

IRXCT, Version 1.2

(manual)

1 Introduction

IRXCT (Iterative Reconstruction and visualization for X-ray Computed Tomography) [1] is a Windows application for reconstruction and visualization in 2D tomography [2, 3] that includes the recently proposed SbIR algorithm [4]. Besides the SbIR algorithm, the SART algorithm [5] is also included. Adding other iterative algorithms to the application is very easy, as it requires only the addition of a new function for each algorithm. The IRXCT application has been designed so that reconstructions and associated calculations could be done by using the programmed interface; so it has been designed so that it is somehow complementary to other applications where the reconstructions and other calculations are usually programmed manually by writing a script that will run the commands.

Three examples of tomography software available for download and regular use are the following: Astra toolbox, CASToR and NiftyRec.

Astra toolbox is a MATLAB and Python toolbox [6, 7] of high-performance GPU primitives for 2D and 3D tomography. It supports 2D parallel and fan beam geometries, and 3D parallel and cone beam. All of them have highly flexible source/detector positioning. A large number of 2D and 3D algorithms are available, including FBP, SIRT, SART, CGLS. The basic forward and backward projection operations are GPU-accelerated, and directly callable from MATLAB and Python to enable building new algorithms. The source code of the ASTRA Toolbox is available on GitHub.

CASToR is an open-source multi-platform project [8] for 4D emission (PET and SPECT) and transmission (CT) tomographic reconstruction. This platform is a scalable software providing both basic image reconstruction features for "standard" users and advanced tools for specialists in the reconstruction field, to develop, incorporate and assess their own methods in image reconstruction (such as specific projectors, optimization algorithms, dynamic data modeling, etc) through the implementation of new classes.

NiftyRec is a software for tomographic reconstruction [9], providing GPU accelerated reconstruction tools for emission and transmission computed tomography.

