Vol. 6, No. 2, February 2015 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

Design and Construction Three-Dimensional Head Phantom Test Image for the Algorithms of 3D Image Reconstruction

[1] Noor H. Fallooh Al-anbari, [2] Mohammed H. Ali Al-Hayani
[1,2] Electronic and Communications Engineering Department, College of Engineering, Alnahrain University, Baghdad, Iraq
[1] anoornhf87@gmail.com, [2] malhayani@gmail.com

ABSTRACT

The Feldkamp-Davis-Kress (FDK) algorithm is used to reconstruct the three-dimensional (3D) image from the projection collected in cone beam multi slice scanner. The computer simulation for reconstruction algorithms must use 3D object containing all possibilities interactions between tissues closer to the human body. In this work we suggest 3D phantom test image for the simulation of the image reconstruction algorithms. The suggested 3D phantom is modified the 2D Shepp-Logan phantom test image to using in the 3D image reconstruction algorithms. The implementation of FDK algorithm performed in this paper with suggested 3D phantom Image.

Keywords: *3D phantom, FDK, Computed tomography CT, Multi-slice CT, Cone beam*

1. INTRODUCTION

Computed tomography (CT), introduced in the early 1970s, has the entire practice of medicine in radiology and diagnostic [1]. Tomographic reconstruction underlies nearly all diagnostic imaging modalities resolution of a CT image depends on the system geometry and on the reconstruction kernel selected by the user [2]. The rapid development taking place CT from single slice to multi slice scanners accompanied by the development of the geometry for the acquisition of the image, parallel beam, fan beam for single slice which required single row of detector rotated in reverse side of X-ray source around the patient in circular or helical trajectory, and cone beam with multi slice which required array of detector rotated in reverse side of X-ray-cone beam source around the patient [3]. The overall performance of a CT system depends on several key components. These include the X ray source, high-powered generator, detector and detector electronics, data acquisition system (slip-rings), and computer system for reconstruction and manipulation the image. The figure (1) shows the block diagram of CT system [4].

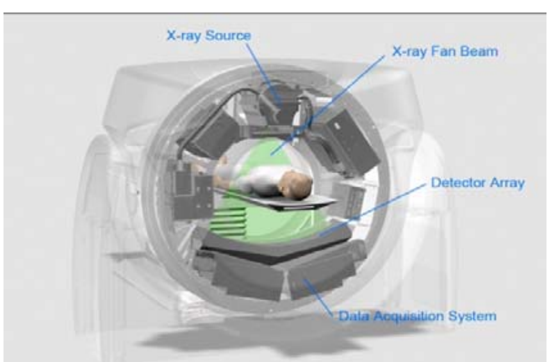

Fig 1: Major components of CT systems.

Some CT system use dual-source to increasing performance evaluation dual-source CT (DSCT) system that equipped with two X-ray tubes and two corresponding detectors as shown in figure(2)[5].

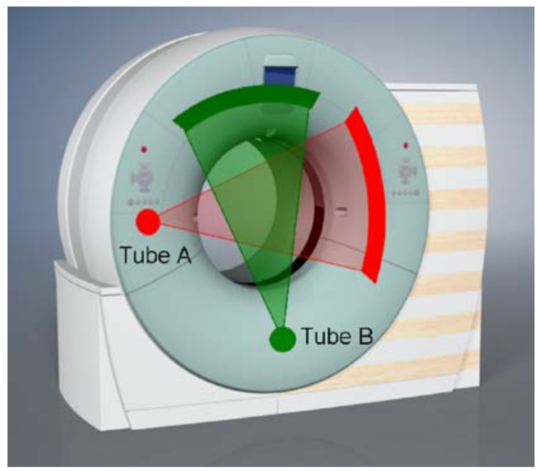

Fig 2: The dual-source computed tomography (DSCT)

2. PRINCIPLES OF MULTI-SLICE CT SYSTEM

The fundamental demands on a modern multi slice CT scanner for large-volume coverage can be summed up in the following two requirements:

a. Continuous data acquisition (the possibility to reconstruct images at any z position).
b. Ability to scan a long range in a short time without compromising longitudinal (z) resolution.

