Novel Perspectives of Engineering Research Vol. 8

Editor(s)
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ISBN 978-93-5547-380-6 (Print)
ISBN 978-93-5547-391-2 (eBook)
DOI: 10.9734/bpi/rtcams/v8

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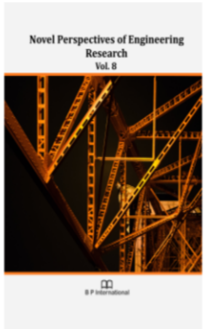
Chapters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Vol. 8
B P International


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Print ISBN: 978-93-5547-380-6, eBook ISBN: 978-93-5547-391-2

Prototype Model Approach for Developing a Computed Tomography Scanner Application

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DOI: 10.9734/bpi/rtcams/v8/1859B

ABSTRACT

The development of software applications for image reconstruction systems is critical in the computed tomography (CT) research study. An experimental prototype was the research tool used to create a series of useful prototypes for evaluating reconstruction methods. The prototype model approach has a short development period when developing an initial prototype for the user. A CT scanner software prototype was created using the MATLAB image processing toolbox together with the Graphical User Interface (GUI) and Graphical User Interface Development Environment (GUIDE). The prototype model was chosen to guide the development of the prototype application and, more importantly, to provide a platform for updating a system using existing knowledge. The prototype model was capable of creating synthetic CT scanner datasets, displaying a sinogram image from the synthetic datasets, constructing images using the back projection technique, and displaying cross-section images. This study yielded two kinds of images: unfiltered and blurry images and filtered and clear images. This study also concentrated on two-dimensional parallel-beam and fan-beam geometry configuration; the principle of transforming fan-beam datasets into parallel-beam datasets was implemented using the classic rebinning concept.

Keywords: Evolutionary; fan-beam; prototype; radon transform; GUIDE; sinogram; CT scanner.

1. INTRODUCTION

In the development of computerised application systems such as management information systems and decision support systems, the prototyping model approach has been widely used. This study employs a prototype model approach to create an application for computerised tomography (CT) image reconstruction. The prototype model approach is comprised of four steps of interactive processes between system developers and system users [1]. The four-step interactive processes for the prototype model approach, which has been adapted in the development of a CT image reconstruction application, are depicted in Fig. 1. The initial versions of a prototype are defined and built by system developers and later used by consumers to identify any flaws in the system. If a problem is discovered during the system implementation process, system developers must take the necessary steps to improve the existing prototype of the image reconstruction applications. Some updates in this area are available elsewhere and may find attention of the readers [2-4]. A prototype model approach can be divided into three different types according to their respective functions that are known as throw-it-away prototyping, evolutionary prototyping and incremental prototyping [5]. For example, the evolutionary prototyping approach develops a system progressively where this method has a functional version during the prototype system development. Therefore, feedback from the user can be obtained either from the current phase or the phase of prototype development through to the final product [6].

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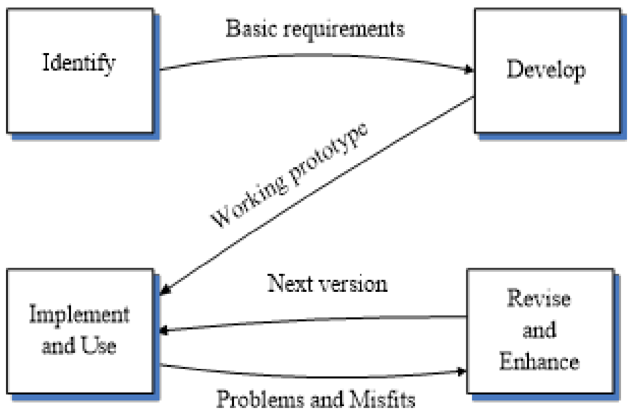

Fig. 1. The prototype model

The main benefit of using a prototype model approach compared to the traditional model of system development life cycle (SDLC) is that a written documentation of the design specification needs not to be provided by system developers. In addition, the prototype model approach has a short development period when developing an initial prototype for the user. Moreover, the development of a computerized system using the prototype model approach helps system developers obtain detailed information and requirements about the system from a user perspective and provide a better understanding regarding the users' environment. Further, user interaction with the prototype system provides the users with access and permission to deliver their responses like comments and suggestions to the system developers. These valuable responses of the user allow system developers to incorporate any necessary changes or improvements to the prototype system during the next prototype life-cycle series [7]. In this study, an evolutionary research prototype model for two-dimensional image reconstruction was developed using MATLAB applications.

