The Indonesian Journal of Computer Science
www.ijcs.net
Volume 13, Issue 6, December 2024
https://doi.org/10.33022/ijcs.v13i6.4463

Simulation on Image Reconstruction of Concrete with Rebars by Filtered Back Projection Algorithm using PHITS and MATLAB Program

Myo Thet Han[1], Thaw Tun Ko[2]
myothethan1980@gmail.com[1], thawtunko@gmail.com[2]
[1]Technological University (Kyaukse)
[2]Mandalay Technological University

Article Information

Received : 22 Oct 2024
Revised : 7 Nov 2024
Accepted : 4 Dec 2024

Keywords

Concrete block, image reconstruction, filtered back projection algorithm, MATLAB program

Abstract

This paper describes simulation on image reconstruction of concrete with rebars by filtered back projection algorithm using PHITS and MATLAB program. In PHITS simulation, a source of Cs-137 and NaI (Tl) detector were used. Concrete block with one rebar was carried out with PHITS simulation. The sample of another concrete block with two rebars with different diameters was also conducted. Linear attenuation coefficient values of the concrete were calculated. These phantoms were rotated with 2.8125 degree intervals over 0 to 180° in PHITS simulation. The objects were scanned with the parallel beam method and the projection data were obtained. The data was built into the image using filtered back projection (FBP) algorithm. The 'spline' interpolation and 'Hamming' filter functions were chosen for the clearest image in image reconstruction. The results indicated that the reconstructed images of the concrete containing one rebar and two rebars can be observed clearly in MATLAB.

A. Introduction

Concrete has been widely used worldwide in the construction industry because of its cheap price and mechanical properties. It can also be used over long periods for nuclear power plant facilities and is very suitable for radiation shielding against gamma rays or neutrons. History shows that concrete structures often deteriorate due to factors such as improper design, sloppy construction work, use of low-quality materials, exposure to high levels of chemicals that may endanger the safety of concrete structures and pose a risk to the safety and health of the public [1].

Concrete is a relatively low-cost material and it can be handle easily as it can be poured into various, complex shapes. More studies were conducted on the use of cement and other materials in radiation shielding. Shielding is considered in the important ways which dependence on radiation protection as well as distance and time, mostly the lead used in shielding against gamma ray and X-ray and concrete is used in nuclear power, X ray rooms, nuclear medical and uses in Nuclear Power plants, Nuclear Power research, laboratories, and hot cells. The choice of shielding materials selection is dependent upon exposure rate reduction, kind of source, and final cost effective analysis. In general, there are different materials used to protect against radiation in different applications, for example, polyethylene, glass, epoxy, lead and concrete were used to shield neutrons and gamma rays [2].

Nuclear radiation is ionizing radiation. It can be generated from many sources, both natural and man-made, such as accelerators, radioisotopes, and reactors. Ionizing radiation has the potential to be both harmful and useful. The emergence of ionizing radiation from its source and interaction with human tissue or instruments can have a negative impact since it can cause disease or damage. By contrast, such radiation can also be useful when used in fields such as nuclear medicine, medical diagnosis, industrial tracing, nondestructive testing, and radiography. Due to its potential adverse effects, nuclear radiation should be properly managed and shielded from those involved in working with it. Adequate protection is thus the first priority when handling radiation sources (IAEA, 2014) [3].

The principle of radiation shielding is to reduce the intensity of external radiation to an acceptable level. A good x-ray/gamma ray shielding material should have a high value of photon attenuation coefficients and the irradiation effects on its mechanical properties should be small. Many types of photon shielding have been produced, using different material compositions. These have ranged from classic ones such as concrete to more advanced materials such as custom-made shielding constructed from heavy metals dispersed inside organic polymers. Shielding has also been produced using alkali minerals, the radiation-shielding properties of which have been compared with those of concretes [3].