The technical challenges of multi-slice CT are manifold: a detector capable of measuring several thousand channels at a time has to be built, the data have to be transferred to the image reconstruction system, and a suitable reconstruction algorithm has to be provided [2]. A volumetric representation is obtained by advancing the table on which the patient rests after every spin, acquiring a stack of such slices. There are several problems in this case:

a. Projection data covering patient regions between the thin slice sections is not available, which can

Vol. 6, No. 2, February 2015 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

be a problem if a tumor is located right between two slices,

b. The stop-and-go table movement may cause patient displacement between subsequent slice-scans,
c. A volumetric scan usually takes a long time, much longer than a single breath hold, due to the setup time prior to each slice acquisition (this introduces respiratory motion artifacts into the data).

The first two disadvantages have been eliminated with the recent introduction of the spiral (helical) CT scanning devices and third have been solution of multi slice scanner common widely used in medical domain [6].

3. ALGORITHMS OF IMAGE RECONSTRUCTION

There are many different algorithms used in the reconstruction image from projections, the two major categories of algorithms are: analytical and iterative algorithms. Many iterative algorithms are available to solve the system of linear equations or to minimize an objective function such as algebraic reconstruction technic (ART), simulation iterative reconstruction technique (SIRT), simultaneous algebraic reconstruction technique (SART), and different method of multiplicative algebraic reconstruction technique (MART) [3].Analytical reconstruction algorithms based on the central slice theorem, which is the function of tomography, the theorem relates to the 2D image with its 1D projection in the Fourier domain. Many image reconstruction algorithms are derived based on central slice theorem, such as the filtered back projection (FBP) algorithm, which consists of a ramp-filtering step and a back projection step. The filtering step can be implemented as a multiplication in the Fourier domain or as a convolution in the spatial domain. In 3D object use different analytical algorithms with important parameter cone angle (Cone angle, is an important parameter in cone-beam imaging. If the cone angle is small, less than 10^o, this algorithm gives fairly good images). In 3D CT image reconstruction, the speed measurement based on the Tomographic reconstruction of a volume intensity field from multiple two-dimensional projections. As such the performance and accuracy of this technique is highly dependent on the cone-beam reconstruction algorithms is Feldkamp's cone-beam algorithm (FDK), Grangeat's Algorithm, and Katsevich's cone-beam algorithm. The FDK algorithm is almost the same as the fan-beam algorithm, except that the back-projection is a cone-beam back projection. The ramp filtering is performed in the row-by-row fashion, it developed by Feldkamp-Davis-Kress, is by far the most popular mainly due to its structure of back projection and best 3D cone beam algorithm to give exact reconstruction of image as shown in figure (3)[7]. In FDK algorithm it is possible to apply different filters in the algorithm and the possibility to propose a filter in the algorithm to get an image with high quality and fast implementation suitable for the implementation of the FDK and then comparing the result of analytical method with different quality parameters such as: RMSE, PSNR, MD, NAE, MSE are used to compare the enhancement.

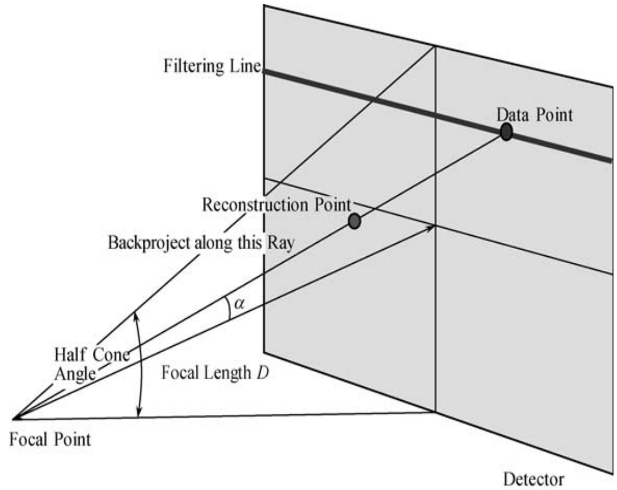

Fig 3: Cone beam projection with FDK algorithm.