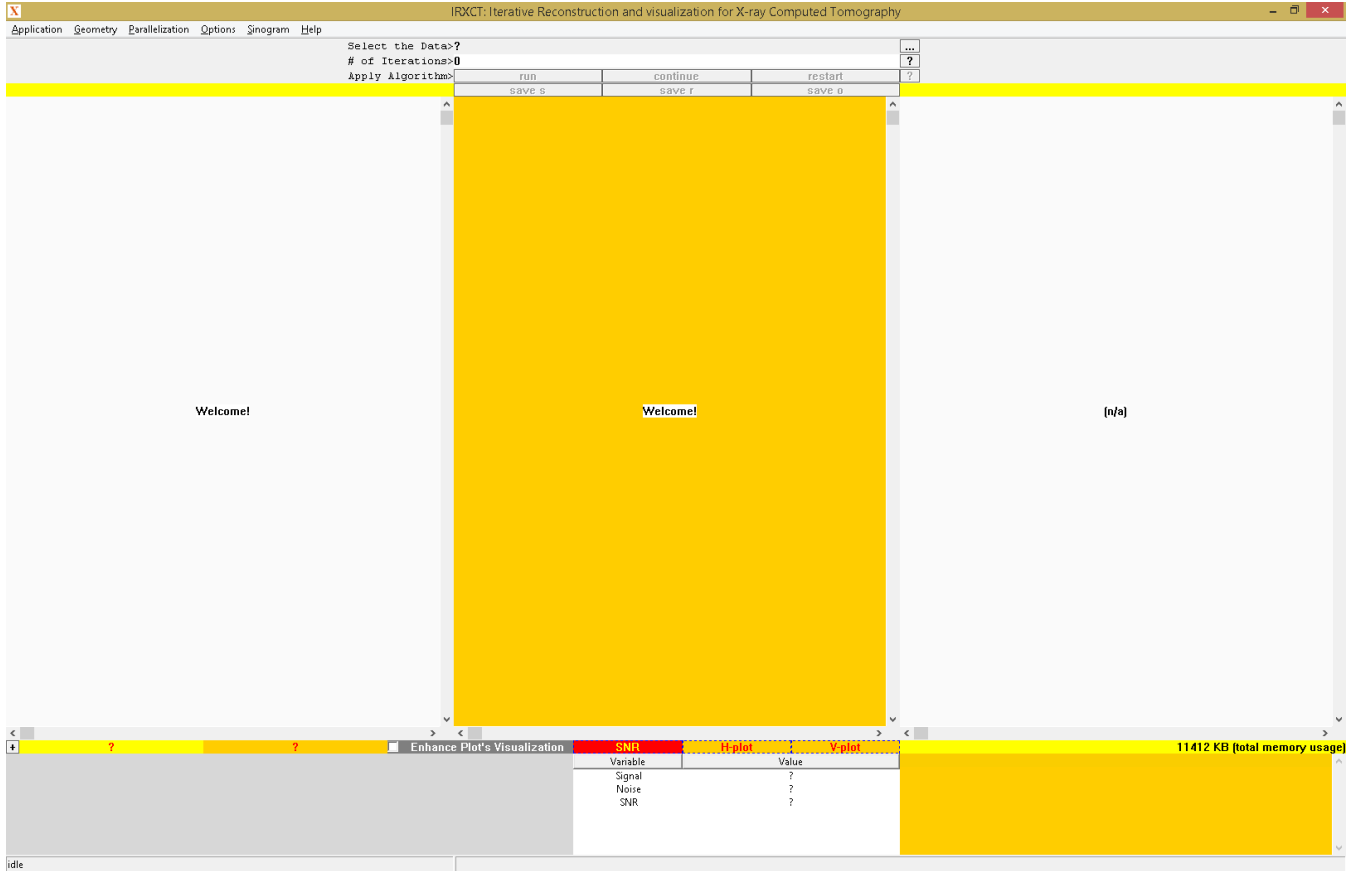


Figure 1: The IRXCT application at start

The IRXCT application has available a number of functions that are complementary to other tomography software like the three software packages described above. For example, one important function is the possibility to see in real-time, that is after each iteration, the current reconstruction along with a plot showing the execution time of all iteration that has been already run. Next we describe in detail all the functionalities currently available in the IRXCT application, Version 1.2.

2 Description of the IRXCT Application

The IRXCT application is written in Visual C++ 2015, using exclusively Windows API functions and Cuda functions. The user interface consists of

1. a toolbar positioned at the top of the application;
2. right after toolbar, three child windows where the sinogram (left child window), the reconstruction (the middle child window) and the original image (right child window, for the simulation mode only) are shown;

3. a child window in the bottom-left corner where, in real-time, it is shown the time taken by each iteration during a reconstruction (this is visible only if the menu option Options → Display Reconstruction's Convergence is checked, and by default this is checked);
4. a list view at the bottom where mean signal, mean noise, and SNR (signal-to-noise ratio) calculations are shown;
5. a report window that, during the reconstruction informs the user about the iteration number, and at the end of the reconstruction shows a report that informs about the time taken to obtain the reconstruction.

The menu of the application consists of six submenus:

