Software Simulation of CT Reconstructions and Artifacts

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Abstract. The paper deals with design of complex simulation environment which is able to simulate on the base of mathematical techniques individual reconstructions methods which are normally used on Computed Tomography (CT). Primary attention is focused on The Single Back Projection technique (SBP) and The Filtered Back Projection (FBP). There is a significant benefit with comparison of normally used mathematical software. This simulation instrument is fully dynamic. Individual transformation methods are generated by form dynamic simulations which graphically explain the process of whole reconstruction procedure. The second part deals with simulation of Beam Hardening artifact. It is special type of artifact which significantly deteriorates CT images. This artifact is created especially on the surround of metal object. This simulation is important especially in term of manifestation of artifact. Simulation is helpful for design of filter for Beam Hardening suppressing as well. The complex simulation environment is performed in software MATLAB.

Keywords: CT reconstructions · Artifacts · MATLAB · Beam hardening · Radon transformation

1 Introduction

The Computed Tomography is based on the same principle as X-ray imagining. We observe decrease X radiation within pass by patient (absorption) between X-ray tube and detector. On the CT, there are also problems with X-ray imagining, where is the main disadvantage the superposition of structures and dispersion of CT beams. The CT produces image of human body as series of tomographic slices (images). The acquisition of image data is performed in consecutive measurement of decrease closely collimated X-radiation within translating and rotating movement of mechanical system X ray tube and detector. Within the translating movement is taken one projection of scene. Consequently is performed the rotating movement of mechanical system X ray tube-detector by angle increment and taking next projection of same scene under different angle [1–5] (Fig. 1).
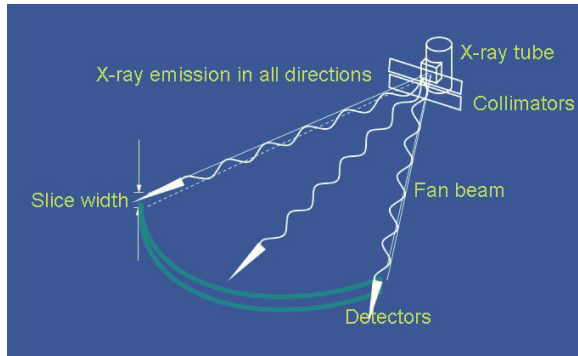
Fig. 1. The principle of CT data acquisition [6]

The cause of metal artifacts consists unwanted blackouts in the images (data become saturated), which might be caused by presence of an object with the highest absorption in the place of scanning. The object absorbs radiation and these results in an artifact. Such object is a standard metal object, for instance, dental materials, clamps or electrodes. The metal artifact is shown as pronounced clear bends which are, often, grouped in a so-called star-like layout [8–10] (Fig. 2).
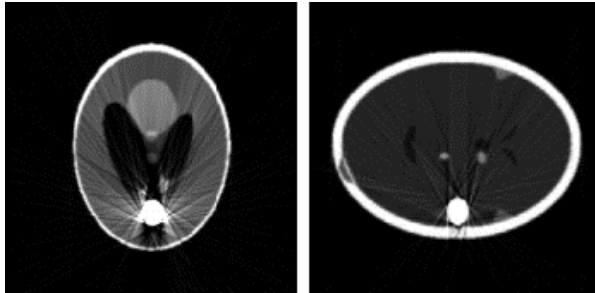

Fig. 2. Manifestation of beam hardening artifact [7]

