INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 17 No. 2 (2025) 30-42
https://publisher.uthm.edu.my/ojs/index.php/ijie

An Educational CT Scanner Prototype of a 3rd Generation CT Scanner

Sin Ting Lim[1]*, Yit Hein Yow[1], Way Soong Lim[1], Chee Siong Lim[1], Li Wah Thong[1]

[1] *Multimedia University, Faculty of Engineering and Technology, Jalan Ayer Keroh Lama, Melaka, 75450, MALAYSIA*

*Corresponding Author: stlim@mmu.edu.my
DOI: https://doi.org/10.30880/ijie.2025.17.02.003

Article Info

Received: 10 November 2024
Accepted: 24 June 2025
Available online: 18 July 2025

Keywords

Computed Tomography (CT), optical CT scanning, prototype, fan-beam, medical imaging, educational setting

Abstract

This project aims to develop an affordable educational prototype of a 3rd generation CT scanner. The proposed prototype uses non-radiative light sources and combines 3D printing, electronics components, and filtered backprojection (FBP) algorithm to generate the cross-section image of a transparent phantom. Key components include an LED light, an Arduino Nano controller, and a camera. The prototype can capture up to 200 images per scan cycle and successfully reconstruct the internal structures of the phantom. However, there were some limitations, including issues with the dataset, light source power, and time efficiency. Results showed that the prototype could create a 3D model of the lemon phantom, though it faced challenges due to the light source and data limitations. Educational workshops were conducted with 38 students and the user feedback survey indicates high level of satisfaction, with an average rating of 4.1 for ease-of-use, 4.5 for effectiveness, 4.47 for interactivity, and 4.6 for overall satisfaction. Additionally, all students reported enjoyment and comprehension, with a 100% positive response in both categories. These findings indicate that the prototype effectively promotes active learning and interactive experiences in STEM education. Future improvements will focus on increasing dataset resolution, using more powerful light sources like laser diodes, and upgrading the camera system for better image quality and faster processing.

1. Introduction

The evolution of the medical industry stems from the rapid advancement of medical imaging devices and monitoring systems [1-2], attributed to breakthroughs in electronics, sensors, and associated technologies. Computed Tomography (CT) is a medical imaging modality that utilizes X-rays and computer algorithms to generate cross-sectional images that allow various internal body structures to be observed by doctors [3]. The development of CT scanning began in the late 1960s and progressed through several technological stages, referred to as 1st to 5th generations, followed by spiral CT, multislice CT, dual-energy CT and the latest being the Silicon-Based Photon-Counting CT [4]. The 3rd generation is identified as the most influential architecture in the evolution of CT as it introduced a design where sufficient detectors were arranged to form a fan-shaped beam. As seen in Figure 1, the physical principles of CT include two major processes which are data acquisition, data processing and image reconstruction. Data acquisition refers to the physical collection of information from the patient. In a 3rd generation CT scanner, as the X-ray tube emits the fan-shaped beam, it rotates around the patient for 360° and data for each slice is collected at each rotation. Transmitted X-rays undergo varying degrees of absorption throughout the body according to Beer-Lambert law, leading to fluctuations in X-ray intensity collected by the detector [5]. This information is then fed for data processing and image reconstruction. The essence of this process lies in utilizing the computer algorithms that calculate differences in the linear attenuation coefficient.