1. Application submenu has the following items: Algorithm is a popup option which the user can use for choosing the algorithm to be applied (currently there are two choices, SART and SbIR); Simulation Mode is an option that can be checked or not depending on whether the reconstruction is to be done for real sinogram (this corresponds to Simulation Mode unchecked, which is the default when starting the application) or for simulated sinogram (this corresponds to Simulation Mode checked); Close the Input DataFile, for closing the current datafile before loading a new datafile; Exit, for exiting the application at any point in time (including during the reconstruction process).
2. Geometry submenu has one item called Specify Geometry... which can be used to modify different parameters of the geometry, including the number of detectors (nd), the number of views (nv), the number of rows (nx) and columns (ny) of the reconstruction, the distance from source to object (STO) and the distance from source to the detectors' line (STD); when starting the application these parameters are initially set as nd=512, nv=64, nx=512, ny=512, STO=1024.0, STD=1024.0.
3. Parallelization submenu has two items: Select GPU card..., which can be used to select a GPU card that will be used when parallelization on GPU is used; Specify Parallelization..., which can be used to select the number of threads and if GPU is to be used also.
4. Options submenu has the following items: Maintain H-V Ratio which refers to displaying the sinogram, the reconstruction and the original image (if any) by maintaining the aspect ratio or by using the entire space available; Display Reconstruction's Convergence can be used for showing a plot with the time taken by each iteration; Calculations using Line Integrals refers to calculations by line integrals or by area integrals (when running reconstructions for real sinograms, area integral is preferred as this corresponds to the way the sinogram has been obtained); Run with Highest Priority refers to setting the highest priority for the application (REALTIME_PRIORITY_CLASS), so when this is checked a slightly faster reconstruction is expected.