2. RESEARCH METHOD

Microwave penetration in a variety of specific materials had provided light for the development of a prototype application for image reconstruction aimed at obtaining information on the internal structure of a physical object [8]. A mathematical model of computed tomography (CT) image reconstruction is defined as a quantitative explanation of radiation interaction with the particle object matter. The ability of a certain object to absorb and reduce the radiation rate is measured as the attenuation coefficient (μ) in the Beer's law, where the mean of μ corresponds to a linear integral transformation called Radon transformation [9].

The MATLAB image processing toolbox has the internal functions of the Radon transform and inverse Radon transformation that could help accelerate the development of prototype CT image reconstruction. Synthetic data acquisition through Radon transformation by MATLAB application requires source images known as the phantom image. The phantom image is the image of an object used to analyze or assess the quality of CT images. The phantom image can be classified into physical phantom to measure the real object and virtual phantom for mathematic simulation [10].

The CT can be divided into several types according to actual usages such as X-ray transmission CT, emission tomography (ET), magnetic resonance tomography (MT) and a less significant usage from ultrasound to infrared application [11]. Generally, a medical imaging system is categorized by transmission data and emission data. A transmission data places radiation sources outside a patient's body, while an emission data injects the radiation sources (isotopes) that radiate photons into the patient's bloodstream. In ET, a gamma detector rotates around the subject to count the photons that are emitted from the patient with the objective to obtain images of the anatomy's function [12]. On the other hand, the transmission data tomography is suitable for obtaining the transparency of the anatomical structure.

2.1 CT Scanner Geometry

The CT scanner is known as a diagnostic tool used to observe the internal properties of an object [13]. The basic principles and the evolution of CT scanner were explained in [14, 15]. A brief description of the evolution of CT scanner is shown in Table 1.

Table 1. The generations of CT scanner

CT scanner generation	CT scanner description
First-generation	The 1st generation of CT scanner was presented in 1972. This generation used an arrangement of linear translation and incremental rotation or merely translate-rotate scanner [14], [15].
Second-generation	The 2nd generation of CT scanner was intended to reduce the scan time taken by the previous generation and was introduced in the late 1974. This generation used multiple narrow beams from a single radiation source and multiple detectors. The scanner was called rotate-translate [14] [15]
Third-generation	The 3rd generation of CT scanner was proposed in late 1975 and remained to obtain a faster scan as compared to the previous generation. The CT scanner detectors array was linked to the X-ray tube and rotated together around the object. The arrangement was referred to as rotate-rotate movement [14], [15].
Fourth-generation	In 1976, the 4th generation of CT scanner generation was proposed. This generation integrated a large stationary ring of detectors and the X-ray tube alone rotating around the object. Therefore, this generation is able to measure rays at any distance from the centre of rotation. Further, this generation can be dynamically calibrated before it passes in the object's shadow [14].
Fifth-generation	The 5th CT scanner is referred to as a multi-slice CT scanner of a multiple-row detector array. This generation used a large ring to circle an object [15].