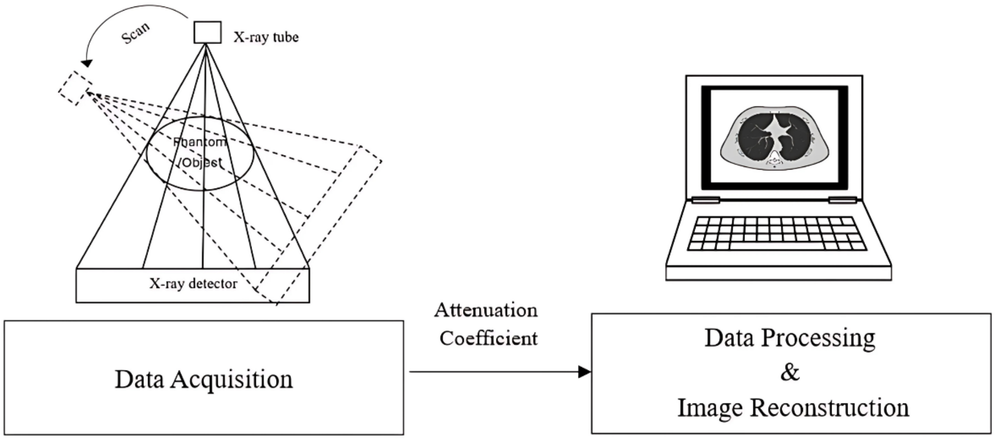


Fig. 1 *Basic principles of 3rd generation CT scanning*

The most challenging teaching concept in CT is understanding the way CT creates a cross-sectional image from a series of slices acquired at different angles [6]. The incorporation of CT scanners in teaching methodologies enhances student understanding and interest [7-8] but introducing CT to educational settings is expensive and requires trained technicians to operate since it employs ionizing radiation. Hence various CT scanner prototypes using different hardware components and in different applications [9-12] such as for gel dosimetry [13-19] and educational setting [20-22] have been introduced earlier. A commercially available educational laboratory module called DeskCAT™, utilizing a cone-beam CT geometry, is available [23]; however, its adoption in school curricula may be limited due to its relatively high cost. A recent prototype developed by Deene [24] used two light sources with different wavelengths to illustrate the principles of dual energy cone beam CT. By integrating a laser as the source and a photodiode as the detector in their prototype, Daley et al. [25] illustrated the fundamental principles of a 1st generation CT scanner. Watanabe et al. [26] developed a CT scanner intending to archive the scanned image using a femtosecond laser. In their prototype, the sample holder was not automated, and the collected images were acquired only from limited angles. Besides, the scanner failed to demonstrate the generation of a cross-sectional image without the use of the image reconstruction algorithm. Three distinctive research work on developing CT scanner prototype were compared in Table 1. While the motivation for this study is to develop a safe and economical apparatus to demonstrate the full principles of a 3rd generation CT scanner, relatively inexpensive, readily available off-the-shelve components, and 3D printing components were used in the proposed design.

Table 1 *Comparison between related work*

Features	Sadrozinski et al. [32]	Campbell et al. [13]	Deene [24]
Primary Purpose	Radiation therapy planning	3D radiation dosimetry	Demonstration for CT and SPECT concepts
Radiation Source	Proton beams	Laser diode (635 nm)	Visible light (tri-color LED)
Detector Type	Silicon telescopes and energy detectors	CCD camera mounted on a collimator	Charge-Coupled Device (CCD) camera
Imaging Technique	Proton CT (pCT)	Fan-beam CT scanning	Cone-beam CT scanning
Materials /Phantoms Used	Human head phantom	Polymer gel dosimeters	Silicone humanoid with 3D printed skeleton
Image Reconstruction	Iterative algorithms	Sinogram filtering	Custom software in Matlab
Safety Features	Non-ionizing protons	Non-ionizing, laser-based system	Non-ionizing radiation
Educational Component	Aimed at medical professionals for clinical application	Focused on accuracy in dosimetry for radiation therapy	Hands-on learning for students
Limitations/Challenges	Complexity of proton interactions; high setup cost	Precision in positioning and artifacts management	Attenuation discrepancies, imaging artifacts

2. Methodology

In a CT scanner, the differences in the X-ray linear attenuation coefficient fundamentally stem from the beer-lambert law below:

$$I_d = I_o e^{-\mu x} \tag{1}$$

where I_d is the intensity of the incident X-ray beam, I_o is the X-ray intensity at a distance *x* from the source, and μ is the linear attenuation coefficient of tissue. The higher the density of the tissues, the higher the absorption rate of the X-ray photon hence the higher the linear attenuation coefficient of the tissues. For instance, $\mu_{bone} > \mu_{blood}$. However, in a CT scanner prototype, an LED light source is used instead of X-rays. The emitted light passes through a translucent phantom, and the variations in material absorption are captured by a camera. Table 2 below compares a 3rd generation CT scanner with the proposed CT prototype. This table will also be used to demonstrate the similarities and differences between the two systems and the principles of CT scanning.

Table 2 *Comparison between 3rd generation CT scanner and its proposed prototype*

Components	CT scanner	CT scanner prototype
X-ray source	X-ray tube	LED light source
Detector	X-ray detectors	Camera
Beam geometry	Fan beam	Light Fan beam
Source-detector movement	Rotate at the same time	Stationary
Rotating gantry	Mechanical gantry houses X-ray tube and X-ray detectors	Rotating platform that houses the phantom
Patient table	Patient table moves with each scan	Phantom is house at the rotating platform
Beam filtering	Lead or Aluminum	Not required
Image reconstruction algorithm	Fourier slice theorem or filtered backprojection (FBP)	Image-based filtered backprojection (FBP)

2.1 Data Acquisition

Hardware components are essential for the CT scanner prototype to facilitate the data acquisition process Figure 2 illustrates the hardware configuration of the proposed system. In this study, a lightbox, equipped with appropriate front lights and backlights, is set up to establish a stable lighting environment during the data acquisition process. Additionally, a scanning stage for the targeted object or phantom is necessary, and the stage must have the ability to rotate the object at a constant angle to demonstrate the working principles of 3rd generation CT scanner. The camera system needs to be attached to the lightbox to carry out image acquisition. Figure 2 illustrates the hardware configuration of the proposed system.