Computed tomography (CT) is a candidate inspection technology that meets many of the above criteria. The strength of this technology is its ease of interpretation. CT canning technology can image the internal structure of concrete, concrete compacted by different methods or mixes, and concrete with various inserted rebars. The internal views of the concrete structure are dimensionally correct, and the picture-element (pixel) variations are reliable and accurate and reflect the variation in material composition and/or density. Although not

https://doi.org/10.33022/ijcs.v13i6.4463

common, fieldable CT systems have been used to rapidly inspect trees and telephone poles *in situ*. Although still not access independent, it is thus known that CT can be designed to be economical, flexible, and weather tolerant. Furthermore, CT is a powerful NDE tool that - coupled with other laboratory techniques such as mechanical loading of autogenous healing - results in a better understanding of these techniques as well as the concrete and reinforced concrete itself [4].

Monte Carlo (MC) method simulates the interaction of radiation with matter. One of the MC programs is PHITS. PHITS (Particle and Heavy Ion Transport code System) is a multi-purpose tool for simulating particle transport phenomena developed by JAEA (Japan Atomic Energy Agency) and several other institutes. This code has widely used in many studies in the fields of accelerator and detector design, particle therapy, and cosmic radiation, etc. With the various nuclear reaction models and atomic data libraries, PHITS code makes it possible to simulate photon interactions in concrete material with accurate results. The capability of PHITS is transport and collision of nearly all particles over wide energy range using Monte Carlo method. All content of PHITS (source files, binary, data labraries, graphic utility, etc.) are fully integrated in one package [5].

The aim of the present work is to reconstruct images of concrete with rebars by filtered back projection algorithm using PHITS and MATLAB program.

B. Materials and Methods

Concrete and its specifications

Reinforced concrete is one of the most used construction materials in civil engineering. Some structures made from this material, such as bridges have intense traffic, support high loads and are exposed to degrading factors from the environment. Therefore inspection work and maintenance of the structures throughout their service life should be on going. The possible presence of faults in the concrete can accelerate the contact of the steel with moisture, favoring the onset of a corrosive process. As a consequence, it is essential to monitor, in situ, the presence of cracks or voids and the quality of the steel present in the structure. Techniques using ultrasound waves and eddy currents have been applied to assess the conditions of reinforced concrete, but both the techniques have serious limitations [6]. Density and atomic compositions of concrete measured by EDXRF method were shown in table 1 and these values were used in PHITS simulation.

Table 1. Density and atomic compositions of concrete

No.	Material	Density (g/cm^3)	Atomic Compositions (%)
1	Concrete	2.35	Ca 49.095
			Si 13.084
			Mg 3.818
			Al 0.885
			S 0.664
			K 0.415
			Fe 1.860
			Ti 0.240
			Sr 0.051
			Mn 0.039

Rebar and its specifications

Rebar, reinforcement bar, is a metal bar that is used to help increase the tensile strength of concrete. As a result, it helps concrete structures withstand thesile, bending, torsion, and shearing loads Since these are areas of weakness for concrete rebar strengthens concrete structures that would otherwise fall apart under these forces. Rebar is used in most concrete structures. Common examples include high-rise buildings, parking ramps, concrete piers, bridges, foundations and thick roads and driveways [7]. Density and atomic compositions of steel bar were shown in table 2 [15]. These values were used in PHITS simulation.

Table 2. Density and atomic compositions of steel bar

No	Material	Density (g/cm^3)	Atomic Compositions (%)
1	Steel bar	7.8416	Fe 98.00 C 0.25 Cu 0.20 Mn 1.03 Si 0.28 P 0.04 S 0.05

Calculation of linear attenuation coefficient (μ)

Interaction of gamma radiation with medium of interest in the object will produce change intensity of the beam which correlated to the properties of the medium. If monoenergetic gamma rays are collimated into a narrow beam and allowed to strike a detector after passing through an absorber of variable thickness, the result should be simple exponential attenuation of the gamma ray. It can be expressed by the Beer–Lambert law: $I = I_0 e^{-\mu t}$ and linear attenuation coefficient value can be calculated by $\mu = \frac{\ln(\frac{I_0}{I})}{t}$.Where I is the intensity of radiation transmitted through the absorber. I_0 is the intensity of initial radiation. μ is linear attenuation coefficient and t is the thickness of the absorber [8].