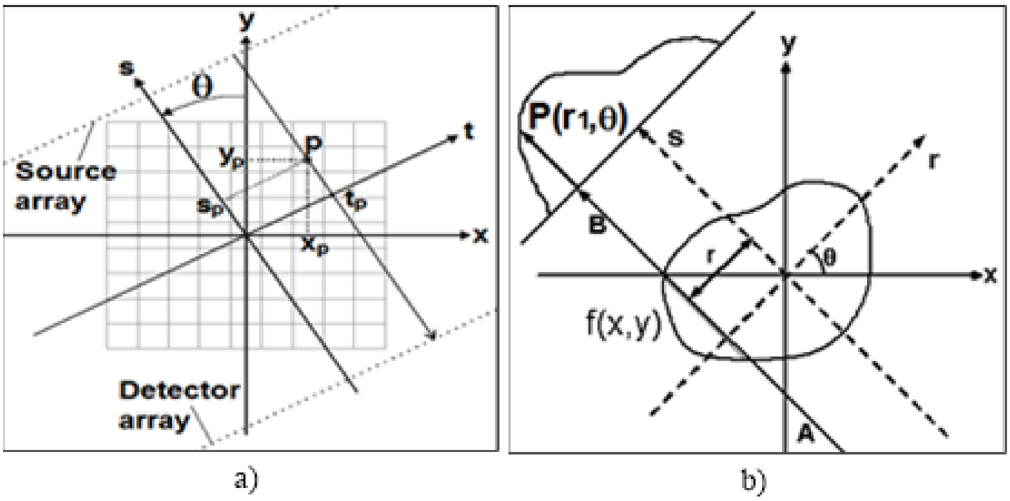

Fig. 2. The parallel-beam geometry model, a) the source-detector array b) The attenuation coefficient profile

Fig. 2(a) shows an illustration of a parallel-beam computed tomography (CT) scanning system that uses an array of equally spaced radiation sources and an array of detector elements in which the radiation energy travels through the object and is expressed by the function μ(x, y) that represents the attenuation coefficient of the radiation sources traversed along a straight line [16]. Further, Fig. 2(b) illustrates the concept of one-dimensional projection datasets of the line integrals P(r, θ), where r is the line distance that is measured from the origin of the coordinate and θ is the angle of rotation, where measurements are taken [17].

In reality, the transmission data CT of fan-beam geometry is greater than parallel-beam geometry because it is more proficient for acquiring multiple projections simultaneously at different angles. Moreover, the emission CT of the fan-beam geometry enlarges the image and escalates the sensitivity of the detection [18].

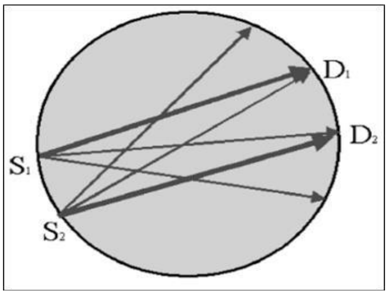

Fig. 3. A concept of the fan-beam rebinning framework

The problems of image reconstruction in respect to fan-beam geometry are solved by rebinning fan-beam geometry into parallel-beam geometry [19]. Fig. 3 shows an illustration of a conceptual fan-beam rebinning framework, where S represents a source of radiation and D represents a fan-beam detector. The parallel-beam dataset from the rebinning method can be reconstructed into a CT image using inverse Radon transformation.

2.2 Radon Transform

The Radon transform is the transformation of two-dimensional Cartesian coordinate system of a graph function f(x,y) into a two-dimensional Polar coordinate system of a distance and an angle represented by the function g(ρ,θ) [20]. This study used synthetic datasets of Radon transform to represent the datasets from the data acquisition system. The synthetic datasets are the image pixels that go through the Radon transformation. In other words, the pixels in Cartesian space of the images are transformed into the Radon space. The Radon transform of a linear integral for the function P(t, θ) satisfies an area of, where θ represents an angle of rotation and t represents a distance from the center of rotation [21]. The Radon transform can be used to turn the intensity pixels of phantom images into synthetic datasets for the computed tomography (CT) scan. The datasets from the CT scan machine is called sinogram. Thus, a sinogram can also be referred to as the Radon transform datasets.