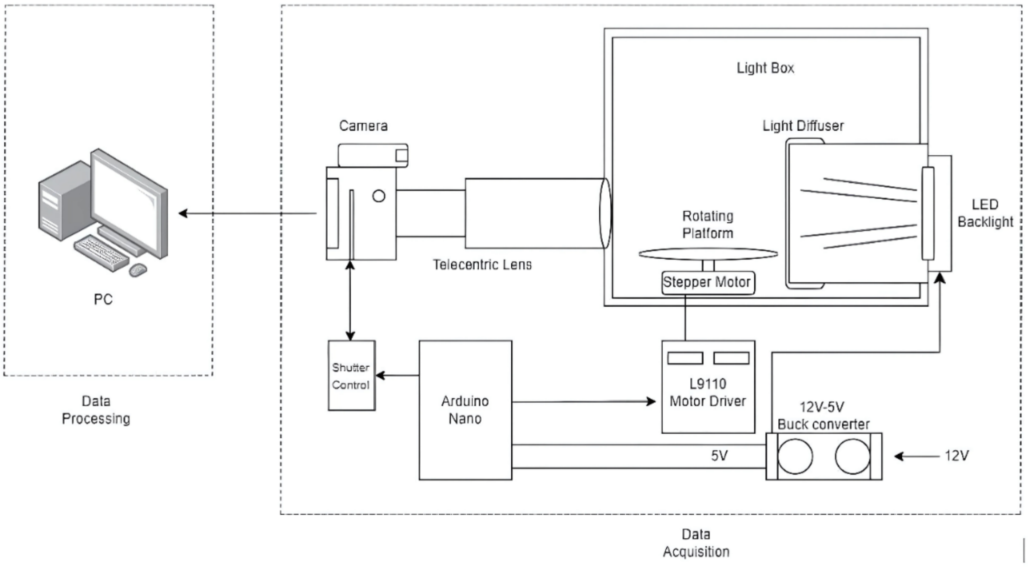


Fig. 2 *CT scanner prototype configuration*

The system is powered by a 12V DC voltage, which is then reduced to 5V DC by a buck converter. This 5V DC supply powers the Arduino Nano, the L9110 motor driver, and the LED backlight. The Arduino Nano serves as the central processing unit of the entire system. It controls the stepper motor via the H-bridge L9110 motor driver and manages the camera system through an external shutter control. To initiate the data acquisition process, a transparent phantom is to be placed on the rotating platform. The LED backlight is designed to simulate lighting conditions analogous to X-ray imaging [27] and it emits light in the range of 510 to 560 nm. Given that the 17HS08-1004S stepper motor has a step angle of 1.8 degrees equating to 200 steps per revolution, the microcontroller unit instructs the camera system to capture an image of the object at each step, resulting in a total of 200 images per revolution.

Figure 3 presents the schematic diagram for the CT scanner prototype. The 1602A LCD module is specifically connected to the Arduino Nano's pins D2, D3, D4, D5, D6, and D12. For communication, the Arduino sends instructions to the motor driver via pins D8, D9, D10, and D11. Additionally, the focus pin and shutter pin of the shutter control are connected to pins D13 and A2, respectively. Two potentiometers are incorporated into the system; one controls the brightness of the LCD at pin 3 of the LCD module, and the other adjusts the number of images to be captured, connecting to pin 19 of the Arduino Nano. Once the schematic design is thoroughly tested on the breadboard configuration, it is then transferred to a universal double-sided PCB prototyping board. The firmware for the data acquisition process is developed through Arduino IDE.