The inverse Fourier Transform taking to the filtered projection and collected correctly. The implementation of the FDK back projection is aback smearing, where each radial sample is taken at each fan angle of each cone projection angel and smeared along the path is integrated collecting all these smears over all radial distance and angles will give an approximation to the original 3D image. In more mathematical formulation, the FDK back projection has the following form for each cone projection and express the image in polar coordinates.

$$f(r,\varphi,z) = \frac{1}{2}\int_0^{2\pi} \frac{D}{D-s} \int_{-\infty}^{\infty} \frac{D}{\sqrt{D^2+l^2+\hat{z}^2}} R(l,\hat{z},\beta)\, h(l'-l)\, dl\, d\beta \quad (1)$$

In formula (1), $R(l,\hat{z},\beta)$ is the cone-beam projection, $\frac{D}{D-s}$ is weighting function, $\frac{D}{\sqrt{D^2+l^2+\hat{z}^2}}$ the cosine of the incidence angle (cosine function), $h(l)$ is function of the ramp filter, D is the distance of the x-ray source to the iso-center (focal length), s is the distance from the reconstruction point to the virtual detector, l is the linear coordinate on the detector and $\hat{z}$ and l are defined in figure (4).

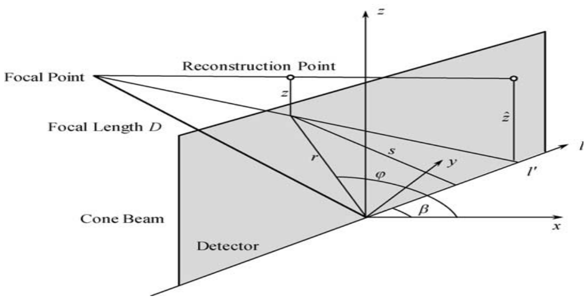

Fig 4: The coordinate system for Feldkamp's cone-beam algorithm.

The FDK may be consists of the following steps:

a. Pre-scale the projections by a cosine function.
b. Row-by-row ramp filter the pre-scaled data.
c. Cone-beam back project the filtered data with a weighting function of the distance from the reconstruction point to the focal point [7].

4. SIMULATION OF THE RECONSTRUCTION ALGORITHMS

The base of CT imaging is to reconstruction any object from the projections of the object. In 2D image *f(x,y)* have 1D projection, each projection is a collection of line integrals according to acquisition geometries to data collection but in 3D object *f(x,y,z)* have 2D projection called cone beam projection, each cone beam projection is collection of plane integrals or cone beam-line integral projections according to geometry of multi slice and algorithms used of reconstruction image[7]. The projections of image used in the computer simulation are implemented by using MATLAB (version R2013a) programming language and computer system: CPU core i5 (2.30 GHz) for the processing. To justify the theory, the results based on MATLAB with Radon Transforms. The path of the X-ray beam travels from the tube to the detector referred to as a beam. After beam X-rays going through the body to be scanned as read, the detectors will measure radiation intensity. The detector read each ray and measures the resultant beam attenuation. The attenuation measurement of each ray is specific a ray sum and the complete set of the ray sums is referred to a view or projection, taking many views to reconstruct a computed Tomographic image [8, 9]. The measurements are collected along different angles and different distance from the iso-center and this process called Radon Transform(RT). RT provides the mathematical basis for reconstructing Tomographic images from measured projection. The most popular presentation of RT is called sinogram. In the sinogram space, the horizontal axis represents the detector channels, and the vertical axis represents the projection angle. To generate a perfect picture used in the simulation to study the efficiency of the algorithms, Shepp-Logan test image used as shown in figure (5)[10].

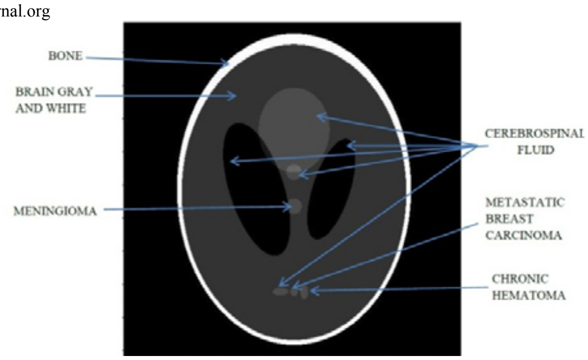

Fig 5: Shepp-Logan head phantom image

The 2D Shepp-Logan phantom image illustrates many of the varieties that you find in a real word Tomographic imaging contain prime a human cross section containing tumors, blood clots, ventricles, skull and the brain. The Shepp-Logan test image is a superposition of ellipses, with each ellipse being assigned a refractive index value as shown in table (1). A major advantage of using an image like that in figure (5) for computer simulation is that one can write analytical expressions for the transforms of the diffracted projections [11]. The Shepp- Logan phantom as illustrated in table (1) of 2D image reconstruction algorithms, 3D image reconstruction algorithms required 3D object as input to obtained it's2D projection. In2005 Matthias Christian [12] modified 3D phantom use to 3D image reconstruction but not include all intersection of original Shepp-Logan. In this paper we design and implemented 3D phantom image to use in 3D Tomographic image reconstruction algorithms, the new suggested 3D test image used to performed the simulation of FDK cone beam algorithm to obtained 2D cone beam projection.