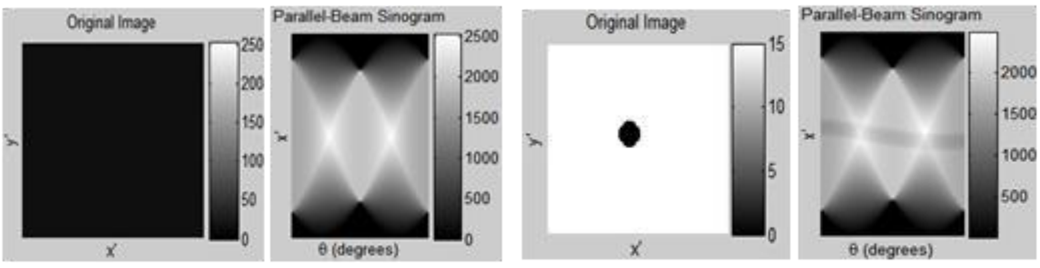

Fig. 4. The Sinograms of Parallel-Beam Projection
a) The blank image b) The sinogram of a blank image c) The dot image d) The sinogram of a dot image

Eq. 1 shows the Radon transformation function, where the integral function of f(x, y) represents the cross-sectional of the object to be reconstructed and the symbol δ is the Dirac delta function of the trigonometry that represents the rotation of the CT scanner. In the meantime, the function g(s, θ) represents the results of the liner integral function that measures the overall movement. The double integration of two-dimensional Radon transformation is considered vital for CT scanner image reconstruction research as the rearrangement of projections at various angles and directions could exemplify the actual motion of the CT scanner radiation sources and detectors [22].

$$g(s,\theta) = \iint_{-\infty}^{\infty} f(x,y)\delta(s - x\cos\theta - y\sin\theta)dxdy \quad (1)$$

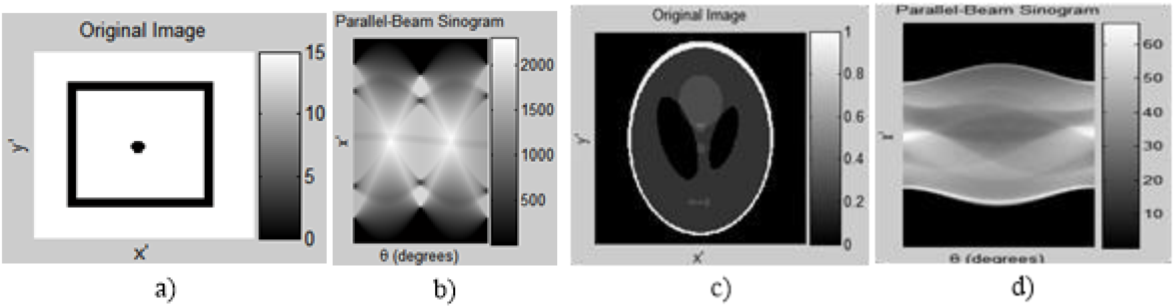

Fig. 5. The Sinograms of Parallel-Beam Projection
a) The dot and rectangle image b) The sinogram of dot and rectangle image c) The Shepp-Logan image d) The sinogram of the Shepp-Logan image

Fig. 4(a) shows a blank rectangle space without any image for control study purposes, and Fig. 4(b) shows the sinogram image of the blank rectangle in parallel-beam space. The synthetic datasets are the pixel intensity of the sinogram image in gray scale level from 0 to 255. Fig. 4(c) shows a dot image at the middle of the rectangle. Fig. 4(d) shows the sinogram image of the dot in the parallel-beam space. It is shown obviously in the sinogram space, that the dot image is transformed into a long curved line.

Fig. 5(a) shows a dot image and rectangle image. Fig. 5(b) shows the sinogram image of a dot image and the rectangle image in parallel-beam space. Furthermore, Fig. 5(c) shows the Shepp-Logan image, and Fig. 5(d) shows the sinogram of the Shepp-Logan image in parallel-beam space Fig. 6(a) shows the original Shepp-Logan image, while Fig. 6(b) shows the sinogram of the Shepp-Logan image in fan-beam space.

