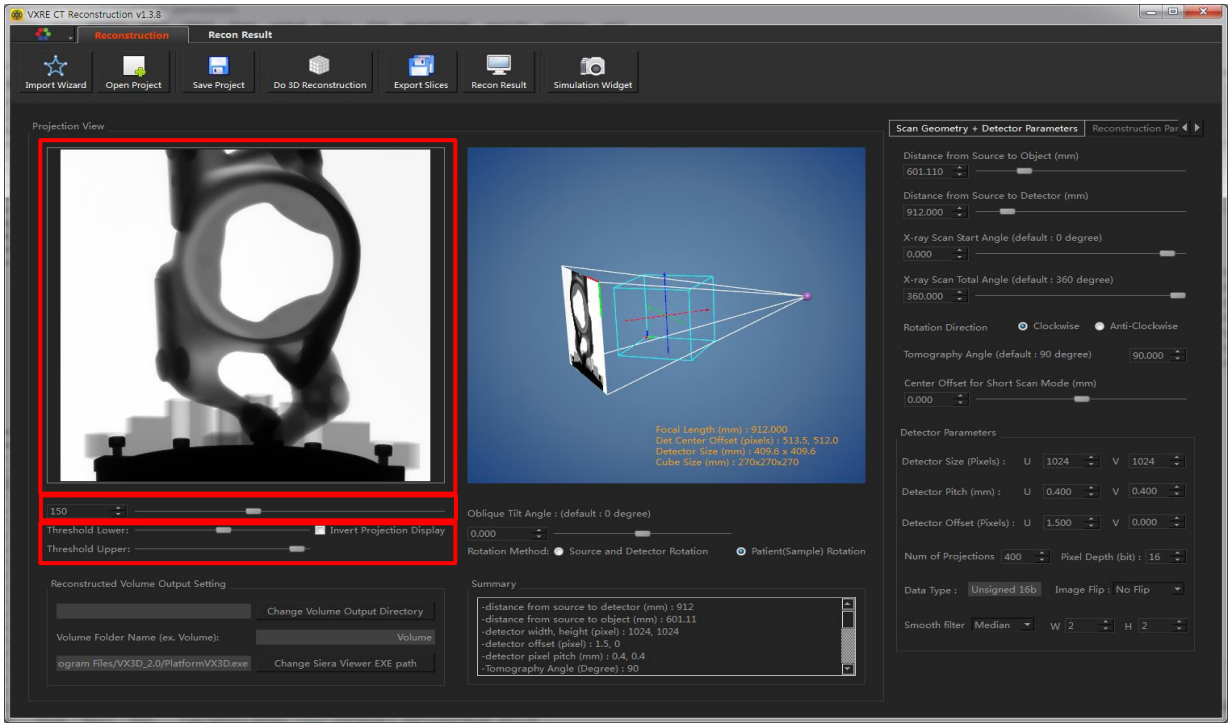
Main UI : Open Project



Open Project file which contains all the parameters for CT reconstruction

- Parameter setting can be done without 'Import Wizard' when project file which contains all the parameters for CT reconstruction is prepared.
- When user click 'Open Project' button, a pop-up window will appear.
- Choose .xml project file with frame directory (which contains 2D projection images).
- By using the information from .xml file, 2D x-ray projection images will be loaded.
- The content of sample .xml file is shown above, including its relevant information such as Source to Detector distance, Source to object center, detector size, projection image information, etc. For more information about project file format, please refer to 'Project file format for reconstruction parameters' section in this manual.

● Main UI : Projection Image View



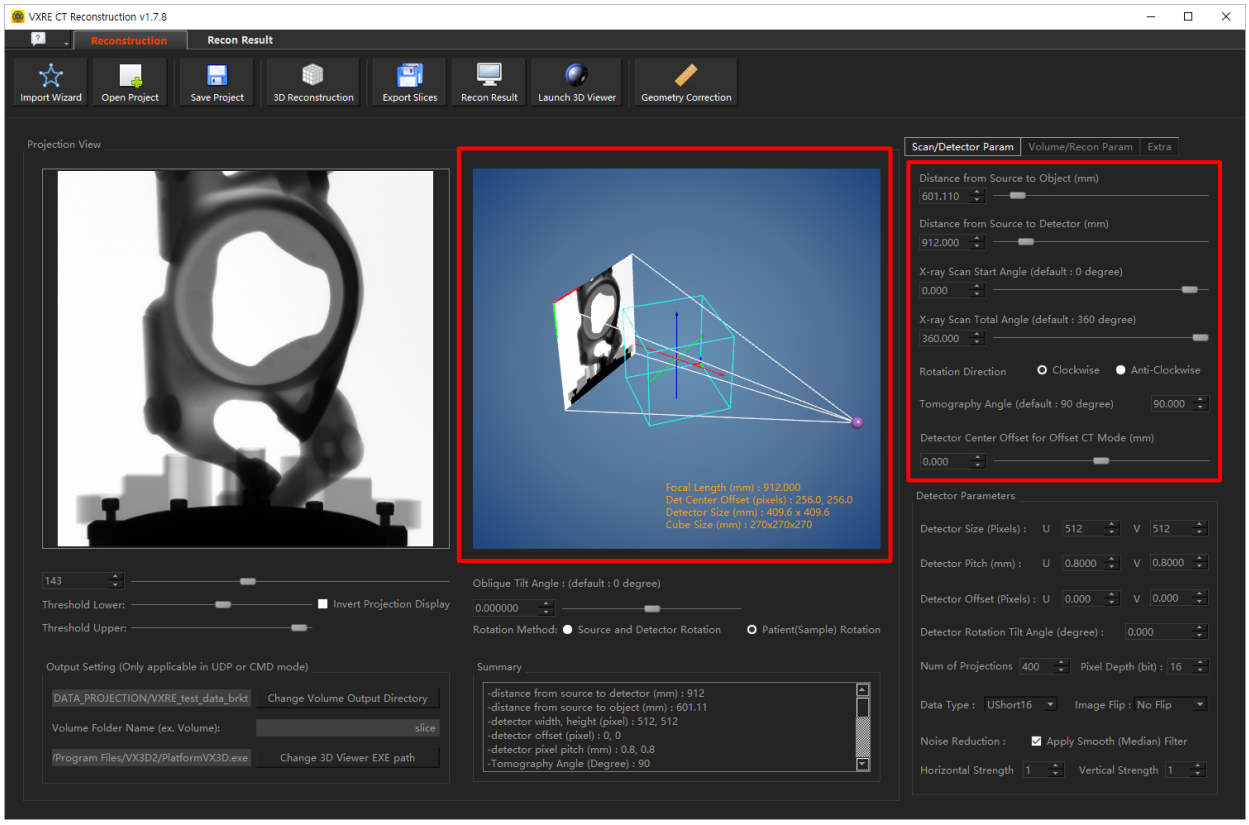
- After loading project file, the first projection image will be visualized on projection view.

- See other projection images by changing the image number of spin box control or by using the slider.

- Change the contrast of the projection image by adjusting ‘Threshold Lower’ and ‘Threshold Upper’ sliders.

- Invert the projection image result (White→Black, Black→White) by using the ‘Invert Projection Display’ check box.

● Main UI : CT Geometry View (3D View)



- Current CT Geometry will be shown in geometry view as 3D lines and cube.

- If you change geometry parameters on right panel, CT Geometry view will get values and update immediately.