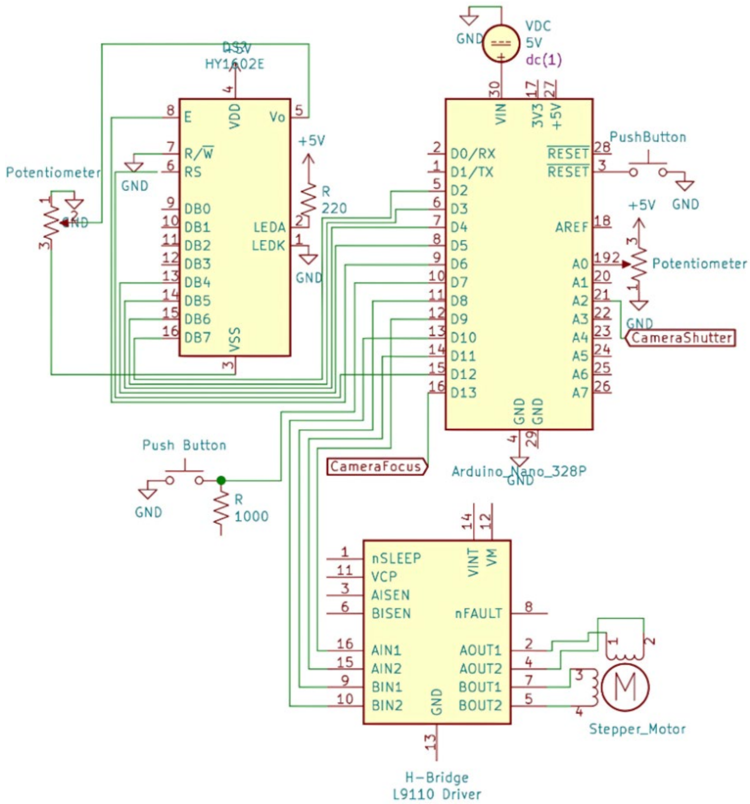


Fig. 3 *Schematic diagram*

The hardware layout was built from scratch in this study. The camera system is mounted on a camera mount built with PVC. ½-inch diameter PVC pipes are cut to the desired length and connected using PVC T-joints. The camera mounting base is customized with a 2.5-inch bolt, threaded through the PVC T-joint. The lightbox for this prototype is constructed from plywood, chosen for its lightweight advantage. The plywood is cut to the desired size, and the centre point is precisely aligned. Ensuring the centre point is accurately located is crucial for the study, as any misalignment of the scanned object will directly affect the 3D result. Holes for the camera lens and backlight are drilled in alignment with this centre point. The material utilized for the interface panel is a 0.6 mm steel plate. The components to be incorporated into the interface panel consist of the 1602A LCD module, which is responsible for displaying information about the prototype. Additionally, two potentiometers are included to manage the brightness of the LCD module and the quantity of images to be captured.

Two momentary Normally opened (NO) press buttons are integrated to oversee the "Enter" and "Reset" functions. Moreover, the panel features a power switch and a 12V socket. To minimize cost in this study, PVC camera mount joint, stepper motor mount, flat motor stage, pivot point motor stage and cable mount are produced using 3D printing. Each part needs to be precisely measured to ensure a perfect fit within the configuration. The 3D designs for the components are shown in Figure 4.

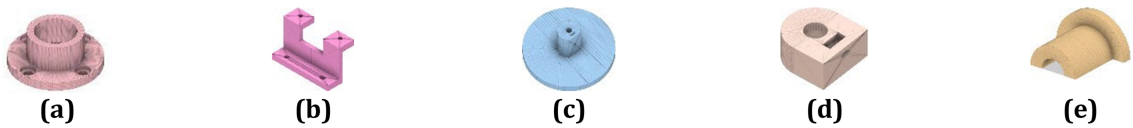


Fig. 4 *3D designs for (a) PVC camera mount joint; (b) Stepper motor mount; (c) Flat motor stage; (d) Pivot point motor stage; (e) Cable mount*

2.2 Image Reconstruction

Filtered backprojection (FBP) is the most fundamental technique used to reconstruct cross-sectional images in a CT scanner. There are several advanced computer algorithms available in tomographic reconstruction for fan beam or cone beam geometry such as the software packages documented in [28-29]. The ASTRA Toolbox is a MATLAB and Python toolbox of high-performance GPU specifically for 2D and 3D tomography [30]. Since this study is to demonstrate the basic principles of CT scanners using light sources instead of X-rays, such complexity is not needed to yield the desirable results and a simple FBP algorithm involving sinograms and Radon Transform were utilized.

Radon Transform is the projection of the image intensity along a line collected at various angels and a sinogram is a graphical representation of the Radon Transform of the scanned object $f(x, y)$ and they contain the intensity profiles from 0 to π angles [31]. In essence, FBP involves summing all backprojected profiles obtained from various angles in the sinogram. For each angle profile in a sinogram, the data are "smeared" to obtain a backprojected image. These backprojected images are then added on top of each other to form the desired cross-sectional image. In the proposed method, the acquired data is processed using the toolboxes in MATLAB, where designated libraries are employed to reconstruct the image. As seen in Figure 5, the process begins with the initialization of variables and the setting up of directories. The number of images to be processed is set as *N*, and the input and output directories are defined. A loop iterates through the images in the specified directory, conducting grayscale conversion and inversion for each image. Processed images are stored in a 3D array, *Z*, with each slice representing an image frame. A scan video is then generated by the code, showcasing the sequence of images as a continuous scan. Subsequently, sinograms are produced by reshaping and transposing the image data in *Z* for each row.

The code proceeds with the application of the inverse Radon transform to the sinograms, leading to the reconstruction of original cross-sectional slices stored in the FBP array. The display of individual cross-sections provides a visual representation of the internal structure of the scanned object slice by slice. In the final step, 3D reconstruction occurs, involving downsampling and interpolation of data in FBP to create a 3D volume. Utilizing the vol3d function, the obtained volume is visualized, allowing interactive visualization of the reconstructed object in three dimensions.