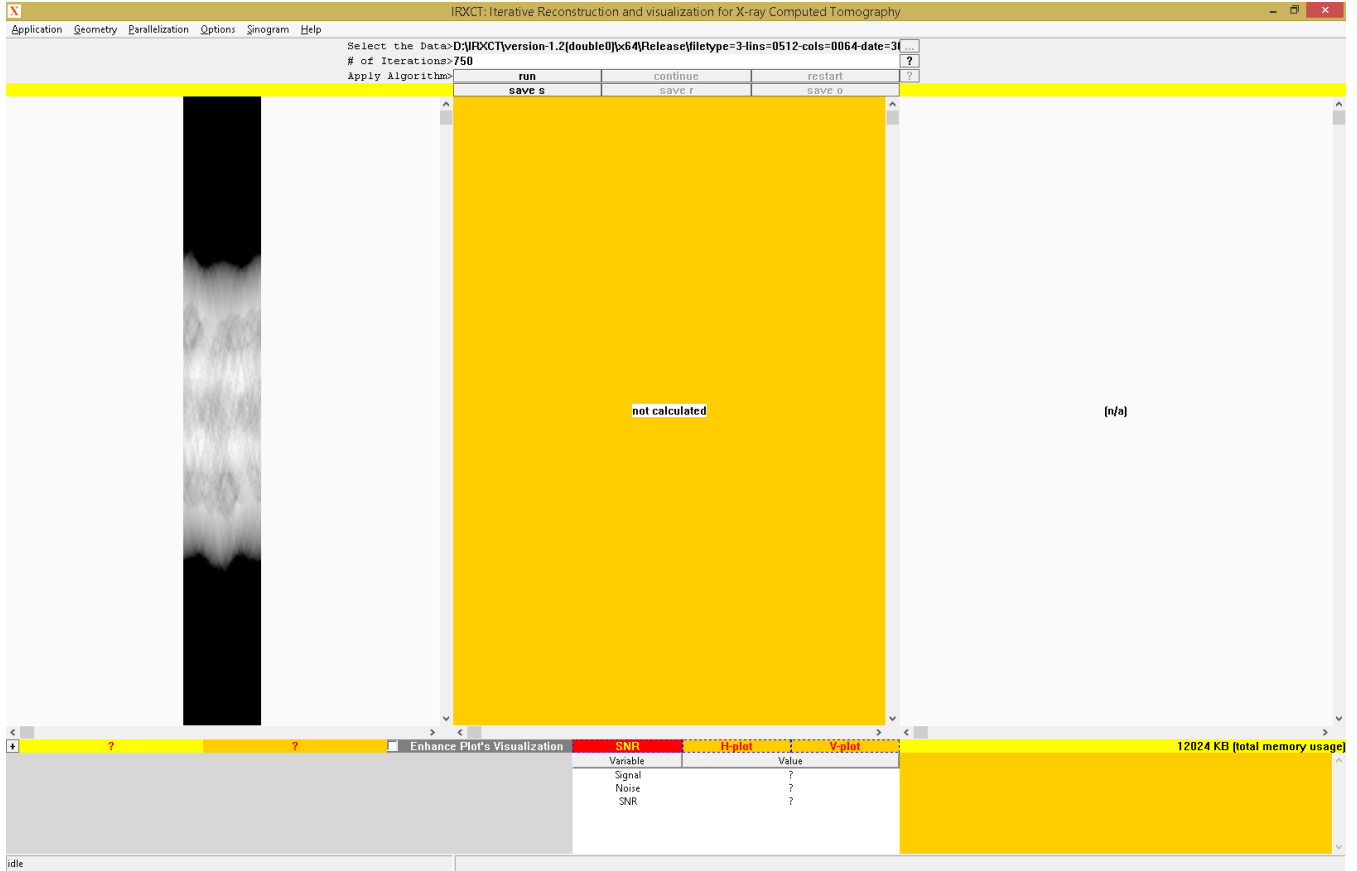


Figure 2: Selection and displaying of the sinogram

5. Sinogram submenu has one item called Add Noise which can be used to add noise to the sinogram (in the simulation mode only) before reconstruction (this is to be implemented in a subsequent version).
6. Help submenu, where the IRXCT manual can be opened in Pdf format.

At start the application looks like in Figure 1. The menu items and their default states (checked or unchecked) at the start of the application are summarized in Table 1.

2.1 Reconstruction from Sinogram

For running a reconstruction from a sinogram (real, or coming from the Simulation Mode of the application), first we make sure that the menu option Application → Simulation Mode is unchecked. Then we make sure that the currently selected geometry (Geometry → Specify Geometry...) is in accordance with the geometry that was used to obtain the sinogram. Then we choose the input data and the number of iterations in the application's toolbar.

To show how a reconstruction from a sinogram is done, we choose the sinogram

Table 1: default states of the menu items

item	checked/unchecked or popup selection	submenu
Algorithm	Sbir	Application
Simulation Mode	unchecked	Application
Close the Input DataFile	n/a	Application
Exit	n/a	Application
Specify Geometry...	n/a	Geometry
Select GPU Card...	n/a	Parallelization
Specify Parallelization...	n/a	Parallelization
Maintain H-V Ratio	checked	Options
Run with Highest Priority	unchecked	Options
Calculations using Line Integrals	checked	Options
Display Reconstruction's Convergence	checked	Options
Add Noise	n/a	Sinogram

filetype=3-lins=0512-cols=0064-date=30.11.2020-time=19.58.18.txt

in the first combobox of the toolbar. This sinogram data consists of $512 * 64$ lines, each line containing the real value (double type) of a (detector,view) pair: the first 512 values are for view 1, the next 512 values are for view 2, and so on. After selecting, the sinogram is shown in the left child window. Then we choose the number of iterations, say 750, from the second combobox of the toolbar and uncheck the option Calculations using Line Integrals from the Options submenu which means that the system matrix and the reconstruction are calculated using area integrals. Selection of the sinogram and its displaying in the left child window is like in Figure 2. Once a sinogram is selected, the middle child window where the reconstruction is to be displayed shows "not calculated".

With the sinogram and the number of iterations chosen, we press the run button so that calculation of the system matrix (using area integrals) and then the reconstruction start. During the calculations the yellow static control right above the report window shows in real-time the current memory usage of the application. Once the system matrix is calculated, the iterations start and after each iteration the reconstruction window shows the reconstruction updated. In Figure 3 it is shown the reconstruction after all 750 iterations are completed. After all 750 iterations are completed, the report window shows a report consisting of four indicators:

1. time 1 is the time taken to calculate the system matrix (in this example, it is 3.0 seconds)
2. time 2 is the time taken to run the 768 iterations (in this example, it is 83.0 seconds)
3. min is the minimum value in the reconstruction (in this example, it is approximately 0.0)