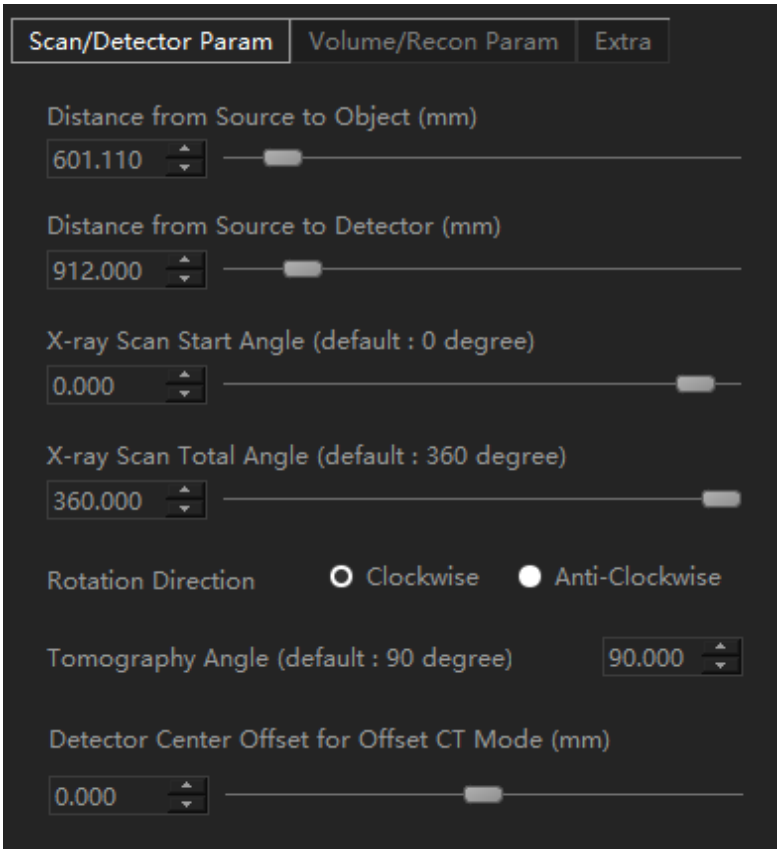
- Purple sphere represents the position of X-ray source position and the yellow rectangle represents the detector plate.

- The blue box between the two represents the object (patient) region.

- The size and position of the geometry object are adjusted automatically, based on the information from the .3dii file.

- Rotate the geometry object by left-clicking on CT geometry view and zoom-in and out object by mouse wheel operation.

- Main UI : Right Panel (Scan Geometry/Detector Parameter)



Right panel : Scan Geometry Parameter

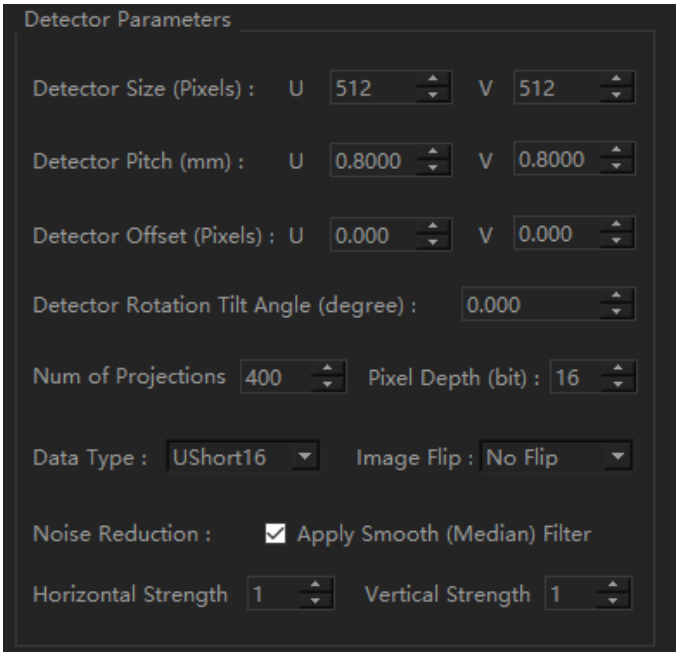
- Modify CT geometry related settings such as distance from source to object, distance from source to detector, X-ray scan start/total angles on the right panel.

- Choose either clockwise or counter-clockwise as the rotating direction of source and detector plate on 'Rotation Direction'.

- 'Tomography angle' determines vertical movement of source and detector. For most cases, user doesn't need to modify this value. (The value from project file will be used.)

- For offset CT scan case (detector is shifted horizontally to shot bigger objects than detector size), please adjust 'Detector Center Offset CT Mode' slider to set the appropriate value.

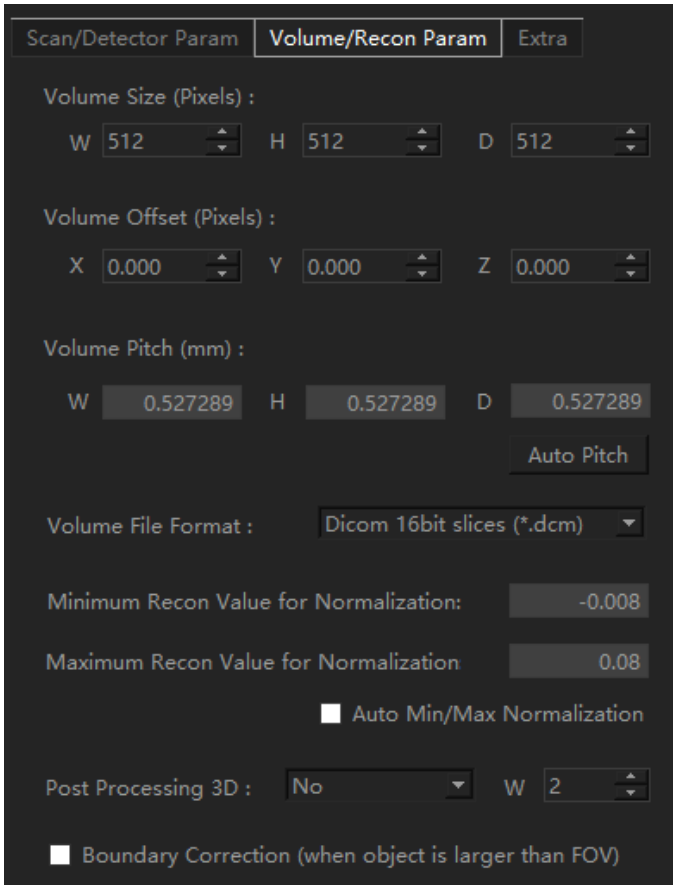
Main UI : Right Panel (Detector Parameters)



Right panel : Detector Parameters

- Set the parameters related to the detector plate on 'Detector Parameters' panel.
- Possible parameters for setting are detector size in pixel, detector pitch in mm, vertical/horizontal offset in pixel, number of projections to be used for reconstruction process. Moreover, it is possible to flip the image. Possible options are no flip, horizontal flip, vertical flip, and flip both.
- Smooth filter to reduce noises in projection images can be set in the last row. Check the 'Apply Smooth Filter' check box and set the filter kernel size. (e.g. when W=1 and H=1, the kernel size will be 3x3.)

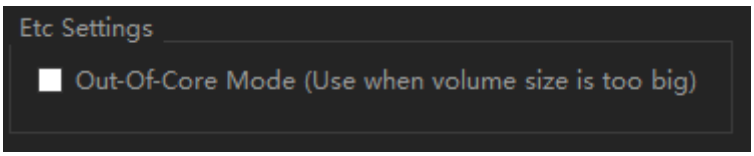
Main UI : Right Panel (Volume/Recon Parameters)



Right panel : Volume/Reconstruction parameters

- Change the setting for reconstructed 3D volume such as volume size, pitch, data type and file format on 'Reconstruction Parameters' panel.
- Volume Pitch shows a size of single voxel. It can be set manually or automatically. (When click 'Auto Pitch' button, volume pitch values will be calculated and set automatically based on current FOV.)
- When 'Auto Min/Max Normalization' check box is checked, reconstructed volume's value will be normalized to minimum/maximum of the entire volume automatically.
- Otherwise, it will be normalized by the user-defined min/max value range.

- In 'Post Processing 3D' combo-box, user can select the type of post-processing filter (Mean or Gaussian filter in 3D) which will be applied to the reconstructed volume before saving to slice files. The size of filter can be adjusted in the 'W' parameter.