Table 1: Parameters of original 2D Shepp-Logan image of tomography simulation

Additive Intensity	X_0	Y_0	Minor Axisx of ellipsoid	Major Axis *y* of ellipsoid
1	0	0	0.69	0.920
-0.5	0	-0.0184	0.6624	0.874
-0.2	0.22	0	0.1100	0.310
-0.2	-0.22	0	0.1600	.410
0.1	0	0.35	0.2100	0.250
0.15	0	0.1	0.046	0.046
0.15	0	-0.1	0.046	0.046
0.15	-0.08	-0.605	0.023	0.046
0.15	0	-0.605	0.023	0.023
0.15	0.06	-0.605	0.023	0.046

5. RESULT AND DISCUSSION

In this work the suggested 3D head-phantom test image used for generating the projections for different slices of the reconstruction image as shown in figure (6), image size (128 x128x128) and can use (64x64x64) or other size according to size of used phantom. We used multi-detector CT (MDCT) scanners to acquire up to 128 slice and we using a MATLAB program to obtained a 2D

Vol. 6, No. 2, February 2015 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

slice from 3D test image to generates a 3D head phantom that can be used to test 3D image reconstruction algorithms as a Shepp-Logan 3D test image which widely used by researchers in tomography. To generate the user-defined phantom, each row of the matrix N specifies an ellipsoid in the image. N has ten columns, with each column containing a different parameter for the ellipsoids.

Column 1: A is the additive intensity (reflective index) value of the ellipsoid.
Column 2: The minor axis the length of the x semi-axis of the ellipsoid.
Column 3: The major axis the length of the y semi-axis of the ellipsoid
Column 4: Represent the length of the z semi-axis of the ellipsoid.
Column 5: x^0 the x-coordinate of the center of the ellipsoid.
Column 6: y^0 the y-coordinate of the center of the ellipsoid.
Column 7: z^0, z-coordinate of the center of the ellipsoid. Column 8: phi is Euler angle (in degrees) (rotation each ellipsoid about z-axis).
Column 9: θ theta is Euler angle (in degrees) (rotation each ellipsoid about x-axis).
Column 10: Psi is Euler angle (in degrees) (rotation each ellipsoid about z-axis).

For purposes of generating the phantom, the domains for the x-, y-, and z-axes span {-1,1}columns 2 through 7 must be specified in terms of this range. For any given voxel in the output image, the voxel's value is equal to the sum of the additive intensity values of all ellipsoids that the voxel is a part of it. If a voxel is not part of any ellipsoid, its value is 0.The additive intensity value A for an ellipsoid can be positive or negative, if it is negative, the ellipsoid will be darker than the surrounding pixels. Note that, depending on the values of A, some voxels may have values outside the range {0,1}. This head phantom is the same as the Shepp-Logan except the intensities are changed to yield higher contrast in the image [11]. The center slice of cross section 3D shepp-Logan depending of original 2D Shepp-Logan is shown in figure(7) with value of ellipsoid parameter as shown in table (2). We suggest a modified of Shepp-Logan used for 3D image reconstruction the center slice of cross section as shown in figure(8). We used values as shown in the table (3) This head phantom is the same as the Shepp-Logan except the intensities and location of ellipsoid are changed to yield higher contrast in the image, in approximately illustrates tissue overlaps with each other through intersections ellipses what is real to the human brain and give best result when use with 3D image reconstruction algorithms. After input all parameter of ellipsoid to simulate the phantom with angel rotation of each axis asin table (3), when input size of 3D image in this work chooses 128. The results of FDK algorithm to reconstructed3D suggest head phantom with different filter of four slice are selected as shown in table 4,5,6 and 7 for slice 51,slice 64,slice 67 and slice 75 along z- axis. Filter in a new window research publication [2012 is used, MdAbdusSamad [13]] and proposed to applied it in the FBP algorithm(that use in 2D image reconstruction [14]). In this work we used filter [Samad 13] with multi slice scanner to 3D object to some form of smoothing and comparison between the performance of the proposed window [Samad 13]and several common windows used in computerized tomography.