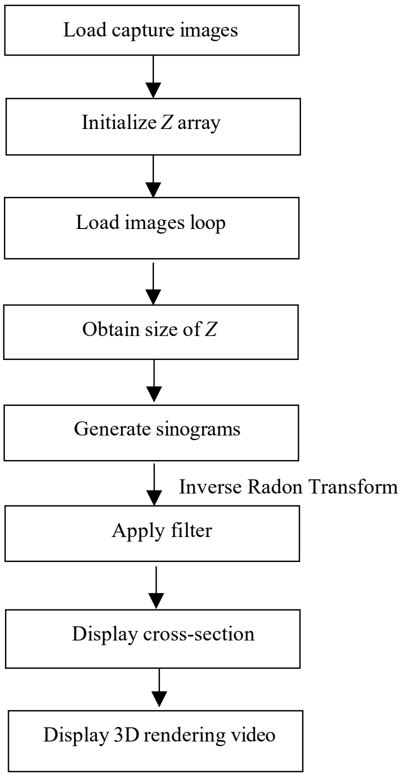


Fig. 5 *Flowchart of data processing and image reconstruction*

3. Results and Discussions

Figure 6 displays the printed components using 3D printing and Figure 7 shows the final outlooks of the CT scanner prototype. The phantom used in this experiment is a slice of lemon because light can only travel through transparent or semi-transparent objects. The complete scanning cycle requires approximately 15 minutes on a laptop with Intel Core i7 2.6 GHz CPU and 32 GB 3200 MHz RAM.

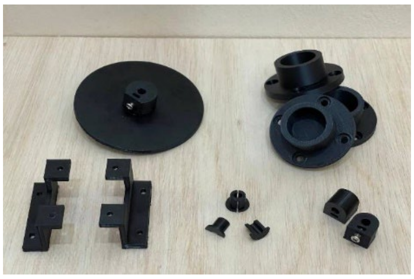
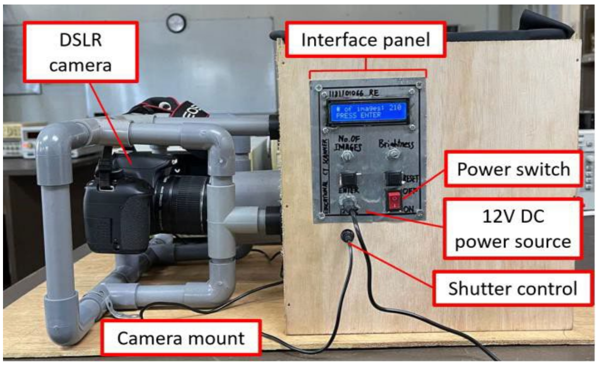


Fig. 6 *Printed components*



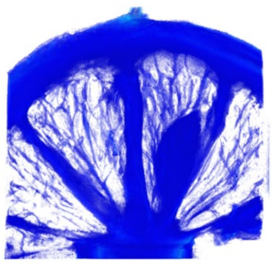
(a)

(b)

Fig. 7 *Prototype outcome (a) Side view; (b) Front view*

Figure 8(a) and Figure 8(b) show a comparative analysis between the original image and its processed counterpart from the scan. In the initial image, it is challenging to visualize the shape of the seed hidden within the lemon's membrane. However, in the processed image, the seed's shape becomes more apparent and easily identifiable. However, the processed image significantly enhances visibility, clearly revealing the seed's shape nestled within the membrane. Additionally, the intricate pattern of the membrane fibers is distinctly observable. This lemon slice analogy can be extended to human anatomy, where the membrane pattern or fibers metaphorically represent blood vessels, and the seed symbolizes internal organs. This CT scanning methodology allows specialists to examine a patient's body health in greater detail, leading to more precise and accurate diagnosis.

(a)



(b)