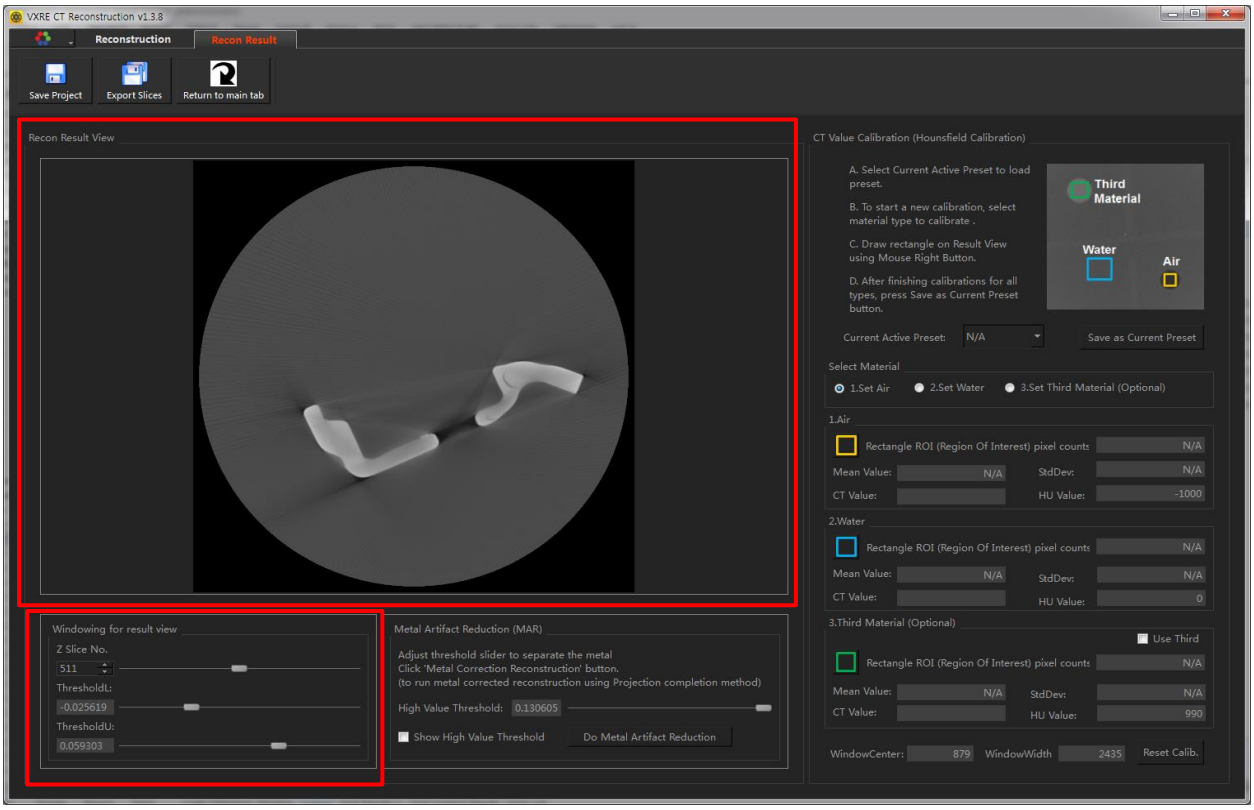


Right panel : 'Out-Of-Core' mode

- When the size of volume is too big and cannot be fitted into the GPU memory (e.g. if the volume has 1024x1024x1204 resolution, it needs 4GB GPU memory because VXRE uses 32bit floating point precision for the reconstruction process), the reconstruction process should be done in 'Out-Of-Core' mode.

- When 'Out-Of-Core' mode check box is checked, the volume data will be divided into multiple subsets (each subset data will be fitted into GPU memory) and the reconstruction process will be applied to each subsets one-by-one.

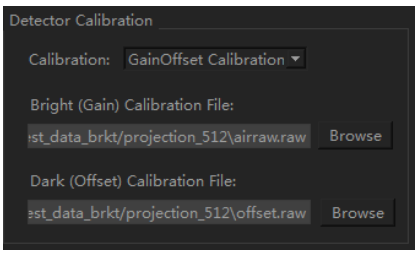
Main UI : Recon Result View



Recon Result View

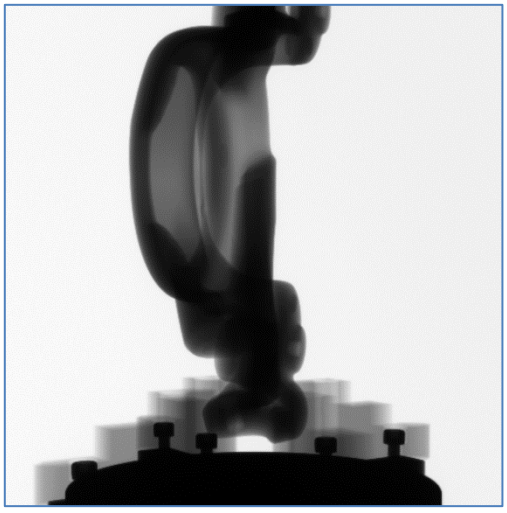
- After the reconstruction, 3D volume data will be shown in Recon Result View as 2D axial slices.
- Adjust 'Z Slice No.' slider to change current volume slice.
- Change slice bright/contrast by changing threshold sliders.

● Basic Features : Dark/Bright field correction



Detector Calibration Menu

Bright and Dark image



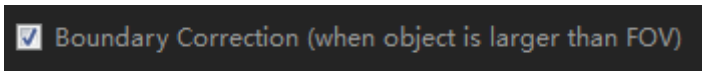
X-ray projection image

Linearized, Calibrated image

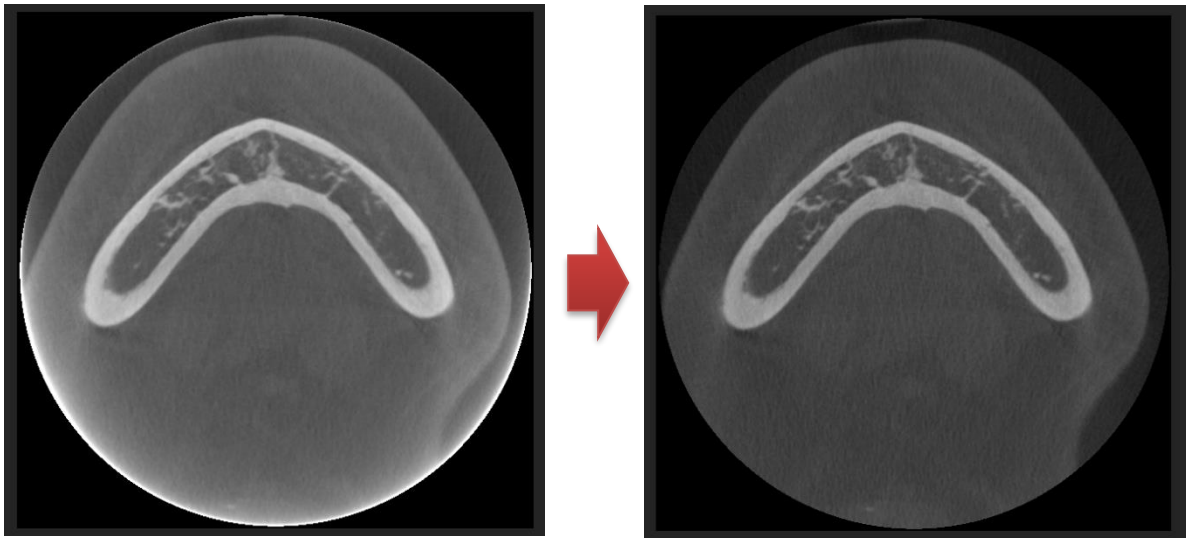
– When detector dark and bright field images are available, detector calibration (linearization) can be done using those images.

– Please set dark/bright images in detector calibration menu inside import wizard panel, or set dark/bright file name inside project file.