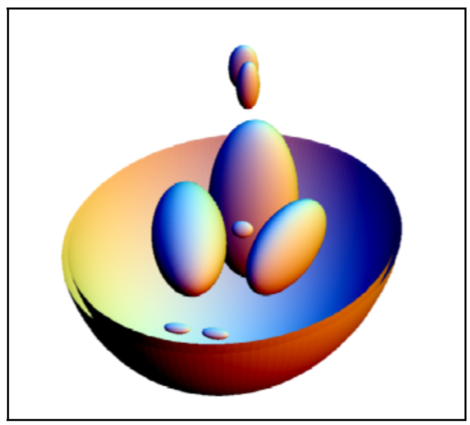

Fig 6: 3D head phantom image suggested

Table 2: Parameters of 3D head phantom Shepp-Logan image of tomography simulation

Int.	X_0	Y_0	Z_0	Minor Axis x of ellipsoid	Major Axis y of ellipsoid	length of z semi-axis of ellipsoid	phi	θ	psi
1	0	0	0	0.69	0.920	0.810	0	0	0
-0.8	0	-0.0184	0	0.6624	0.874	0.780	0	0	0
-0.2	0.22	0	0	0.1100	0.310	0.22	-18	0	10
-0.2	-0.22	0	0	0.1600	0.410	0.280	-18	0	10
0.1	0	0.35	-0.15	0.2100	0.250	0.410	0	0	0
0.1	0	0.1	0.25	0.046	0.046	0.050	0	0	0
0.1	0	-0.1	0.25	0.046	0.046	0.050	0	0	0
0.1	-0.08	-0.605	0	0.046	0.023	0.050	0	0	0
0.1	0	-0.605	0	0.023	0.023	0.020	0	0	0
0.1	0.06	-0.605	0	0.023	0.046	0.020	0	0	0

Table 3: Parameters of suggested 3D head phantom image image of tomography simulation

Int.	X_0	Y_0	Z_0	Minor Axis x of ellipsoid	Major Axis y of ellipsoid	length of z semi-axis of ellipsoid	phi	θ	psi
1	0	0	0	0.69	0.920	0.810	0	0	0
-0.8	0	-0.0184	0	0.6624	0.874	0.780	0	0	0
-0.2	0.22	0	0	0.1100	0.310	0.22	-18	0	10
-0.2	-0.22	0	0	0.1600	0.410	0.280	-18	0	10
0.1	0	0.35	-0.15	0.2100	0.250	0.410	0	0	0
0.1	0	0.1	0.25	0.046	0.046	0.050	0	0	0
0.1	0	-0.1	0.25	0.046	0.046	0.050	0	0	0
0.1	-0.08	-0.605	0	0.046	0.023	0.050	0	0	0
0.1	0	-0.605	0	0.023	0.023	0.020	0	0	0
0.1	0.06	-0.605	0	0.023	0.046	0.020	0	0	0

Fig 7: Center slice of cross section 3D head phantom.

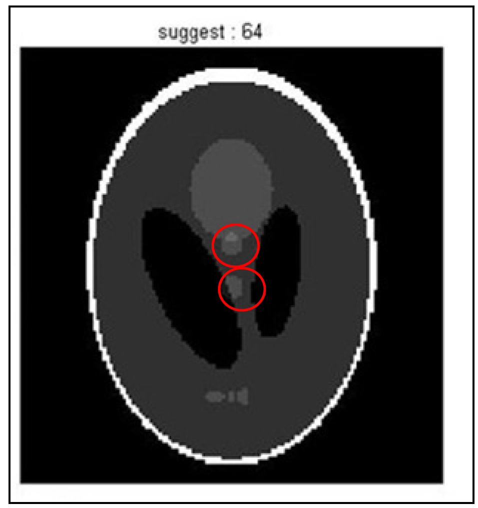

Fig 8: Center slice of cross section 3D suggested head phantom

Table 4: The result of quality parameter of image reconstruction for FDK of multi slice cone beam slice=51

Filters	RMSE	PSNR	MD	NAE	MSE
Ram-Lak	0.0026	99	0.3847	0.1630	2.7936E-5
Humming	0.0031	99	0.4246	0.1885	3.8718E-5
Suggested [Samad 13]	0.0032	99	0.4308	0.1920	4.0088E-5
Hann	0.0032	99	0.4305	0.1909	3.9779E-5

Table 5: The result of quality parameter of image reconstruction for FDK of multi slice cone beam slice=64.