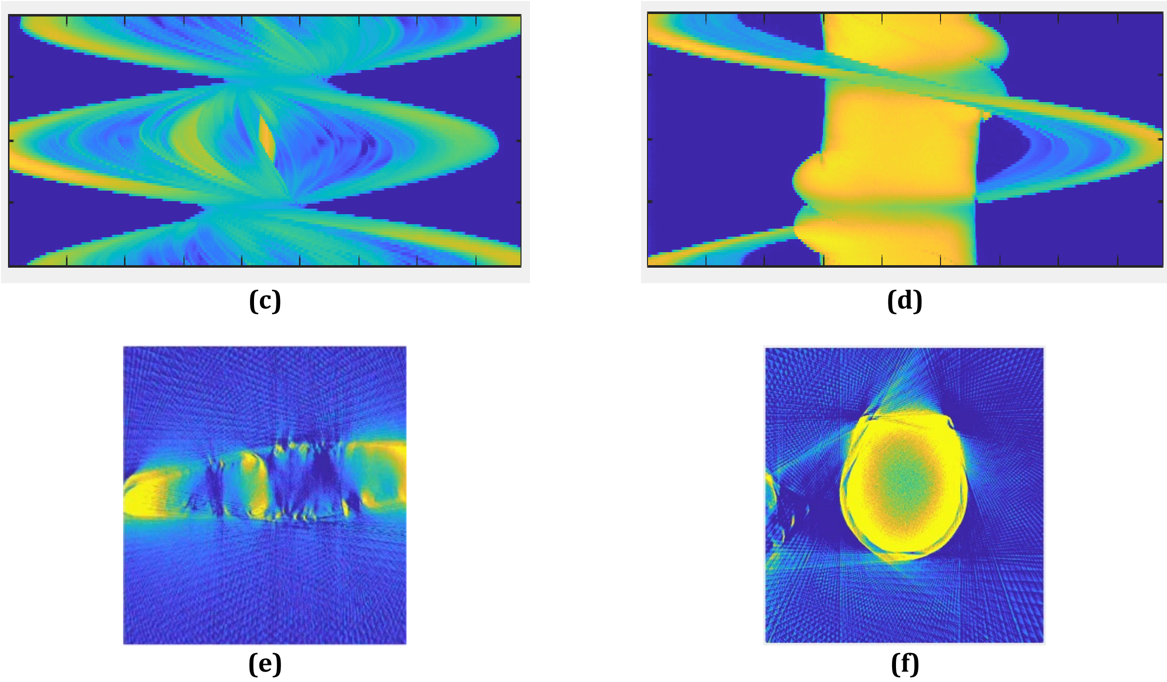


Fig. 8 *The generated images (a) Phantom image captured by the camera at angle 0°; (b) Top view of the scanned image; (c) Sinogram of the middle part; (d) Sinogram of the bottom part; (e) Cross-sectional of the middle part; (f) Cross-sectional of the bottom part*

Figure 8(c) and Figure 8(d) show the sinogram representation of the middle and bottom part of the scan respectively. Throughout the 360-degree rotation following the principles of the 3rd generation CT scanner, 200 images are taken at 1.8-degree intervals. Each image, representing a projection of the lemon slice from a specific angle, varies in X-ray intensity according to the density of the object. These projections are then arrayed side by side to form the sinogram, where each horizontal line correlates with a distinct angle of projection. The sinogram effectively displays the sinusoidal patterns formed by denser areas within the lemon slice, showcasing its internal structure. The level of detail in the results is directly influenced by the number of lemon images taken per cycle. Figure 8(e) and Figure 8(f) show cross-sectional views of the middle and bottom segments of the lemon slice obtained through the scanning process.

Figure 9 shows the 3D representation of the scanned phantom from multiple angles captured from the reconstructed video. Initially, the individual 2D cross-sectional images of the lemon slice are compiled into a 3D array, aligning them to accurately represent the internal structures of the object. To enhance the visualization, adjustments can be made to parameters such as opacity, colour mapping, and lighting and allow users to rotate, zoom, and slice through the 3D model, facilitating a detailed examination of different aspects of the lemon slice's internal composition. Once the desired visualization is achieved, the resulting 3D model can be exported from MATLAB for further utilization, providing a valuable tool for educational purposes, research, and applications in fields such as medical imaging and material science.

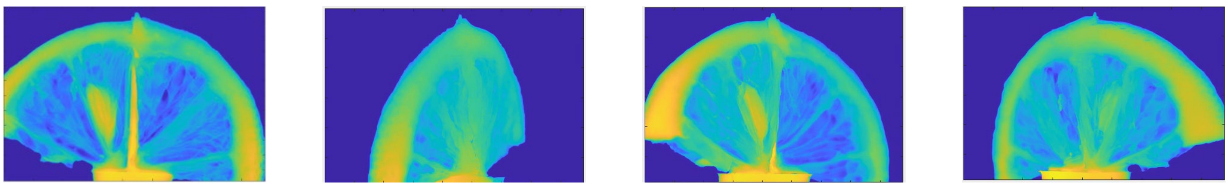


Fig. 9 *3D representation of the scanned phantom from multiple angles*

Three workshops were conducted for three groups of students from secondary school to university with diverse educational backgrounds. The session began with an informative presentation and a thorough overview of CT scanner fundamentals before proceeding to the prototype demonstration. In total, 38 students took part in the workshop, where they were introduced to an educational CT scanning prototype and engaged in hands-on activities aimed at deepening their understanding of the operational principles behind CT scanners. Out of the 38 participants, 13 students are undergraduate university students while 25 of them are secondary school students. Figure 10 shows the active participation of the secondary students in the workshop.