● Basic Features : Outside FOV (Field Of View) Boundary Artifact Correction



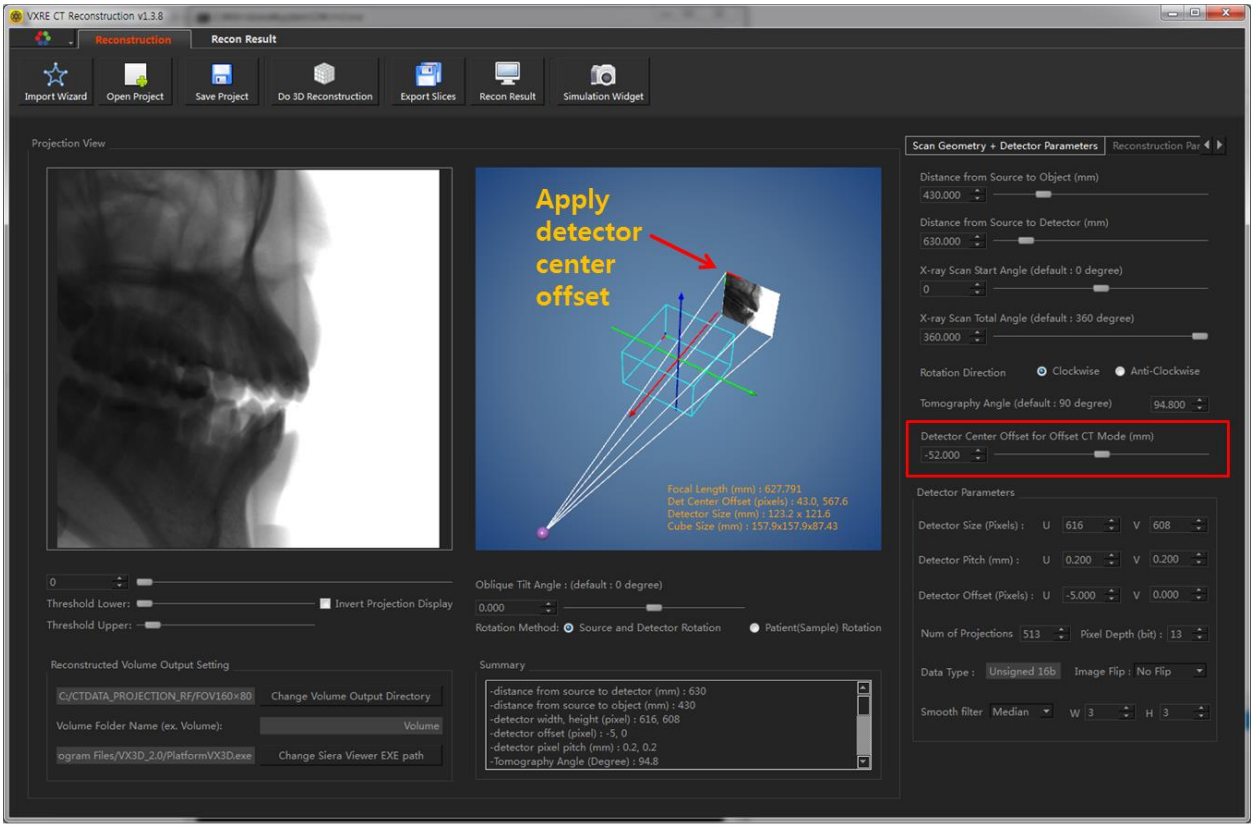
Boundary Correction Check Box



Before the correction **After the correction**

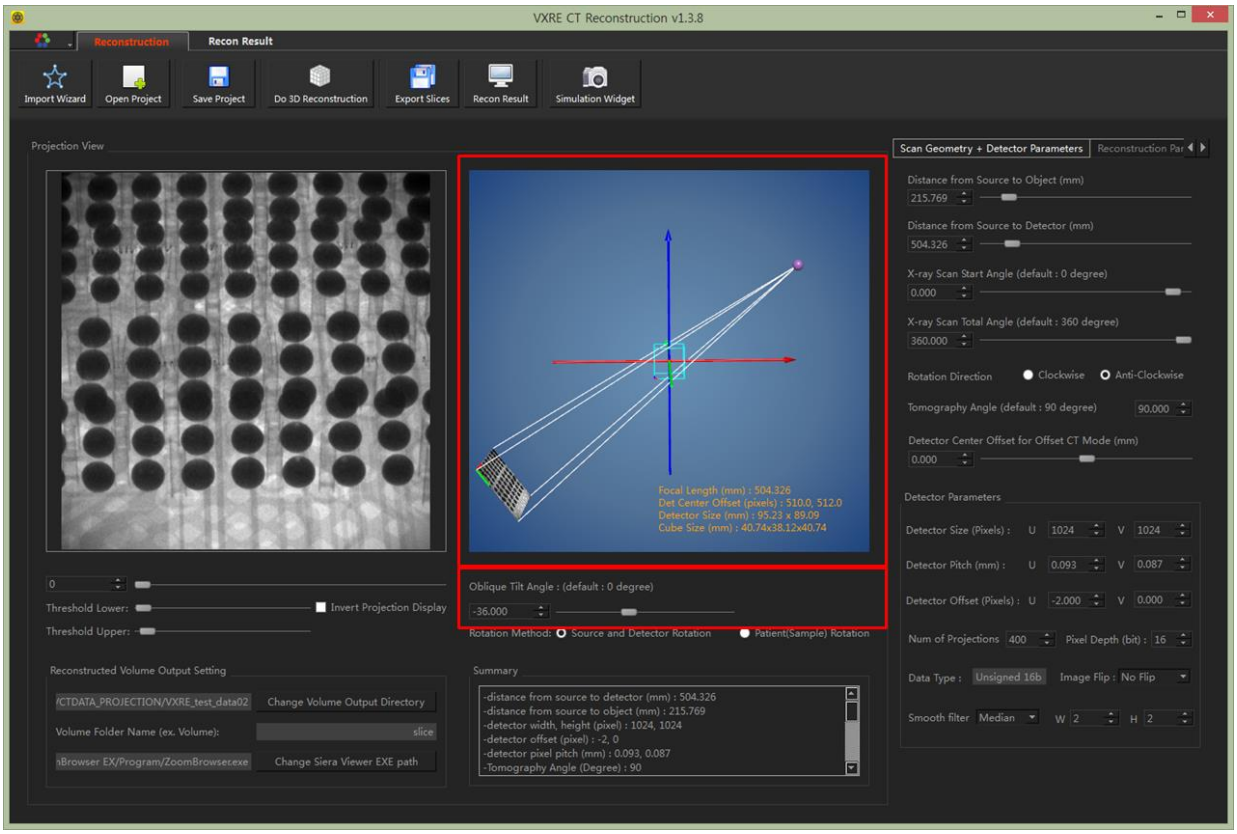
- When the object's size is larger than FOV (Field Of View) of CT scan geometry, artifacts will appear at the object boundaries.
- Set 'Boundary Correction' check box in import wizard panel or Main UI's right panel to correct those artifacts.
- 'Boundary Correction' feature can slow down the reconstruction process, please turn on this feature only when the object is larger than FOV.