2 Simulation of Radon Transformation

For creation of Radon transformation we must keep on mind that software MATLAB works with discrete data, therefore within simulation resulting image is summed by certain trajectory. By summing of columns image matrix we obtain projections under one angle. For obtaining system of all projection it is necessary to perform rotation of image. The rotation is taken in certain interval (0°, 180°) and within the rotation it is necessary to perform rotation in steps (iteratively) with stable angle increment. Result of described operation is called sinogram. Sinogram is two dimensional image which is created by sorting of 1D projections under their scanning angle (Figs. 3 and 4).
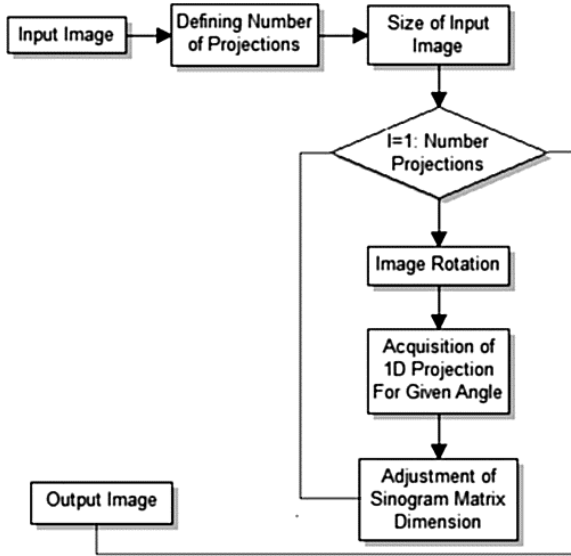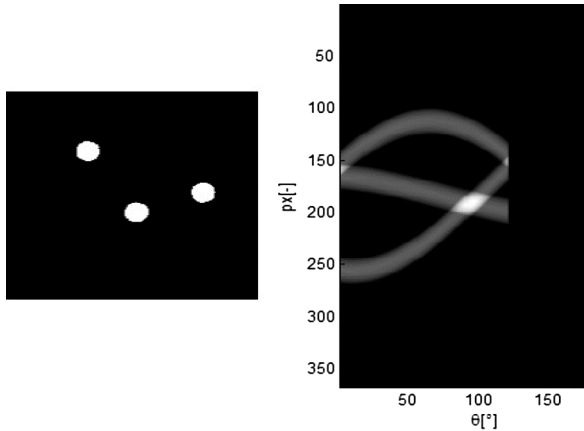
Fig. 3. Block diagram of radon transformation

Fig. 4. The illustration of consecutive filling 1D projections to empty matrix, where px[-] is length of projection, θ[°] is angle of individual projection – number of projections: 180

The dynamic animation of sinogram is performed by consecutive sorting of 1D projections under specific angle to empty matrix. The length of x axes is depended on number of projections. The length of y axes is same as the length of projection. In the algorithm input is possible to take number of projections which form whole transformation process (Fig. 5).
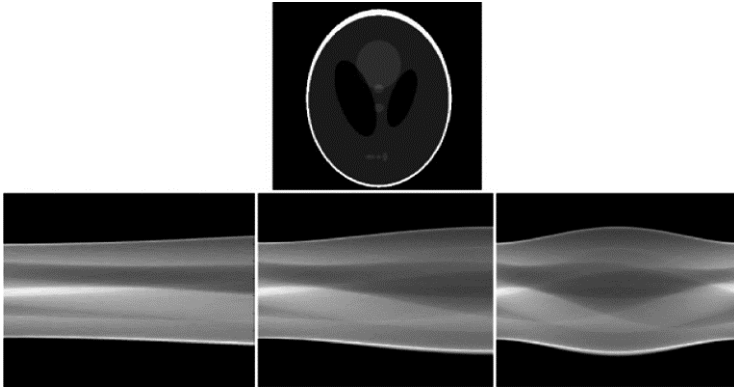
Fig. 5. Testing head phantom (upside), sinogram: number of projections: 1–45 (left), sinogram: number of projections: 1–90 (in the middle), sinogram: number of projections: 1–90 (right)

3   Simulation of Single Back Projection (SBP)

Practical realization is identic as in the case of Radon transformation. After creating sinogram is generated reconstruction matrix. The reconstruction matrix is created as zero matrix. Size of the matrix is same as matrix of reconstructed image. By loop for is consecutively scanned vector which contains information of taken projections and individual projections from sinogram are spread. This matrix is again rotated under same angle, which projection is obtained. By this procedure it is kept size of the matrix. After comparison of sizes spread and reconstructed projection, divided by two and rounding, we get values which are necessary for adding spread and rotated projection to reconstruction matrix under given angle. In the next step overlaps are removed in order to reconstructed image has same size as input image and let him draw [11, 12] (Figs. 6 and 7).