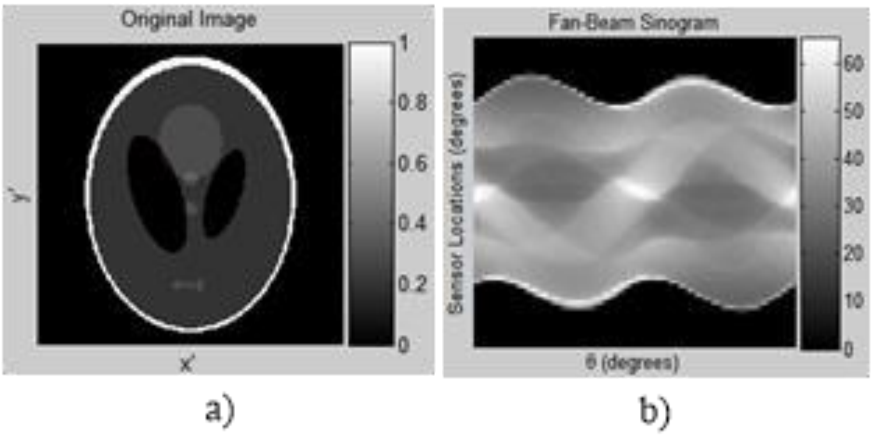

Fig. 6. The sinograms of fan-beam projection
a) The Shepp-Logan image b) The sinogram of the Shepp-Logan image

The program was written by Justin K. Romberg mainly to create synthetic datasets using MATLAB language, was viewed as an acceptable research tool to represent a physical data acquisition system in a virtual environment [23].

3. RESULTS AND ANALYSIS

The computer system platform for the development of the computed tomography (CT) prototype used Windows 7 operating system. The software application used was MATLAB version 2008a. The hardware system requirements used were Intel Core i5-2410M, CPU (2.3GHz), 4GB DDR3 RAM with 750 GB HDD.

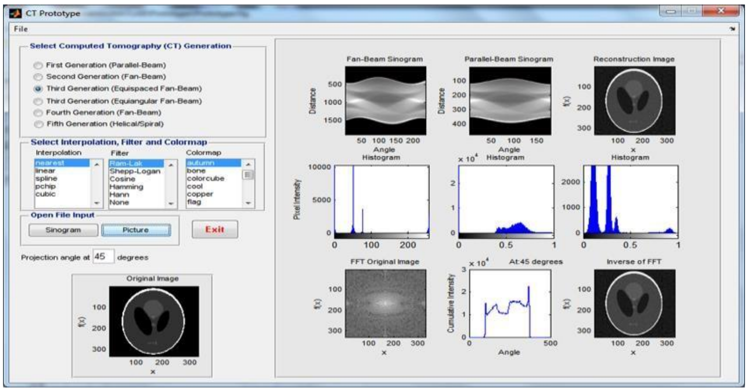

Fig. 7. The CT Prototype for Image Reconstruction

3.1 The Prototype Application

Fig. 7 shows the user interface of the computed tomography (CT) prototype application that was developed using MATLAB toolbox for the image reconstruction system. The user input was divided into four groups which are shown in Fig. 8(a), 8(b), 8(c) and 8(d). Fig. 8(a) shows the screen shoot for the selections of CT generation specifications as shown in Table 1. This selection option allows the user to experience with different generations of CT scanner evolutions. The selection option evaluated was the third generation equispaced fan-beam CT scanner. Fig. 8(b) shows the original image used to generate synthetic datasets. Fig. 8(c) shows a selection of five options for interpolation, 6 options for filter and 16 options for colour mapping. The user default values were provided from the nearest interpolation, Ram-Lak filter and autumn colormap scheme. Fig. 8(d) shows the command buttons for the user to interact with the computer program and to start the reconstruction operation.