- Basic Features : Offset CT mode support



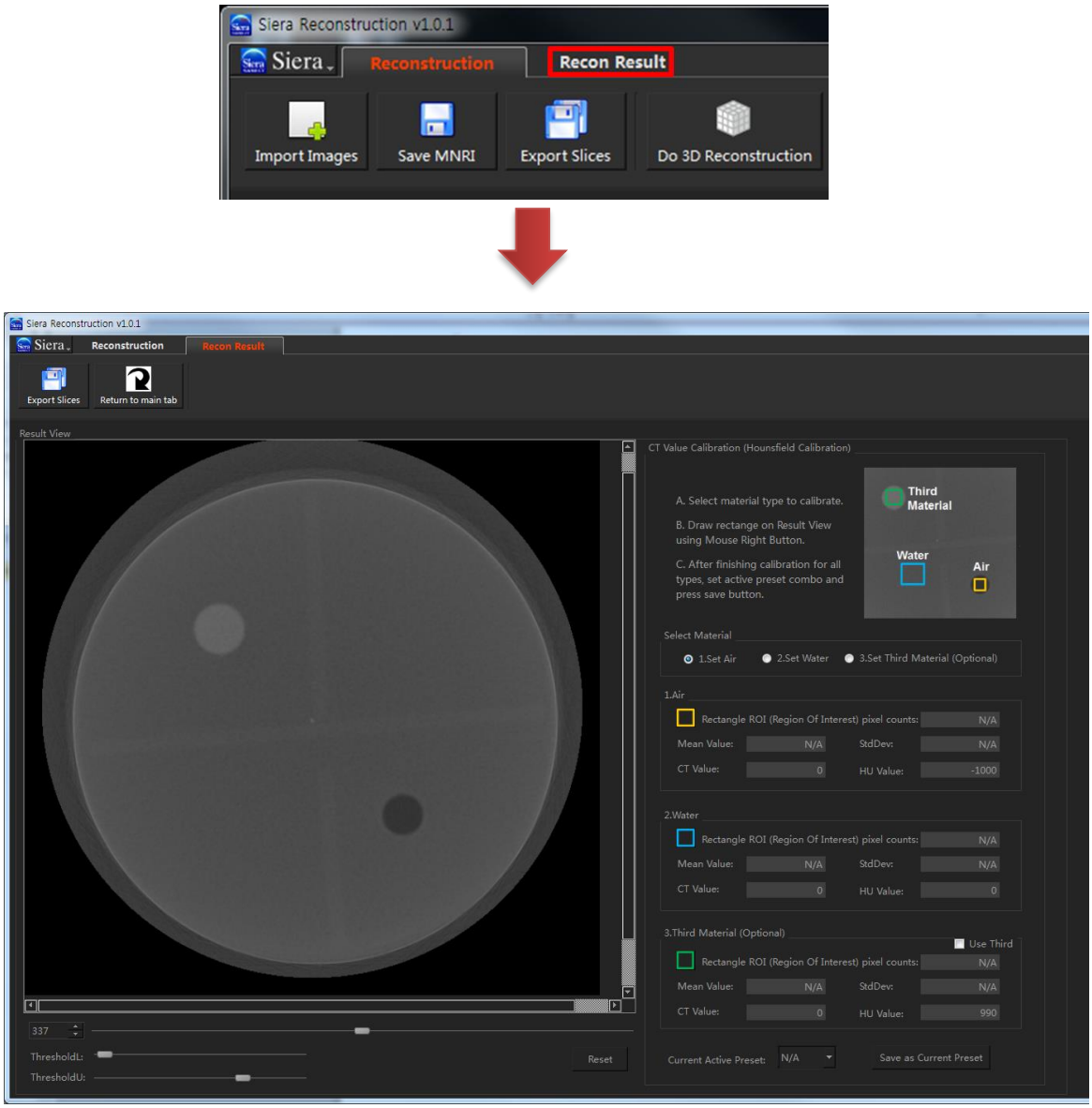
- Offset CT mode scan support: adjust ‘Detector Center Offset’ slider in projection view to shot big size object using small size detector.

- Basic Features : Oblique CT mode support



- For Oblique CT, adjust ‘Object Tilt Angle’ slider to set tilted angle value.
- Both of X-ray source and detector will be rotated together.
- If you want to move X-ray source and detector separately, refer to ‘Custom Geometry XML Generation’ section in this manual.

- Advanced Features : CT Value Calibration (Hounsfield Calibration)

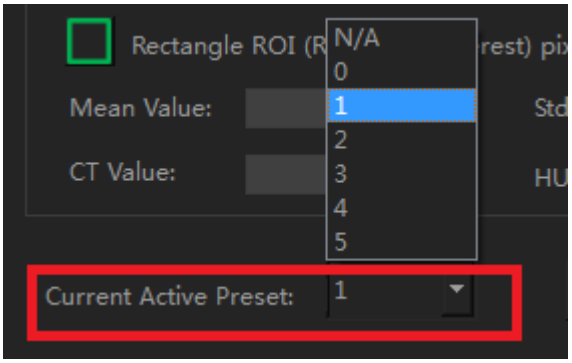


CT Value (HU) Calibration

– After the reconstruction is finished, change the ‘Reconstruction’ view to ‘Recon Result’ view by clicking ‘Recon Result’ tab button.

- On Recon Result view, you can calibrate CT value to Hounsfield Unit value. For example, HU value is set as -1000 HU in the air region, and 0 HU in the water region.

- To calibrate the CT value to HU value, first choose 'Current Active Preset' by clicking the combo box. Currently six CT value presets are supported. If N/A is selected, calibration will not be applied.



Current Active Preset Combo Box

- To calibrate CT value for Air, press '1.Set Air' button and draw a rectangle on the desired air region using the right mouse button. This yellow rectangle represents the ROI (Region Of Interest) of air. The mean CT value of selected ROI will be calculated and set as CT Value automatically. It is also possible to modify CT value to any desired value.

- Repeat the same process for Water calibration. The blue rectangle represents the ROI of water. Its mean value will be set as CT Value as well.

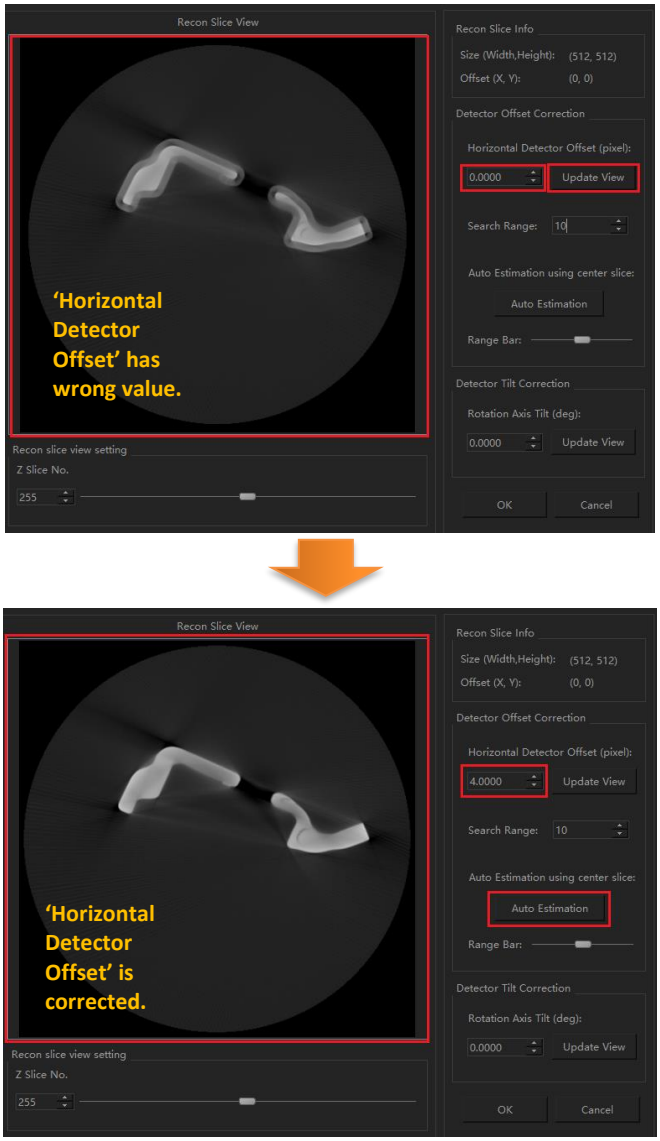
- Calibration for any third material is optional.

- Click 'Save as Current Preset' button after calibration, to save the calibrated preset as current active preset. Whenever any current active preset is chosen among the combo box, its saved setting will be automatically loaded.

- Calibrated preset will be saved to the following path.

→ 'C:₩Users₩***₩Documents₩VXRE₩CTValuePreset.ini'.

- Advanced Features : CT Geometry Correction (Detector Offset/Tilt angle)



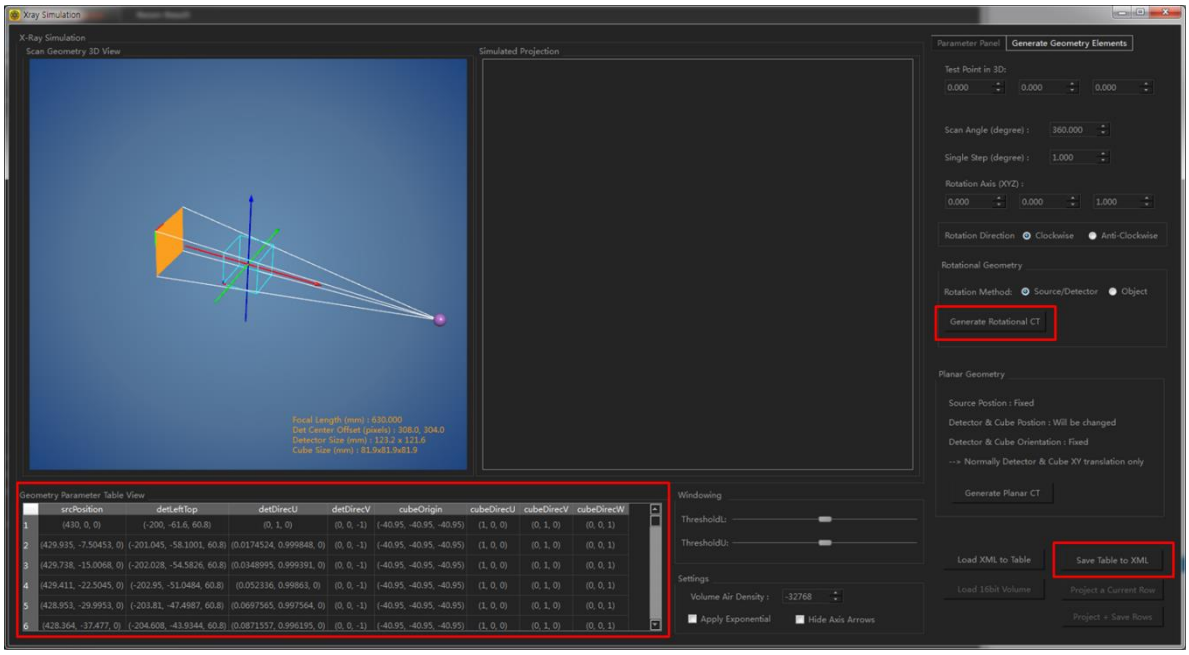
Find Correct Detector Offset Parameter using CT Geometry Correction feature