In Fig. 8, there is demonstrated process of reconstruction SBP by form dynamic animation. For individuals outputs have been used 35, 70, 105 and 140 projections. In Fig. 9, there is comparison of reconstruction by using various numbers of projections. These outputs conclusively declare that number of projections significantly influences quality of imaging process (Figs. 8 and 9).
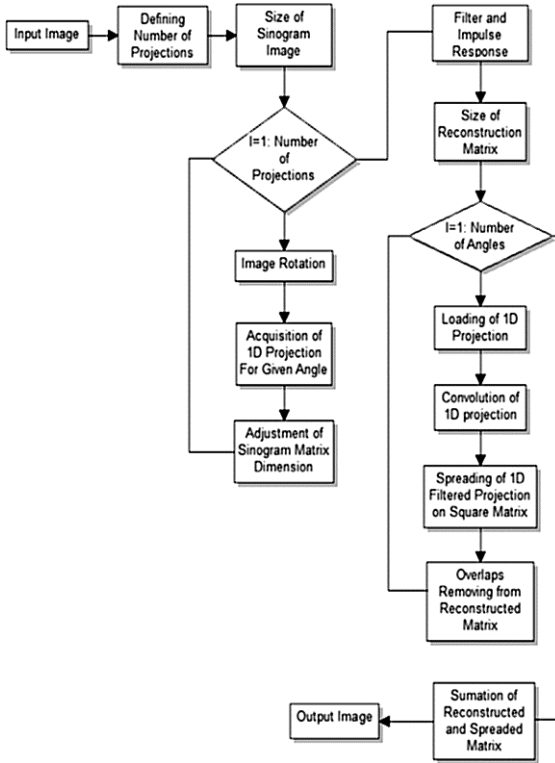
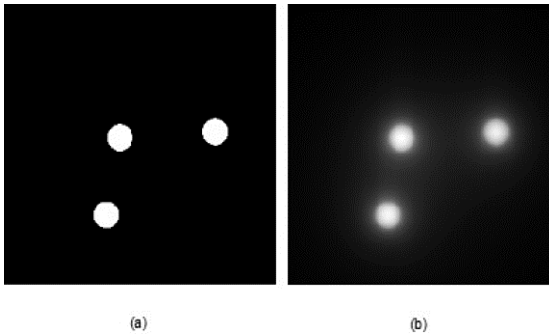**Fig. 6.** Block diagram of Single Back Projection (SBP)

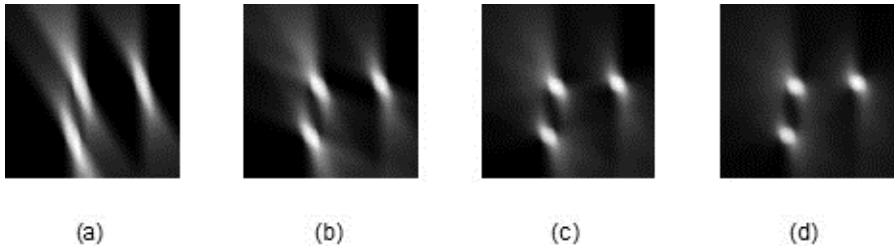**Fig. 7.** Original image (a) and reconstructed image by method Single Back Projection (b)