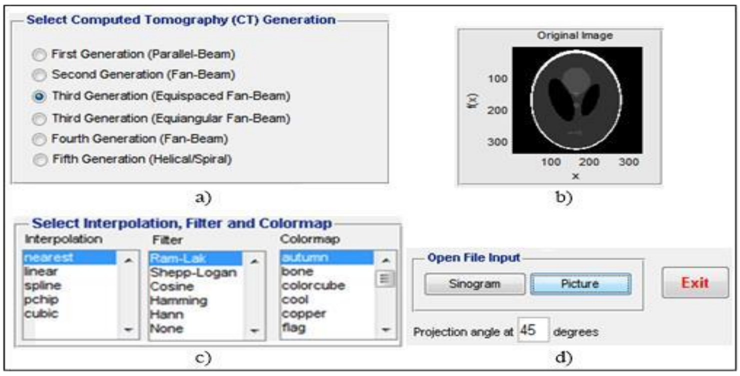

Fig. 8. The User Input for the CT Prototype
a) The user selection for CT scanner generations b) The original image c) The user selection for interpolations, the filters and the color maps d) The command button and the input angle

The prototype provides the user with two buttons to open the input file. The first button labelled as “Picture” is a function to read a graphic file and the second button labelled as “Sinogram” is a function to read a numeric file. The projection angle text box is used to provide numeric data to draw a graph at a certain degree of CT scan rotation.

Fig. 9 shows the output images from the CT prototype. The first row of images shows the fan-beam sinogram, the parallel-beam sinogram and the reconstruction image using the filtered backprojection technique, respectively. The second row of images shows the distribution of data in the histogram for each of the first row CT scanner images. Lastly, the third row shows the one-dimensional Fast Fourier Transform (FFT) of the original image, the summation intensity of a projection of 45 degrees and the two-dimensional inverse Fast Fourier Transform (IFFT) image of the FFT function, respectively. The FFT function is a one-dimensional complex number of linear transformation from the time domain to the frequency domain [24] where the output given is similar to the sinogram or synthetic datasets.

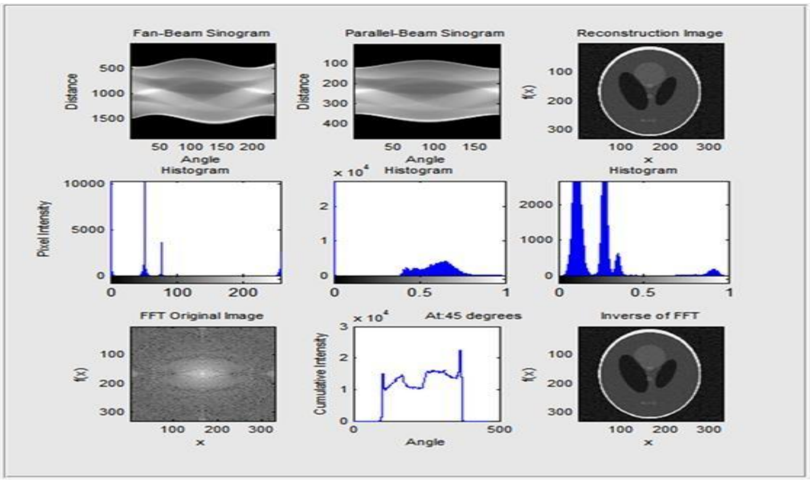

Fig. 9. The user output for the CT prototype

4. CONCLUSION

The computed tomography (CT) prototype application was developed using MATLAB program language to study the image reconstruction of CT by focusing on the construction of divergent beam and parallel beam in two-dimensional space. The prototype model of the system development life cycle (SDLC) was used to assist the development of the prototype image reconstruction application. In addition, the MATLAB application has many built-in functions, which are helpful in areas of image processing. Therefore, CT prototype was implemented using MATLAB image processing. The CT prototype application was developed based on the research methods of analytical approach for parallel beam and divergent beam CT system. Further study is recommended to lengthen the research on statistical image reconstruction methods and three-dimensional geometry space for cone beam image reconstruction.

ACKNOWLEDGEMENTS

This research was supported by the National University of Malaysia research grant HEJIM-FTSM-FKAB-MTDC-101101005 and TAP-K007341. The authors would like to acknowledge special thanks to Mohd Ikram Mohammad from the Rubber Research Institute of Malaysia (RRIM) and other colleagues rendering their technical support and assistance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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International Journal of Software Engineering and Technology (IJSET), 2(2):93~100, August 2016.