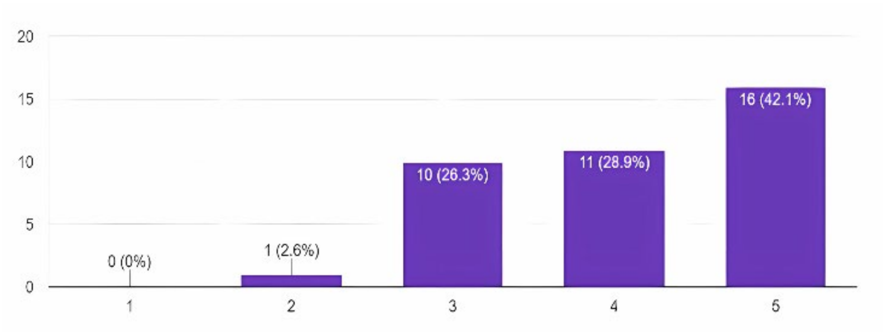
(a) **(b)**

Fig. 10 *Workshops were conducted to demonstrate the effectiveness of the proposed educational CT prototype for (a) Secondary school students; and (b) Undergraduate university students*

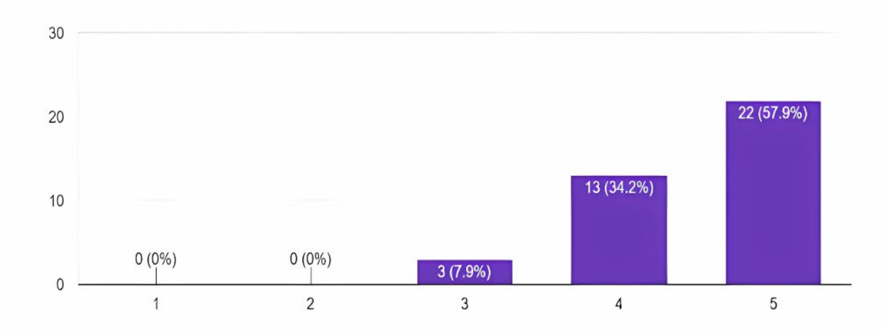
To evaluate the effectiveness of the workshop, a feedback survey with six questions was conducted using Google Forms at the conclusion. The survey included a 1 to 5 scale, where 1 represented 'very negative' and 5 'very positive,' for questions 1, 2, 3, and 4. Questions 5 and 6 used a yes/no format. This survey served as a benchmark to assess whether the CT scanner prototype achieved its intended objectives. The questionnaire includes the following items:

1. How easy or difficult was it to use the CT scanner prototype?
2. How effective was the prototype in helping you to understand the concept of CT scanning?
3. How interactive is the CT scanner prototype?
4. How would you rate your overall satisfaction with the learning experience?
5. Did you enjoy using the CT scanner prototype?
6. Do you understand the concept of a 3rd generation CT scanner after using the prototype?"

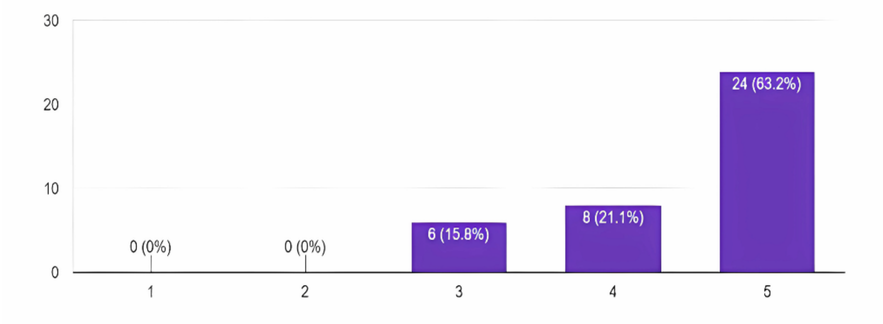
Figure 11 presents a graphical representation of the questionnaire results for each item. The data shows that 71% of the students rated the ease of use of the CT scanner prototype with a 4 or 5. When asked about the effectiveness of the prototype in helping them understand the CT concept, 92.1% of students rated it 4 or 5. Additionally, 84.3% of students believed the CT scanner prototype was interactive, and 92.1% reported being satisfied or very satisfied with the learning experience. Notably, all students enjoyed using the prototype and felt confident in their understanding of the 3rd generation CT scanner after using it.