Filtered Back Projection (FBP) Algorithm

The FBP algorithm is often referred as the convolution method using a one-dimensional integral equation for the reconstruction of a two-dimensional image. This method is the most popular reconstruction algorithm used at present in CT application.. The filtered back projection algorithm is used to reconstruct an object from its projections. A simple back projection causes blurring of the reconstructed object. To overcome this effect the projections is filtered using a high pass filter [6]. After applying the computer simulation of FBP on the image, the performance of algorithm and the quality of the image will be dependent on many considerations such as image size, number of projections and theta incremental [9].

During the scanning, the projection will be acquired by gamma-ray snapshot on the object at theta angle, the data acquired can be represented by 2D sinogram. A sinogram is the collection of parallel projections of the object taken at equidistant angles, and forming a map of the projection data. It is based on the concept of line integral and Radon transform is used for image reconstruction processes. Image reconstruction using back projection algorithm successfully showed cross-sectional profile of the object but cannot show the difference of density distribution of the object. The algorithm produced blur at image and there was a shadow of light around the object. Filtered back projection algorithm resolved the problem by using a convolution filter. The image can show the density difference of the objects. Filters are very important in image reconstruction process. It enhances the quality of the resulting image [9].

Image Reconstruction

Image reconstruction has major effects on image quality and therefore on radiation dose. For a given radiation dose, it is preferable to reconstruct minimal noisy images without disturbing image accuracy and spatial resolution. Reconstructions that enhance image quality can reduce radiation dose, since lower dose can be used to reconstruct the same quality images. It is important to investigate the reconstruction of CT images, because CT imaging is widely used in various areas for treatment and diagnostics due to its ability to image the anatomical details. Also, advantages such as high spatial resolution and slice selection in any direction make CT imaging preferable. In addition, as it can be concluded from the present researches, high diagnostic quality CT images can be achieved by using FBP in most circumstances [10].

MATLAB Simulation

In this paper, a method of image reconstruction for concrete block has been presented and the performance of FBP algorithm has been improved. The MATLAB package was used as a tool in performing the programming of the proposed reconstruction process. When acquiring the data from the DAS obtained by parallel beam geometry of scanning by using MATLAB functions for image reconstructions [5]. The MATLAB program is extensively used in engineering and scientific circles for numeric intensive computing. There are many toolboxes available, the DSP toolbox & others in areas of optimization, spline, control and estimation, and system identification. There are some useful functions in the DSP toolbox for 2-dimensional signal processing: 2-D DFT's, convolution, correlation, and graphing. Separable and non separable processing is conveniently described in terms of matrices. Also many topics in image enhancement and restoration are conveniently described in terms of matrices. PC-MATLAB is a very convenient tool for processing small images or blocks, 64 × 64 often being an upper limit for processing, although larger blocks can be imported and displayed. In spite of these restrictions, it is possible to display and process full size 600 × 800 images using PC MATLAB and a graphics processor. The signal processor adds the possibility of accelerating numeric intensive operations by a factor of 10 to 40 [13]. The reconstruction process was shown in figure 1 [14].