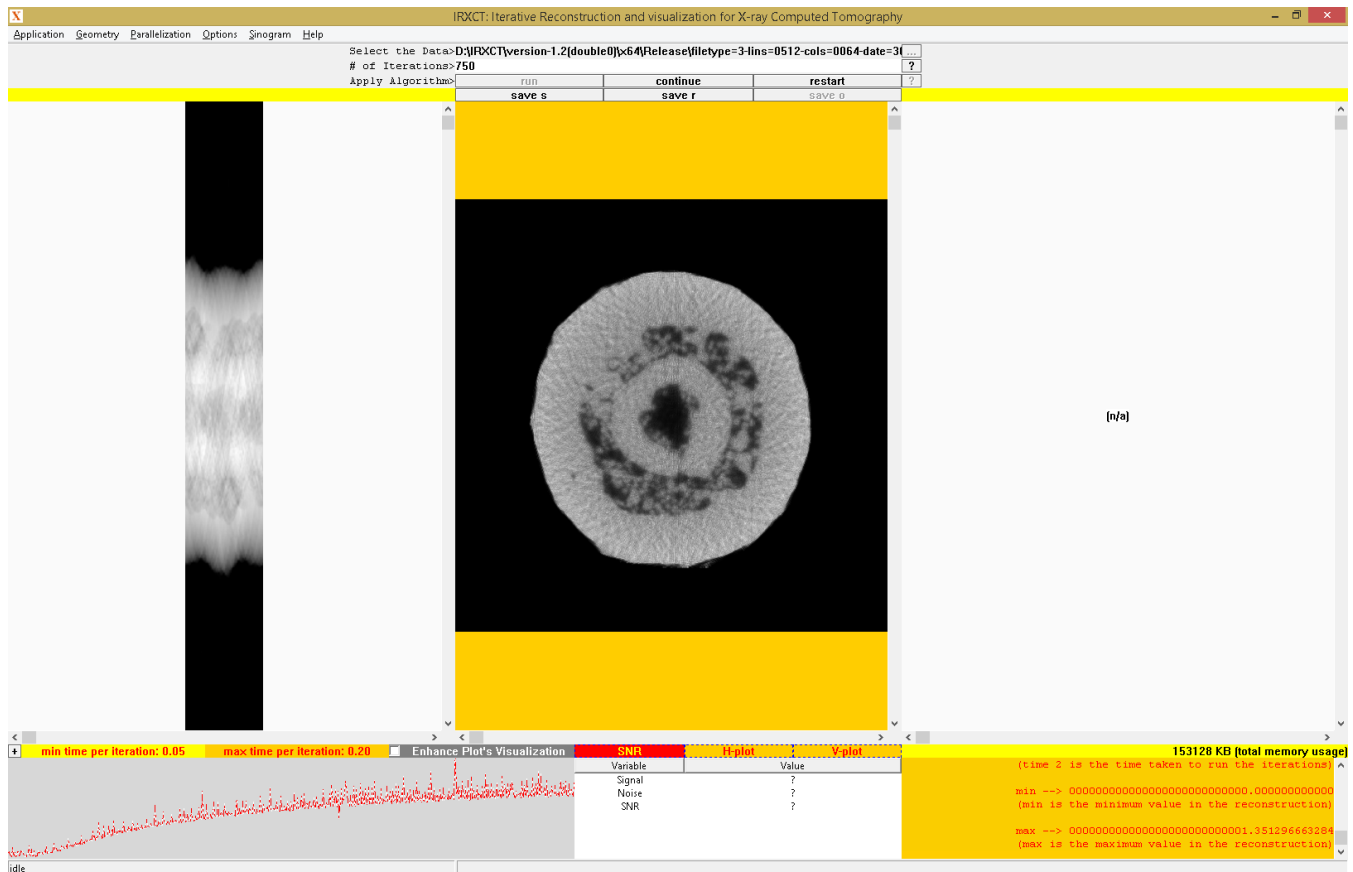


Figure 3: Situation after running all 750 iterations

4. max is the maximum value in the reconstruction (in this example, it is approximately 1.351)

At any point, before reconstruction, during reconstruction or after reconstruction, the user can check or uncheck the Options \rightarrow Maintain H-V Ratio menu option so that each image is displayed by using the entire space available or by maintaining aspect ratio. Also, the small + button right above the bottom-left child window can be used to increase the space used by the bottom part of the application, as in Figure 4.