Filters	RMSE	PSNR	MD	NAE	MSE
Ram-Lak	0.0026	99	0.3939	0.1685	2.7198E-5
Humming	0.0031	99	0.4298	0.1976	3.9208E-5
Suggested [Samad13]	0.0032	99	0.4376	0.2015	4.0696E-5
Hann	0.0032	99	0.4352	0.2005	4.0405E-5

Table 6: The result of quality parameter of image reconstruction for FDK of multi slice cone beam slice=67

Filters	RMSE	PSNR	MD	NAE	MSE
Ram-Lak	0.0026	99	0.3942	0.1693	2.7450E-5
Humming	0.0031	99	0.4321	0.1985	3.9363E-5
Suggested [Samad13]	0.0032	99	0.4391	0.2024	4.0836E-5
Hann	0.0032	99	0.4369	0.2014	4.0548E-5

Table 7: The result of quality parameter of image reconstruction for FDK of multi slice cone beam slice=75.

Filters	RMSE	PSNR	MD	NAE	MSE
Ram-Lak	0.0026	99	0.3776	0.1670	2.7367E-5
Humming	0.0031	99	0.4486	0.1950	3.8847E-5
Suggested [Samad13]	0.0032	99	0.4553	0.1988	4.0271E-5
Hann	0.0032	99	0.4552	0.1977	3.9982E-5

The performance measurement of the reconstruction image by applying FDK cone beam multi slice algorithm for reconstruction all slice along z–axis of object with Ram–Lak filter is 164.61711sec., but by applying Hamming filter is 124.40508 sec., suggest filter 124.83668 sec., and Hann filter is 124.43627 sec., In multi slice scanner Hamming filter give minimum time of reconstruction comparing with other filters the scheme of time as shown in figure (9).

In slice 64 the root mean square error of Ram-Lak filter is 0.0026,Hamming filter is 0.0031, suggest filter is 0.0032 and Hann filter is 0.0032.The power of single to noise ratio of all filters is 99 and this excellent result achieved with multi slice scanner and cone beam algorithms. The minimum value of maximum difference, normalize absolute value and mean square error obtained when reconstruction with Ram-Lak filter.

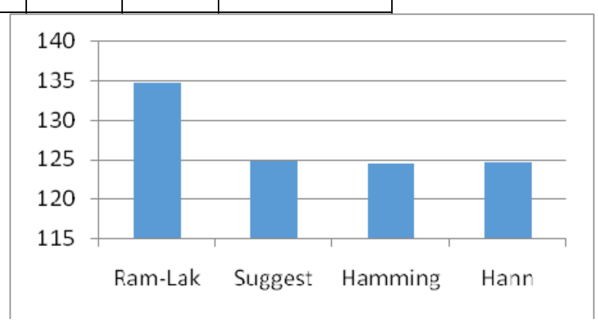

Fig 9: Time performance of different filter.

We select some slices: 51, 64,67,and 75 of 3D image reconstruction of suggest 3D head phantom and 3D head phantom as shown in figure (10) and (11) respectively.

6. CONCLUSION

Radiographic of 3D object with multi slice scanner gives the speed and accuracy of the image reconstruction in 3D algorithms and reduces the patient's body from exposure to radiation. Suggest 3D head phantom have different concentrations and interactions are closer to what exists in the real human brain. Using the new 3D phantom in the 3D reconstruction algorithms gives best results in studies. FDK algorithms used in this work to reconstruction 3D image with different filters are used. Hamming filter give result with minimum time of performance algorithm but Ram-Lak filter give RMSE, MSE, MD, NAE less than other filters. Suggested [Samad13] filter use in 2D image can use with 3D image cone beam projection and obtained excellent results as shown in above table.