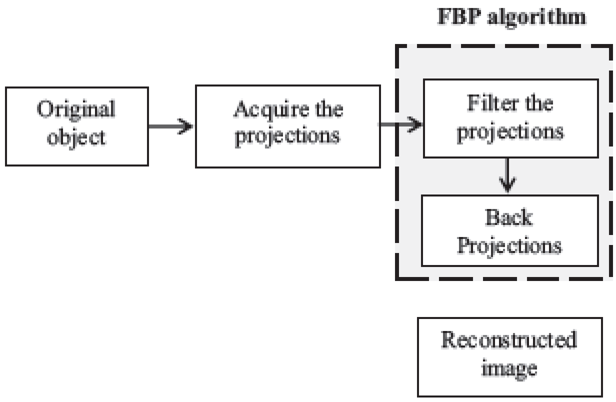


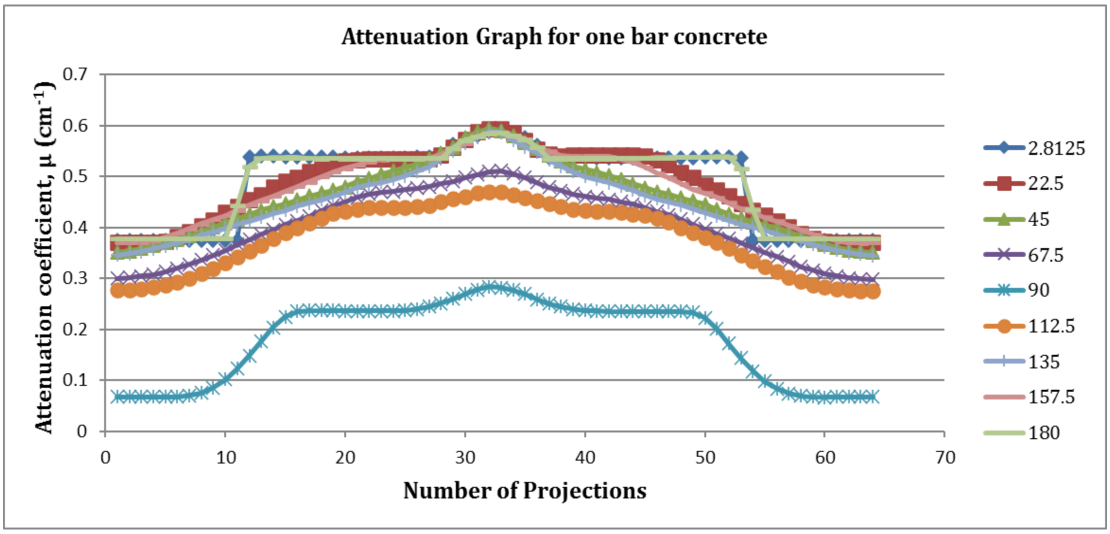
Fig.ure 1. The reconstruction process

C. Results and Discussion

Linear attenuation coefficient (μ)

The most important quantity characterizing the penetration and diffusion of gamma radiation in extended media is the attenuation coefficient, μ. This quantity depends on the photon energy (E) and on atomic number (Z) of the medium. Definition of narrow beam attenuation coefficient is the probability per unit pathlength that a photon will interact with medium [11]. In characterizing the penetrating of gamma rays in materials, the μ value plays an important role depending on the photon energy and the density of the shielding material also proves linear attenuation coefficient obtain increases as the thickness increases [1].

The projection data were obtained from PHITS simulation for one bar concrete. In this graph, linear attenuation coefficient values (μ) calculated by the attenuation equation were illustrated. The sample was measured by a number of 64 projections from 0 to 180 degree with the step of 2.8125 degree intervals. The values of linear attenuation coefficient varied depending on the thicknesses of the concrete and rotation of the corresponding angles. The vaiation of linear attenuation coefficients values for one bar concrete was shown in figure 2.



Figrue 2. Attenuation graph for one bar concrete

PHITS Monte Catlo Simulation

The calculation of deposited energy for photon transport through material specimen was realized by PHITS code. PHITS is developed for numerical experiments by Monte Carlo techniques for dosimetry, radiation damage, radiation therapy and other actual applications of these particles. For the photon history, following it from scattering to scattering using corresponding inverse distribution between collision, types of target, types of collisions, types of secondary, their energy and scattering angles generates the trajectory. Photon interactions are coherent scattering, incoherent scattering, photoelectric absorption and pair production [11].

The radiation attenuation properties of the concrete containing rebars were calculated using the Monte Carlo PHITS transport code. The geometry model was based on concrete block. The sample block contains one steel bar at the center and two steel bars at the left and right of the center with different locations and surrounded with concrete. Steel bars size with differnet diametes were used and the simulation has been conducted for the attenuation evaluation of the composite concretes. The detector and source were located from the concrete block center to the left and to the right [12].