After all iterations are completed and the final reconstruction is shown, the continue button can be used to continue running another set of iterations, starting with the currently obtained reconstruction. The restart button restarts everything and cleans up the used memory space so that the user can check, choose, or uncheck different options and then run iterations starting again from the initial solution. Also, once the final reconstruction is shown, the user can move with the mouse pointer over the reconstruction window and calculate either mean signal for a rectangle (chosen with left mouse button) or mean noise for a rectangle (chosen with the right mouse button). When both signal rectangle and noise rectangle are chosen, the SNR is automatically calculated and shown in the list view control at the

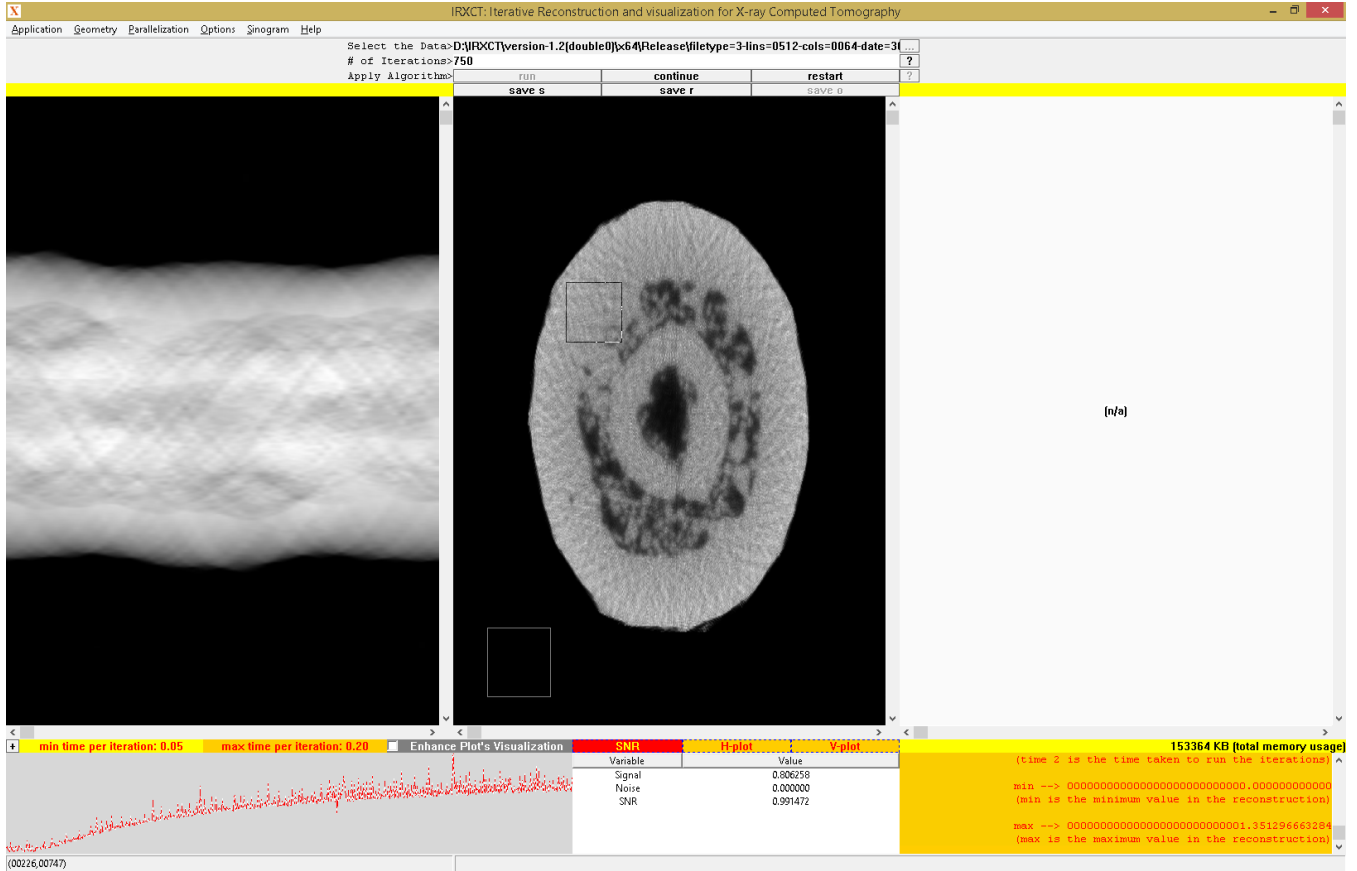


Figure 5: when the SNR button is checked, the user can choose a signal rectangle and also a noise rectangle; when both rectangles are present the SNR value is automatically calculated and shown in the list view control at the bottom of the application