- User can correct detector offset and tilt angle by using 'CT Geometry Correction'.

- When 'Geometry Correction' button is clicked in the top toolbar, CT geometry correction window will be shown.

- 'Auto Estimation' feature will find detector horizontal offset automatically using only center slice reconstruction. User can check differents result using 'Range Bar' slider.

- Advanced Features : Custom Geometry XML Generation (Experimental)



- User can specify arbitrary position/orientation of source/detector/cube for each projection angle. If CT scanner has stationary mis-alignment which can be measured, exact CT geometry values for each projection angle can be set using custom XML file.

- For this feature, click 'Simulation Widget' button in the top toolbar.

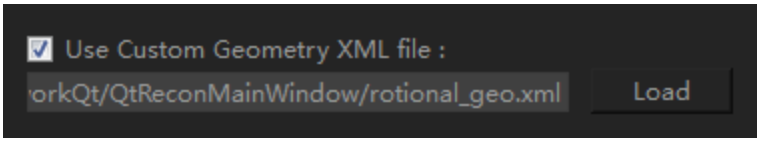
- In 'Generate Geometry Elements' tab, set parameters and click 'Generate Rotational CT 'button.

- Generated custom geometries will be displayed in the table view.

- Click 'Save Table to XML' button to save generated geometries.

- Generated XML file contains custom geometry information for each projection angle (refer to above figure).

- User can view and modify parameters to arbitrary values in the XML file.

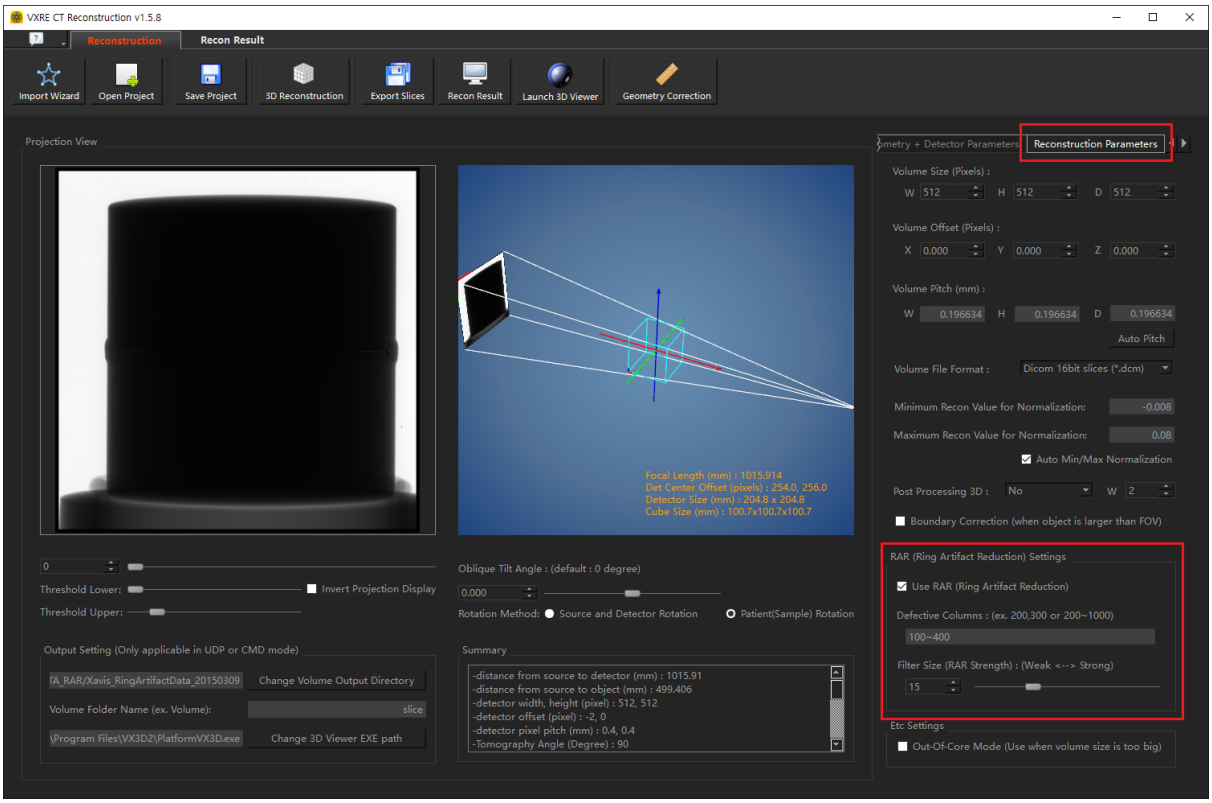


- The custom geometry XML file can be used as an input for the reconstruction.

- Set ‘Use Custom Geometry XML file’ check box and click ‘Load’ button to load the XML file.

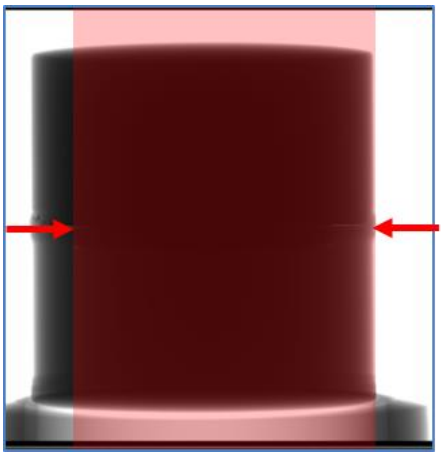
- After the XML loading, reconstruction process will use xml data for the reconstruction. (Basic/Advanced Geometry Parameter Setting will be ignored.)

● Advanced Features : RAR (Ring Artifact Reduction)

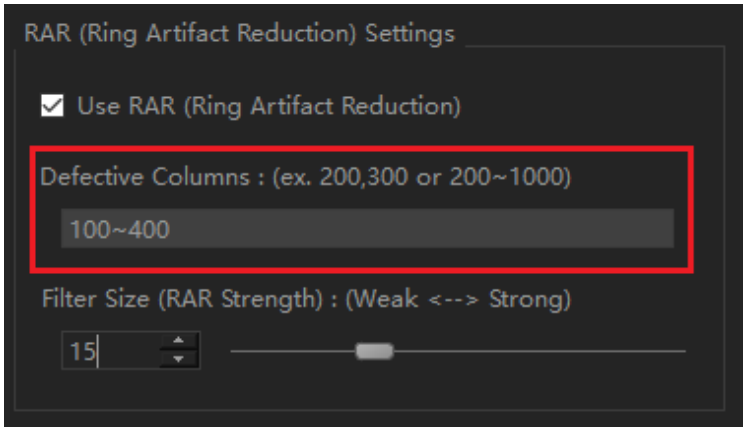


– Even though the detector calibration was applied using dark/bright images, projection images couldn't be calibrated perfectly in some cases. It will result in ring artifacts in the reconstructed volume.

– By using RAR (Ring Artifact Reduction) feature, ring artifacts can be reduced in the reconstructed volume.