Scan of Concrete block with one bar

Concrete block size with 10 cm × 10 cm × 10 cm containing one steel bar was carried out in PHITS simulation. This sample was used to determine the shape of the steel bar inside the block. To acquire the data for the sample block, the measured source was 0.662 MeV energy of Cs-137 gamma source and the detector was NaI crystal detector. The distance between source and detector was 16 cm. The steel bar size with 1.8 cm diameter was located at center in the vertical direction inside the block. The block sample was scanned and measured with various degrees from 0 to 180 degree. The sample was scanned in translational mode at 0 degree to get the projections profiles. Each translational scan was conducted with 64 steps to cover all the dimension of the sample. The sample was rotated about 2.8125 degree intervals and then continue to measure 5.625 degree, 8.4375 degree, 11.25 degree, etc. until 180 degree and proceeded translation scan to get the next projection data again. It was continued to carry out scanning sample again in every degree until all the projections data were obtained.

Linear attenuation coefficients values from the output results of PHITS were computed. The projection data were built into the image using filtered back projection algorithm. PHITS model of one bar concrete block was presented in figure 3. Image reconstruction was performed from the computed values of linear attenuation coefficient using MATLAB. The sinogram for one bar concrete in MATLAB was shown in figure 4.

https://doi.org/10.33022/ijcs.v13i6.4463

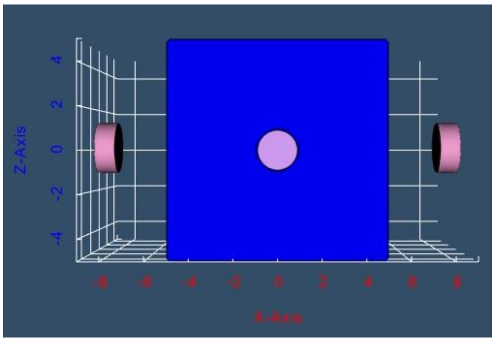


Figure 3. PHITS model for one bar concrete

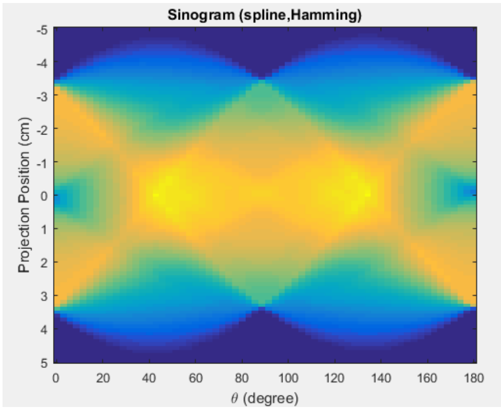


Figure 4. Sinogram for one bar concrete

In MATLAB, there are five interpolation functions, namely, nearest, linear, pchip, v5cubic and spline. One bar concrete with various filter functions such as 'Shepp-Logan', 'Ram-Lak', 'Cosine', 'Hamming', 'Hann', as well as 'without' filter was tested in MATLAB simulation. Among them, 'spline' interpolation and 'Hamming' filters functions are the clearest images for one bar concrete in image reconstruction. Reconstructed Image for one bar concrete using 'spline' interpolation and 'Hamming' filter was shown in figure 5. It was cleared that 'spline' interpolation and 'Hamming' filter offered the clearest image for one bar concrete in image reconstruction.

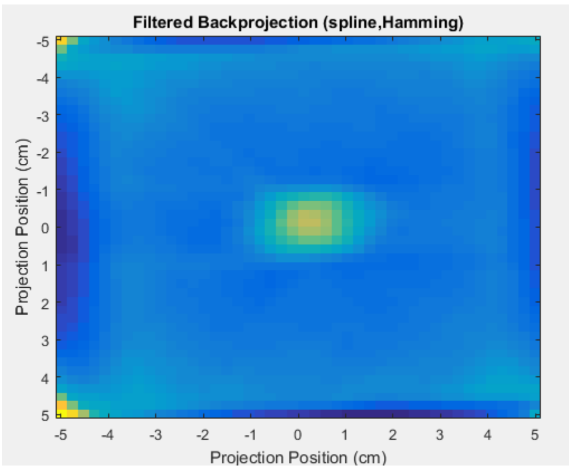


Figure 5. Image Reconstruction for one bar concrete

The projection data were obtained from PHITS simulation for two bars concrete. In this figure, linear attenuation coefficient values (μ) for two bars concrete were presented. The sample was measured with 2.8125 degree intervals until 180 degree. The values of linear attenuation coefficient for one angle were different from another angle. Similarly, according to the data analysis, linear attenuation coefficient values varied for every angles. The vaiation of linear attenuation coefficients values was shown in figure 6.