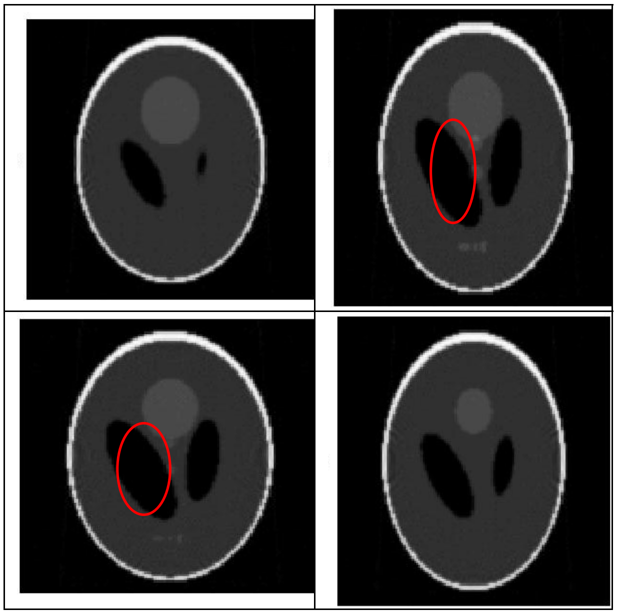

Fig 10: Different reconstructed slice of suggest 3D head phantom.

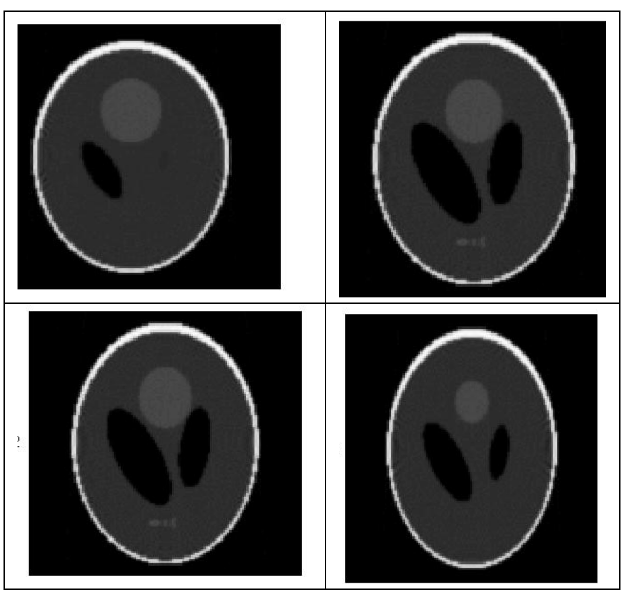

Fig 11: Different reconstructed slice of Shepp-Logan 3D head phantom

REFERENCES

[1] Amir Averbuch, IlyaSedelnikov, and YoelShkolnisky, “CT Reconstruction From Parallel and Fan-Beam Projections by a 2-D Discrete Radon Transform”, IEEE, VOL. 21, NO. 2, February 2012.

[2] Thomas Flohr and Bernd Ohnesorge,” Multi-slice CT Technology” ,ch3.

[3] Gabor T. Herman, “Fundamentals of Computerized Tomography-Image Reconstruction from Projections”, Second Edition, Springer-London 2009.

[4] Thomas Flohr and Bernd Ohnesorge, “Multi-slice CT Technology” ,ch1.

[5] Thomas G. Flohr Cynthia H. McCollough, “First performance evaluation of a dual-source CT (DSCT) system”, Springer-Verlag 2005.

[6] Wojciech Chlewicki,’’3D Simultaneous Algebraic Reconstruction Technique for Cone-Beam Projections”, master this is, university of Patras, Department of Medical Physics,2001.

[7] Gengsheng Lawrence Zeng, “Medical Image Reconstruction”, Springer, New York,2010.

[8] Jiang Hsieh,’’ Computed tomography: principles, design, artifacts, and recent advances’’, second edition,2009 Society of Photo-Optical Instrumentation Engineers

[9] Rainer Grimmer & Markus Oelhafen, ”Cone-beam CT image reconstruction with extended z range”, Am. Assoc. Phys. Med., 13 May 2009.

[10] Shepp L.A & Logan BF., “The Fourier reconstruction of a head section”, IEEE Trans,1974.

[11] KAK. A.C. and M. Slaney, "Principle of computerized Tomographic imaging" New York, 1999.

[12] www.MathWorke .com

[13] Md. Abdus Samad, "A novel window function yielding suppressed main lobe width and minimum side lobe peak ", April, 2012.

[14] Doaa. N. Al Sheack1 and Dr. Mohammed H. Ali Al-Hayani, “Enhancement Image Quality of CT Using Single Slice Spiral Technique”, IJCSET, February 2014 ,Vol 4.