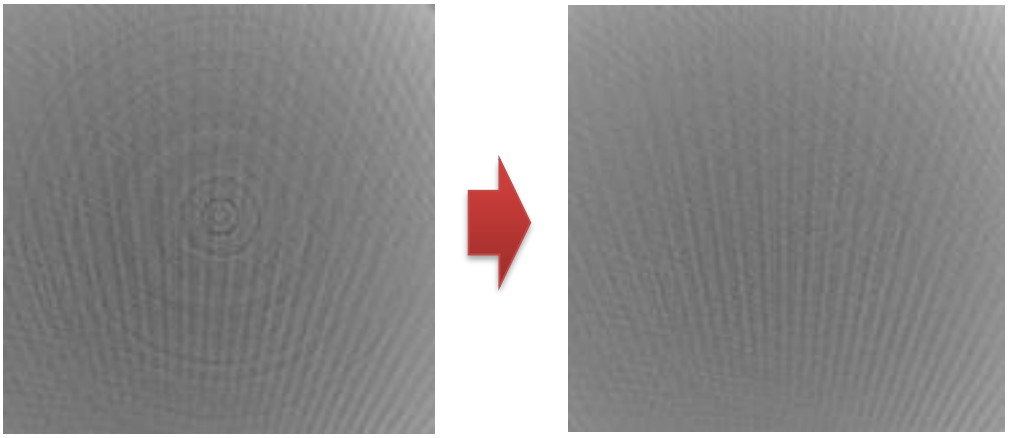


Projection Image (ex. 512x512)



RAR Setting UI

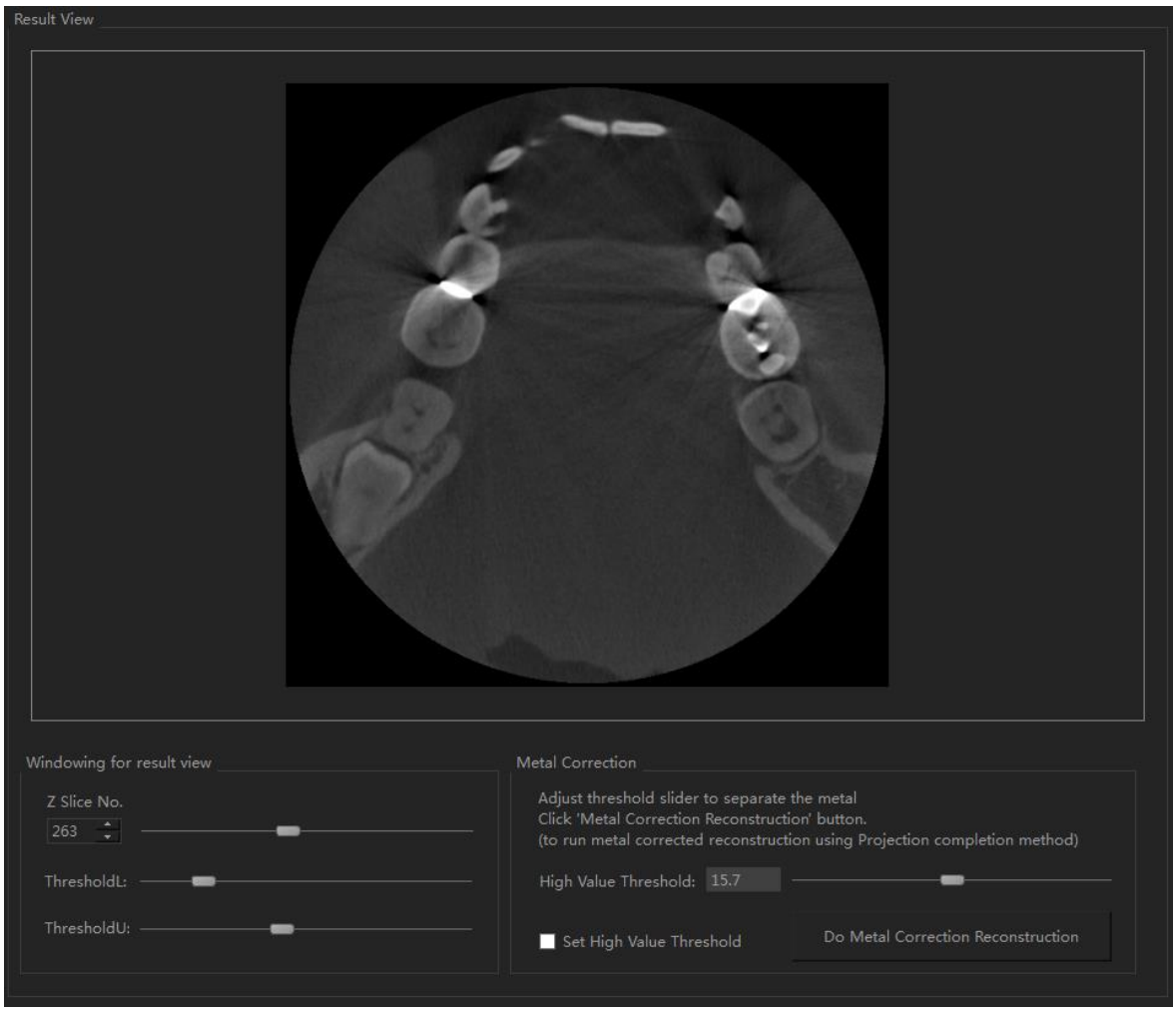
- To use RAR (Ring Artifact Reduction) feature, check 'Use RAR' check box in the right panel inside 'Reconstruction Parameters' tab.
- RAR needs two kinds of parameters. First, 'Defective Columns' parameter should be set. It will restrict the region where the RAR will be applied (RAR will be applied only to the columns specified by this parameters in projection images).
- Another parameter is 'RAR Strength' parameter. It controls how much RAR effect will be applied. Large value results in strong RAR effect, but subtle details can be blurred.



Before RAR

After RAR

- Advanced Features : MAR (Metal Artifact Reduction)



Result view after initial reconstruction

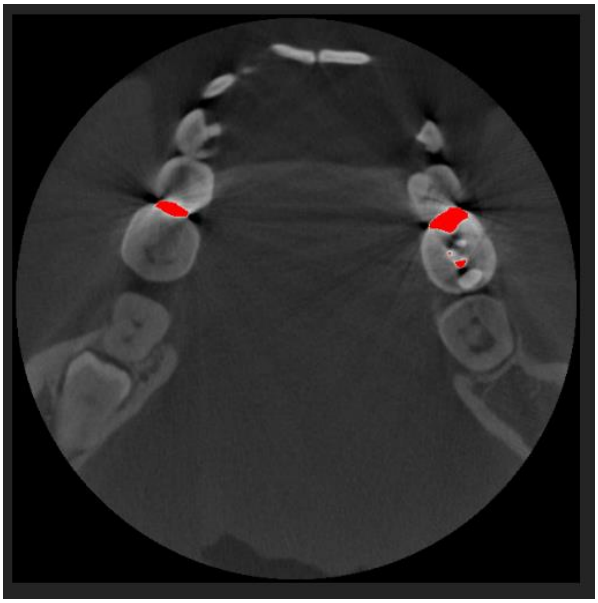
- VXRE has MAR (Metal Artifact Reduction) feature for Medical/Dental CT.

- If the patient has dental filling or metal pins near the soft/bone tissue, reconstructed volume will show metal artifact near metal regions.

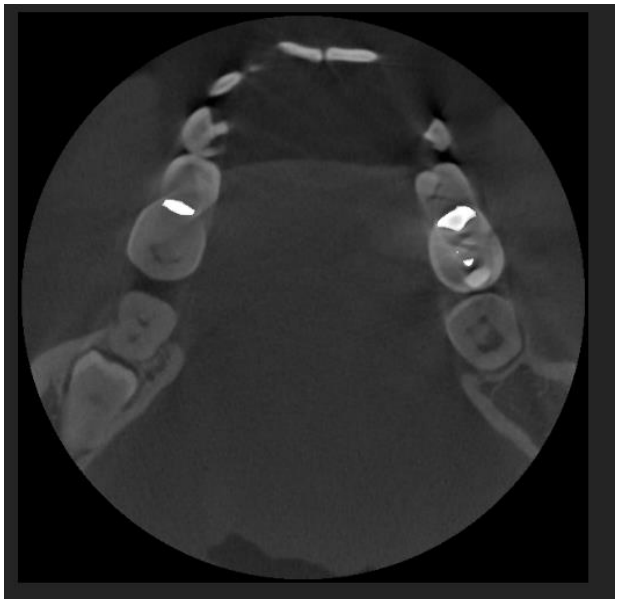
- After the initial (normal) reconstruction, 'Metal Artifact Reconstruction' feature will be enabled. Current implementation supports metal artifact reduction algorithm using Projection completion method.