bottom of the application, as in Figure 5. For choosing a different signal or noise rectangle the user just needs to choose the desired new rectangle, as the current rectangle will be automatically deselected. A currently selected rectangle can also be manually deselected by clicking with the respective mouse button (left button for signal, or right button for noise) anywhere on the reconstruction.

If the H-plot button is checked then the user can click on any (line l , column c) point of the reconstruction and a plot showing line l will be displayed (in a separate dialog box, like in Figure 6).

If the V-plot button is checked then the user can click on any (line l , column c) point of the reconstruction and a plot showing column c will be displayed.

After displaying of a plot, if needed we can save the plot on the disk (the default name for the saved plot is "p.bmp") using the SAVE button.

2.2 Simulating a Sinogram, and then Reconstructing from it

For doing a simulated sinogram, and then reconstruction from it, we first need to make sure that the Application → Simulation Mode menu option is checked, then we choose the input image, number of iterations and then press the run button. The chosen input image will be displayed in the right child window, then the simulated sinogram in the left child window as usual and then the reconstruction in the middle child window as usual.

Again we can choose signal and noise rectangles, but if noise for example is 0 then SNR will not be available ("n/a"). If SNR is very large (> 10000.0) then SNR will show " > 10000.0 ". The SNR is calculated using the formula

$$\frac{\text{mean of the signal region}}{\text{standard deviation of the noise region}}.$$

In the simulated mode, when choosing a rectangle in the reconstruction window, then the same rectangle is chosen in the original image, and values are calculated for both images (first value for reconstruction, second value for original image). In the simulated mode, mean-square-error (mse) of the two regions is also calculated automatically and shown as mse:value.

Also, since we are now in simulated mode, choosing a line of the reconstruction when H-plot is checked, will show a comparison plot between the two lines (in blue for the original image, and in red for reconstruction).

2.3 Parameters

The Geometry → Specify Geometry... menu option opens a dialogbox like shown in Figure 7, where the following parameters can be adjusted:

1. nd is the number of detectors, and accepted values are between 50 and 2500;
2. nv is the number of views, and accepted values are between 50 and 2500;
3. nx is the number of rows of the reconstruction matrix, and accepted values are between 50 and 2500;
4. ny is the number of columns of the reconstruction matrix, and accepted values are between 50 and 2500;
5. STO is the distance from X-ray source to center of rotation, and accepted values are up to 25000.0;
6. STD is the distance from X-ray source to detector's line, and accepted values are up to 25000.0;
7. rotation (of the X-ray source around object) could be "clockwise" or "counterclockwise"; rotation "clockwise" it corresponds to "counterclockwise" rotation of object, and rotation "counterclockwise" it corresponds to "clockwise" rotation of object (in case the object is moving, and not the X-ray source);