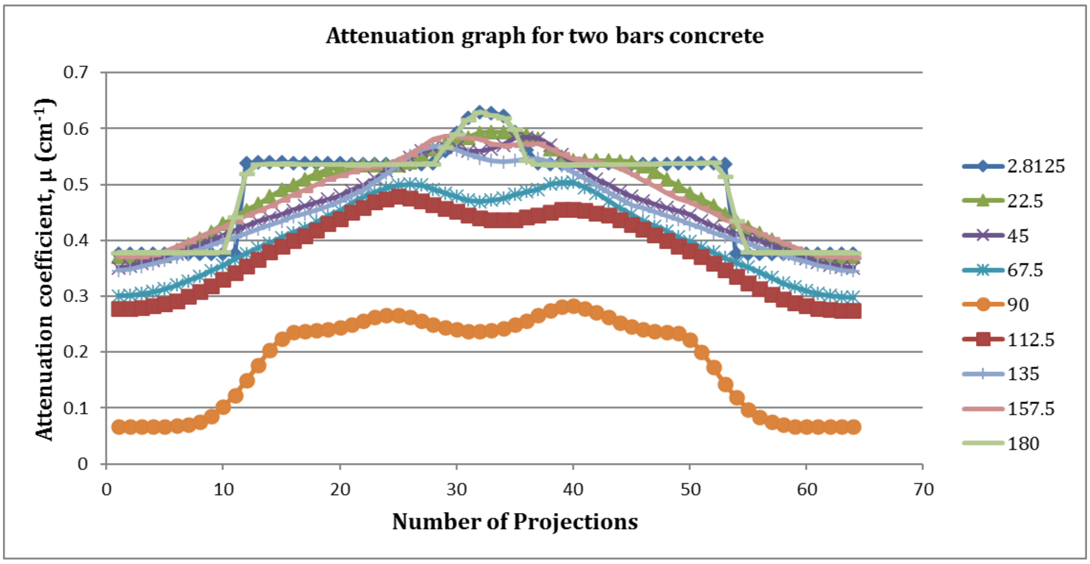


Figure 6. Attenuation graph for two bars concrete

Scan of Concrete block with two bars

Concrete block size with 10 cm × 10 cm × 10 cm containing two steel bars was tested in PHITS simulation. This sample was used to determine the shape of the steel bars inside the block. To acquire the data for the sample block, the measured source was 0.662 MeV energy of Cs-137 gamma source and the detector was NaI crystal detector. The distance between source and detector was 16 cm. Two steel bars size in the vertical direction inside the block are 1.4 cm and 1.8 cm diameters and the distance between two bars was 2 cm. The block sample was scanned with source and detector as mentioned in one bar concrete and linear attenuation coefficients values from the output data of PHITS were calculated. The projection data were built into the image using filtered back projection algorithm. PHITS model of two bars concrete block was presented in figure 7. Image reconstruction was performed from the computed values of linear attenuation coefficients using MATLAB. The sinogram for two bars concrete in MATLAB was shown in figure 8.