- In result view, check ‘Set High Value Threshold’ check box to enable metal correction feature. Then adjust high value (value for metal area) threshold slider to separate the metal region (Metal area will appear as red color in the result view).

- Click ‘Metal Artifact Reduction’ button to run metal corrected reconstruction using Projection completion method. Metal corrected result will be shown in result view.



Left : Metal regions appear as red colr



Right : Metal corrected reconstruction result

Appendix : Project file format

- xml project file is a text file which contains parameters for the reconstruction.
- The following lines show a single parameter and corresponding its meaning.

<GeometryMode> : geometry mode (ConeBeam, ParallelBeam, FanBeam)

<FOD> : Distance from X-ray source to Object center (mm)

<FDD> : Distance from X-ray source to Detector center (mm)

<StartAngle> : Start angle (degree)

<ScanAngle> : Total scan angle (e.g. 360 degree)

<ProjCount> : Number of total projection images

<ProjStart> : Index of first projection image (e.g. 0)

<TomoTheta> : Tomography angle (e.g. 90 degree)

<TiltAngle> : Oblique tilt angle (degree)

<RotDirection> : Object (or Source/Detector) rotation direction (CW or CCW)

<RotMethod> : 0=Source/Detector rotation, 1=Object rotation

<DetSizeU> : Detector Width (pixels)

<DetSizeV> : Detector Height (pixels)

<DetPitchU> : Detector pitch in horizontal direction (mm)

<DetPitchV> : Detector pitch in vertical direction (mm)

<DetOffsetU> : Detector offset in horizontal direction (mm)

<DetOffsetV> : Detector offset in vertical direction (mm)

<DetRotAngle> : Detector rotation tilt angle (degree)

<DetCenterOffset> : Detector center offset for half beam mode (mm)

<ImgFlipU> : Flip projection image horizontal direction (0 or 1)

<ImgFlipV> : Flip projection image vertical direction (0 or 1)

<ImgCropBorders> : Crop projection image border pixels (pixel)

<ImgSkipHeader> : Skip header in projection image (byte)

<BitDepth> : Bit depth of the projection image

<DetDarkValue> : Detector (Projection image) offset constant value

<DetBrightValue> : Detector (Projection image) air constant value

<DetBrightAuto> : ‘air value’ will be estimated from the first projection image

<ImgFormat> : Projection image format (UShort16, Short16, Byte8 or Float32)

<ImgScaleValue> : This value will be multiplied when loading projection images

<CubeSizeX> : Reconstruction volume width (pixels)

<CubeSizeY> : Reconstruction volume height (pixels)

<CubeSizeZ> : Reconstruction volume depth (pixels)

<CubePitchX> : Reconstruction volume pitch in x direction (mm)

<CubePitchY> : Reconstruction volume pitch in y direction (mm)

<CubePitchZ> : Reconstruction volume pitch in z direction (mm)

<CubeOffsetX> : Reconstruction volume offset in x direction (pixels)

<CubeOffsetY> : Reconstruction volume offset in y direction (pixels)

<CubeOffsetZ> : Reconstruction volume offset in z direction (pixels)

<CubeFlipX> : Reconstructed slice flip along x direction (0 or 1)

<CubeFlipY> : Reconstructed slice flip along y direction (0 or 1)

<CubeFlipZ> : Reconstructed slice flip along z direction (0 or 1)

<PreProcessFilterType> : Smooth filter type for projection images (No, Median)

<PreProcessFilterW> : Half kernel width for the projection smooth filter

<PreProcessFilterH> : Half kernel height for the projection smooth filter

<PostProcessFilterType> : Post processing filter for recon volume (No, Mean, Gaussian)

<PostProcessFilterSize> : Half kernel size for post processing filter

<BoundaryCorrection> : Boundary correction for outside FOV object (true, false)

<ReconValueMinMaxAuto> : 3D will be normalize to volume min/max (true, false)

<ReconValueMinValue> : Minimum recon value for normalization

<ReconValueMaxValue> : Maximum recon value for normalization

<ProjFolderName> : Folder name which contains projection images

<SliceFolderName> : Folder name where recon volume will be written

<ProjNameFormat> : Projection image name format (e.g. %04d.raw → 0000.raw, 0001.raw,…)

<DarkFrameName> : File name of dark (offset) image for detector correction

<BrightFrameName> : File name of bright (air) image for detector correction

<CTValuePreset> : Set current ‘CT Value Calibration’ preset (0,1,2…,etc.)

<CTValuePresetUseThird> : Use third material during ‘CT Value Calibration’

<UseRAR> : Turn on/off RAR (Ring Artifact Reduction) (true, false)

<RARDefectColumns> : Set defective columns for RAR (e.g. 100~1000)

<RARStrength> : Set RAR strength

<MARMinMetalRatio> : Set minimum metal ratio for MAR mode 2

<MARMode> : Set MAR mode (1=MAR mode1, 2=MAR mode2)

< Parameter name in xml project file format >

Appendix : Command line & TCP remote commands

[Main UDP command channel]

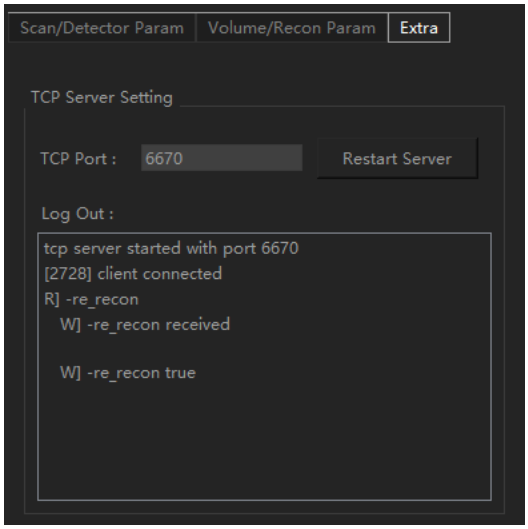
-re_log_path "C:\Users*\Documents\communication.txt"**
: Change log file path for command line commands
-re_load_project "C:\CTDATA\project.xml"
: Open a project file
-re_recon
: Do 3D Reconstruction
-re_recon_mar
: Do 3D Reconstruction using MAR
-re_recon_mar_reuse
: Do 3D Reconstruction using MAR (Re-use non-MAR recon volume if exist.)
-re_save_dcm
: Save reconstructed data as dcm
-re_easy_mode_recon "C:\CTDATA\project.xml"
: run '-re_load_project', '-re_recon', '-re_save_dcm' and load dcm using VX3D
-re_show
: Show VXRE GUI
-re_hide
: Hide VXRE GUI
-re_close
: Close VXRE process

[Idle Check command channel]

-re_check_idle
: true if VXRE is in idle, false if running recon or saving DICOM files
-re_cancel_recon
: cancel the 3D Reconstruction progress

< CMD/TCP commands >

- VXRE supports CMD commands and TCP-based commands for remote control
- Each TCP commands are same with Command line method.
- TCP Server in VXRE : VXRE runs TCP server for network communication and opens 6670 port (default value, can be changed in UI) and listen TCP client request.



< TCP Server Setting UI >

- When VXRE receives a TCP command, it will return a immediate message (ex. '-re_recon' received → '-re_recon received' will be returned). After processing the command, it will return final return message (ex. '-re_recon true' will be returned).

- If VXRE receives '-re_check_idle' TCP command, it will return '-re_check_idle true' (when idle) or '-re_check_idle false' (when doing recon or saving files).

-When using command line commands, return values will be saved to the following path as a log file. → 'C:₩Users₩***₩Documents₩communication.txt'. This path can be changed using '-re_log_path' command.