Fig. 8. Partial reconstruction from: 35 projections (a), 70 projections (b), 105 projections (c) and 140 projections (d)
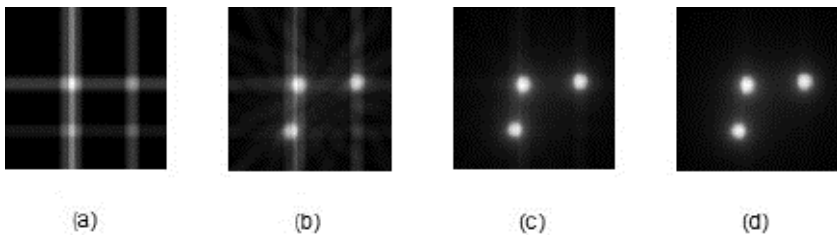

Fig. 9. SBP from various number of projections: 2 projections (a), 10 projections (b), 60 projections (c) and 180 projections (d)

4   Simulation of Filtered Back Projection (FBP)

Practical realization of FBP is quite similar as SBP. After creating sinogram, reconstruction matrix is generated which represents the output image. Individual projections are again spread to this matrix. Impulse response of ramp filter is consequently designed. By loop for are consecutively loaded individual projections from sinogram matrix. These projections are filtered by convolution process. Filtered projections are spread and rotated under angle which was projection taken. After taking correction of size spread and reconstruction projection, we obtain values which are necessary for adding spread and rotated projection to reconstruction matrix under given angle. In the final step all overlaps are removed in order to reconstructed image has same size as input image and let him draw [13] (Fig. 10).
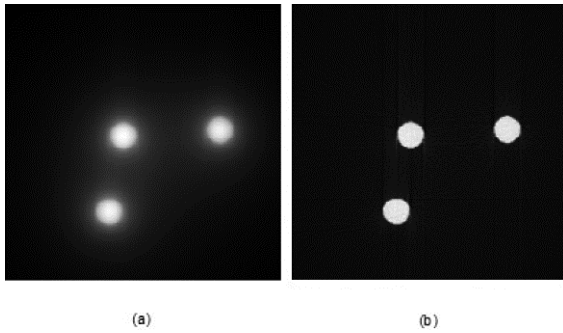
Fig. 10. Original image (a) and reconstructed image by method Filtered Back Projection (b)

It is obvious that reconstructed image by FBP is not so impairs by noise of lower frequencies with comparison of image from SBP. The lower frequencies are filtered out by low pass Ram-Lak filter. In Fig. 11, there is demonstrated process of reconstruction FBP by form dynamic animation. For individual outputs are used 30, 70, 130 and 140 projections. In Fig. 12, there is comparison of reconstructions by using various numbers of projections. This output conclusively declares that increase number of projections significantly influences quality of imaging process. On the other hand increasing number of projections increases computation time of reconstruction process (Figs. 11 and 12).
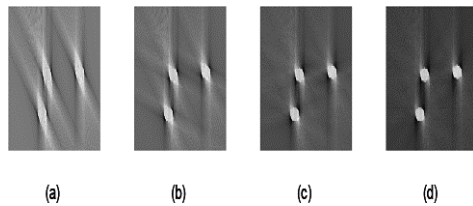

Fig. 11. Partial reconstruction from: 30 projections (a), 70 projections (b), 130 projections (c) and 140 projections (d)
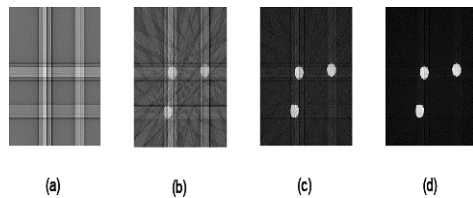

Fig. 12. FBP from various number of projections: 2 projections (a), 10 projections (b), 60 projections (c) and 180 projections (d)