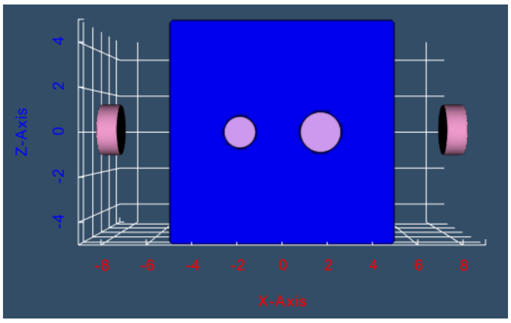


Figure 7. PHITS model for two bars concrete

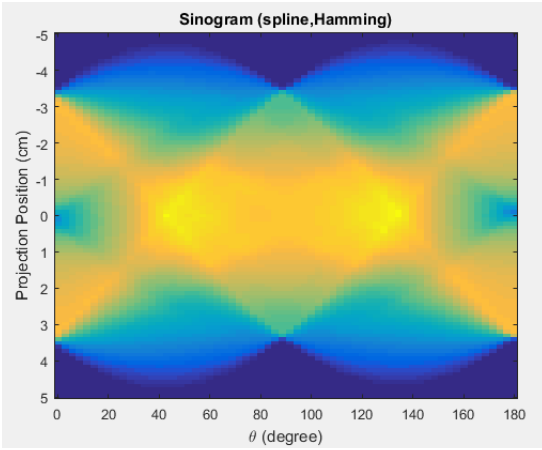


Figure 8. Sinogram for two bars concrete

Reconstructed Image for two bars concrete with various interpolation and various filter was performed in MATLAB. It was observed that 'spline' interpolation and 'Hamming' filter functions were the best functions for the clearest image of two bars concrete in image reconstruction. Reconstructed image for two bars concrete was shown in figure 9.

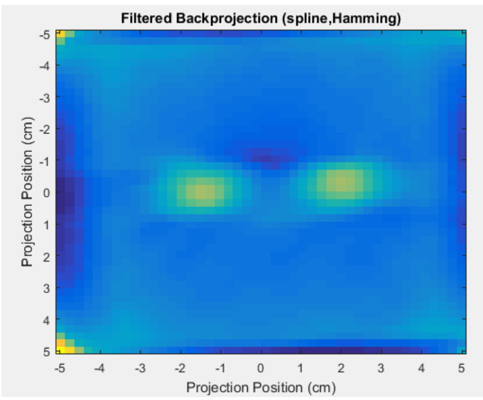


Figure 9. Image Reconstruction for two bars concrete

D. Conclusion

The use of gamma ray tomography provided a non-destructive and accurate method for investigation of steel bars inside the concrete block. In this study, concrete block samples have been studied by PHITS code and linear attenuation coefficients (μ) of concrete block has been calculated by PHITS code. Concrete block with one bar has been simulated by the PHITS code and the sample was scanned from 0 to 180 degree with the step of 2.8125 degree. The moving of center to center spacing was 0.25 cm distance for 64 projections for every degree. FBP algorithm can be considered as a useful and effective reconstruction method for computed tomography (CT) images. In the one bar concrete, various interpolation and various filter functions have been tested for image reconstruction using MATLAB program. The results revealed that 'spline' interpolation and 'Hamming' filter functions are the clearest images for image reconstruction. Concrete block with two bars has been conducted in PHITS and MATLAB simulation. In the two bars concrete, it was found that 'spline' interpolation and 'Hamming' filter functions produced higher images resolution. The image reconstructions of concrete with rebars have been investigated by the MATLAB program. In contrast, PHITS simulation can be an alternative method for studying attenuation coefficients of concrete blocks and overall, 'spline' interpolation and 'Hamming' filter can be recommended to reconstruct images of the objects with MATLAB from projections data in the research work.

E. Acknowledgment

The authors are greatful to the JAEA (Japan Atomic Energy Agency) and several other institutes for providing simulation software.

F. References

[1] Farah Ainin Sofiya Muhd Syazl and Mohd Idzat Idris, "Effects of gamma rays on normal-high-density concrete," Nuclear Science Program, Applied Physics Studies, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia, 2023.

[2] Adel Abdulhadi Jawad, Ahmed Fadel Mkhaiber, Khaled Hadi Mahdi, Sabah Ageeb Kassi , Zaidoon Hafed Ibrahem, "Prepare Concrete Shielding from Local Materials and Study Linear Attenuation Coefficients," Ministry of Science and Technology, Central Laboratory Directorate, Baghdad, Iraq Department of Physics, College of Education Ibn Al-Haithem, University of Baghdad, Baghdad, Iraq, vol.4, pp.100-103, 2021.

[3] Ferhat Aziz, Mardiyanto Panitra, Abu Khalid Rivai, "SYNTHESIS AND MONTE CARLO SIMULATION OF IMPROVED CONCRETE COMPOSITES FOR ENHANCED X-RAY/GAMMA RAY RADIATION SHIELDING," Center for Science and Technology of Advanced Materials, BATAN, Kawasan Puspiptek, Serpong, Tangerang, Banten 15314, Indonesia, vol.4, pp: 695-706, 2018.