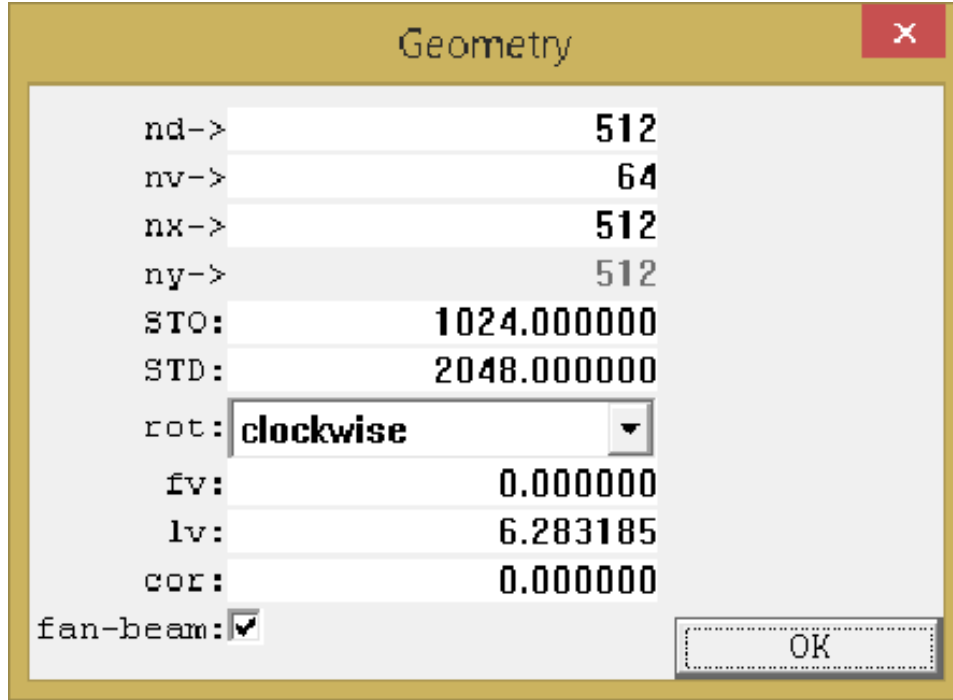


Figure 7: Geometry's parameters

8. fv is the angle (in radians) of the first view (default value is 0.0, which means the first view the X-ray beam is at the point (x=STO,y=0.0) while the center of reconstruction is at point x=0.0,y=0.0)
9. ls is the angle (in radians) of the last view (default value is $2\pi = 6.273185$);
10. cor is a parameter that corresponds to the misalignment between the perpendicular line from X-ray source to detector's line and center of rotation (for example, cor = -1.0 means that the perpendicular line is misaligned at a distance 1.0 at left)
11. fan-beam specifies if the geometry corresponds to fan-beam scanning (checked) or parallel beam scanning (unchecked); when the application is started fan-beam is checked by default

2.4 Running with Highest Priority

When the Options → Run with Highest Priority menu option is checked, the priority class is changed to the highest possible. For a reconstruction that normally takes a few seconds the improvement may not be so visible, but for longer reconstructions this should normally decrease the execution time with a couple of seconds or so.

2.5 Parallelization

Every time the run button (or continue button) going to be pressed for starting a reconstruction, the user can before choose the number of threads used to do the reconstruction and also if GPU card is to be used. This can be done by going to Parallelization → Specify Parallelization... in the menu and then choosing the appropriate options in the associated dialogbox.

3 Adding a new iterative algorithm to the application

Including additional iterative algorithms to the application is quite easy. The two functions that correspond to the SbIR and SART algorithms are called SbIR and SART. For example, in the case of the SbIR algorithm, the function is declared as

```
DWORD WINAPI SbIR(LPVOID lpParam);
```

In the implementation of the SbIR function, first the lpParam is converted to the id of the current thread:

```
unsigned int id = PtrToInt(lpParam);
```

Then the code of the function is divided into two parts: the part corresponding to "run == true" means that the function is called as a response of pressing the 'run' button; the part corresponding to "run == false" corresponds to the "continue" button; however, in each of the two parts, the code that implements the iterative algorithm is the same, just that some initializations and calculations are done only once in the part "run == true". The SbIR algorithm itself is implemented in the for loop

```
for (z = NI; z != 0; z--)  
    {  
        ...  
    },
```

where Z is the system matrix, pZ is a pointer to the current (detector,view) pair under processing, S is the sinogram, and RI1 is the current reconstruction. So an iterative algorithm can be added by writing a new function with the same code of the SbIR function and modifying the code in the for loop.

References

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- [10] Phantom database, Institute of Medical Physics, Friedrich-Alexander-University Erlangen-Nurnberg, Erlangen, Germany; available at <http://www.imp.uni-erlangen.de/phantoms/index.htm>