5   Simulation of Beam Hardening Artifact

From theory it is obvious that Beam Hardening artifact is caused by weak attenuation in given voxel. Within the simulation image is loaded where is artifact simulated and image which contains metal object which introduces the source of artifact. In the next step Radon transformation is created from both images. After that output matrix is created where is saved resulted sinogram created by comparison of point values from sinograms. The first dimension of matrix is same as the maximum length of projection created sinogram from image without metal objects. The second matrix dimension is same as number of angles of given projection - 180[px]. By loop for are values of individual points from sinogram of image with metal object compared with zero value. If this value greater than zero, this value will be rewritten by maximum value from sinogram image. Otherwise value of pixels from image sinogram is copied. By described procedure Beam Hardening artifact is appeared in the resulting sinogram matrix. This matrix is consequently reconstructed by inverse Radon transformation. Artifact is appeared in the resulting reconstructed image [7] (Figs. 13 and 14).
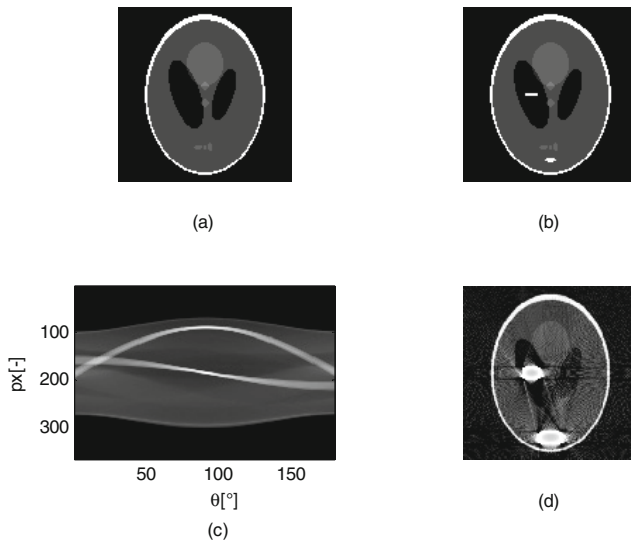

Fig. 13. Original image (a), Image with metal object (b), Radon transformation (c) and simulation of Beam hardening in reconstructed image (d)
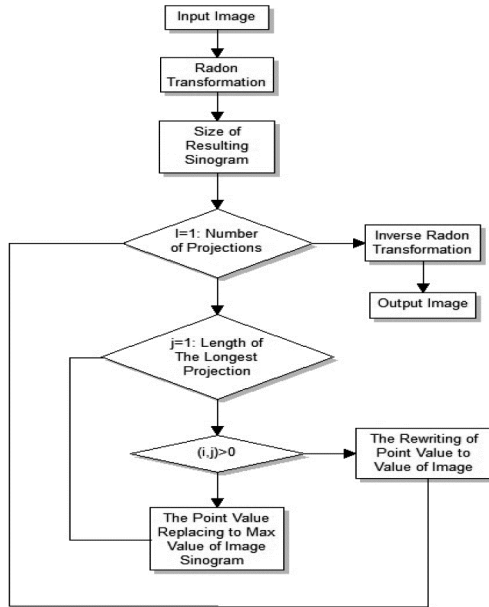
Fig. 14. Block diagram of simulation Beam Hardening artifact

6   Conclusion

The aim of the work is complex graphical user interface which serves as educative portal for studies of mathematical reconstruction methods which are used for image reconstruction from individual projection imaging. The significant benefit of software solution is also generating of artifacts which are created during CT examination and deteriorate resulting images. Simulation methods of artifact consists important base for design and implementation of filtration methods to their elimination. Reconstruction methods on the base of Radon transformation are often contented in mathematical software. The main benefit of proposed solution introduces fully dynamic animations of these methods. These simulations in consecutive iteration steps demonstrate whole process of reconstruction. The quality of output image signal is strongly depended on number of set projections. If we chose lower number of projections, output image would be in worse quality. From this view is better to perform reconstruction form more projections. On the other hand for increase number of projections computation time is also increased. In the coming time we would like to focus our research on simulation of mathematical methods for Algebraic iterative methods. These methods are principally different then SBP and FBP. By these methods is possible partially eliminate Beam Hardening artifact and therefore these methods consist reliable base for suppressing of this unwanted phenomenon.

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