[4] HARRY E. MARTZ, DANIEL J. SCHNEBERK , G. PATRICK ROBERSON & PAULO J.M. MONTEIRO, "Computed Tomography Assessment of Reinforced Concrete," Lawrence Livermore National Laboratory, Livermore, CA, 94550, USA Civil Engineering Dept., Univ. of California , Berkeley, CA, 94720, USA, Vol. 8-9, pp. 1035-1047, 2014.

[5] Marwa. T. Al Hussani Mohammed H. Ali Al Hayani, "The Use of Filtered Back projection Algorithm for Reconstruction of tomographic Image," Electronics and Communication Eng. Dept, Al-Nahrain University Baghdad, Vol.17 No.2, 2014 pp.151-156, Iraq, 2014.

[6] E.M. Boldo, C.R. Appoloni, "Inspection of reinforced concrete samples by Compton backscattering technique," State University of West of Parana, CCET, P.O. Box 701, Zip Code 85819-000, Cascavel-PR, Brazil State University of Londrina, CCE, P.O. Box 6001, Zip Code 86055-900, Londrina-PR, Brazil.

[7] Fro Old cars Comes Rebari Concrete Construction Magazine, Concrete 101 all about rebar, Custom Concrete Turning Billets into Barsi Concrete Construction Magazine.

[8] Wibisono, Bayu Azmi, Sastra Kusuma Wijaya, Prawito, and Firliyani Rahmatia Ningsih, "Cross Sectional Imaging of Tree Stem Density Distribution using Gamma-Ray Tomography Technique." Center for Isotopes and Radiation Application, BATAN, Jl. Lebak Bulus Raya No 49, Jakarta 12440, Indonesia Department of Physics, Universitas Indonesia, Depok, 16424, Indonesia *E-mail: bayuazmi@batan.go.id, IOP Conf. Series: Journal of Physics: Conf. Series 1198 (2019) 022012.

[9] Bayu Azmi, Wibisono, Darman, "Effect of Filter on Image Reconstruction using Filtered Back Projection Algorithm for Industrial Gamma-Ray Tomography Technique," Sugiharto Center for Isotopes and Radiation Application, National Nuclear Energy Agency (BATAN) Jl. Lebak Bulus Raya No. 49, Jakarta 12440, Indonesia, 2019.

[10] C Sriwunkum1 and T Nutaro, "Study on gamma-ray shielding properties of lead tellurite glass systems using PHITS," Department of Physics, Faculty of Science, Ubon Ratchathani University, Ubon Ratchathani, 34190, Thailand, 2019.

[11] S.J. Stankovića, R.D. Ilića, K. Jankovićb, D. Bojovićb and B. Lončarc, "Gamma Radiation Absorption Characteristics of Concrete with Components of Different Type Materials." Vinča Institute of Nuclear Sciences, P.O. BOX 522, 11001 Belgrade, Serbia, Institute for testing materials-IMS, Bul. Vojvode Mišića 43, 11000 Belgrade, Serbia, Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, vol.117, no.5, Serbia.

[12] K. Mokhtari, M. Kheradmand Saadi, H. Ahmadpanahi, Gh. Jahanfarnia, "Fabrication, characterization, simulation and experimental studies of the ordinary concrete reinforced with micro and nano lead oxide particles against gamma radiation," Department of Nuclear Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran, Department of Chemistry, Islamic Azad University, Central Tehran Branch, Tehran, pp.3051-3057, Iran, 2021.

[13] Parul Goyal, "Image processing using Matlab," Associate Professor, Department of Computer Science Engineering, Uttaranchal Institute of Technology, Dehradun.

[14] Tugba Ozge Onur, "An application of filtered back projection method for computed tomography images," Electrical-Electronics Engineering, Beulent Ecevit University, 67100 Zonguldak, Turkey, 12 (2021) 2, pp: 194–200.

[15] https://www.infra-metals.com, Infra Metals Co.6 Penns Trail Suite 201, Newtown PA, 18940, Tel: 800-899-3432, Fax: 215-741-5973, info@infra-metals.com.