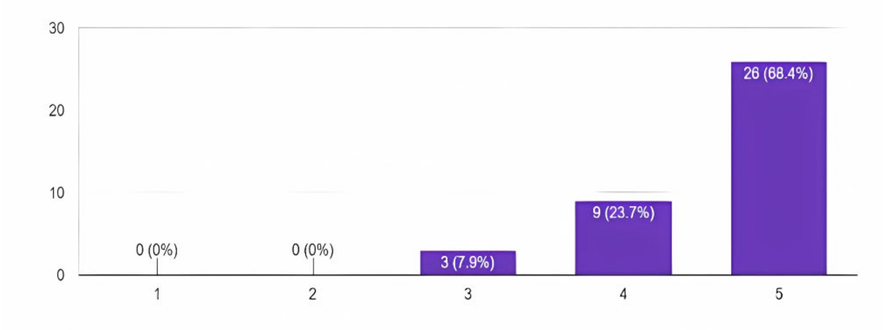
(a)



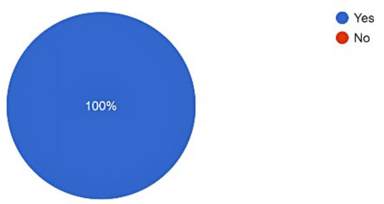
(b)



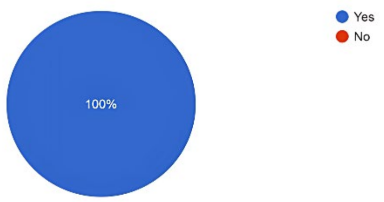
(c)



(d)



(e)



(f)

Fig. 11 *The questionnaire results on (a) Ease-of-use; (b) Effectiveness; (c) Interactivity; (d) Overall satisfaction; (e) Student enjoyment; (f) Student comprehension*

Table 3 summarized the average rating for all items. The average rating for each feedback item surpasses 4.0. This indicates a positive response to the educational CT scanning prototype, suggesting its effectiveness in enhancing students' comprehension of 3rd generation CT scanning geometry.

Table 3 *Students' feedback*

Item	Evaluation criteria	Average Ratings
1	Ease-of-use	4.1
2	Effectiveness	4.5
3	Interactivity	4.47
4	Overall satisfaction	4.6
5	Student enjoyment	100% Yes
6	Student comprehension	100% Yes

4. Conclusion

The educational objectives of designing and building a CT scanner prototype based on 3rd generation CT scanning geometry were successfully achieved and the generated images demonstrated the details of the internal structures of the phantom. Feedback evaluation also shows that hands-on demonstration makes traditionally challenging and abstract concepts such as X-ray attenuation and the backprojection algorithm more accessible with a cost-effective device. The educational CT prototype provides a safe and engaging demonstration of the underlying concepts in CT scanners and showcases the basic electronics implementation for engineering courses or STEM programs without the need for expensive specialized equipment and mitigating the risks associated with ionizing radiation. It is hoped that students will develop a heightened awareness and interest in the practical implications of engineering coursework within the medical industry. However, the developed prototype faced certain limitations. Limited to a maximum of 200 images per scanning cycle, which encompassed a complete 360-degree view of an object, the dataset was not comprehensive enough to capture more detailed structures of the scanned object. This constraint in the number of images may result in an incomplete representation, hindering the ability to achieve a higher resolution and more intricate detail in the final scans.

The dependence on LED lights, while safe and appropriate for an educational setting, restricted the clarity and the range of objects suitable for scanning due to their lower penetration power. Consequently, the prototype was limited to scanning only transparent or semi-transparent objects. The scanning speed can impede the efficiency of the CT scanner prototype, especially in a classroom setting where quick demonstrations are often preferred. Hence, the speed of the existing stepper motor can be increased or replaced with a faster motor. However, implementing these changes could incur additional costs to the current project and may not be feasible during the development of the project.

Acknowledgement

This work is supported by the Faculty of Engineering and Technology, Multimedia University under the FYP fund.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

References

[1] S. N. Tang et al. "FDOCT imaging processor for portable OCT systems with high imaging rate", *IEICE Electron. Express* 15 (2018) 20171128 DOI: 10.1587/elex.15.20171128

[2] L. Liu et al. "Automatic throat swab collection system" *IEICE Electron. Express* 21 (2014) 20230510 DOI:10.1587/elex.20.20230510

[3] J. Hsieh, Computed Tomography: Principles, Design, Artifacts, and Recent Advances, SPIE Press, Bellingham, 2003.

[4] H. Almqvist et al. "Initial clinical images from a second-generation prototype silicon-based photon-counting computed tomography system."*Acad. Radiol*. 31, (2024) 572 DOI: 10.1016/j.acra.2023.06.031.

[5] N. Hashem et al. "Design of a computed tomography automation architecture." *Appl. Sci*. 11, (2021) 2858 DOI:10.3390/app11062858.

[6] O. Taubmann, *et al*.: “Computed tomography” In: Medical Imaging Systems: An Introductory Guide (Internet), A. Maier et al. (Springer, 2018) 147-189.

[7] D. C. González, *et al*.: “The use of computed tomography as a teaching resource for the teaching of structural concrete in the degree of civil engineering,” *Educ. Sci.* (2021) DOI:10.3390/educsci11120768/

[8] W. Christensen *et al*. “Developing and assessing curriculum on the physics of medical instruments,” *CBE Life Sci. Educ.* 12, (2013) 250 DOI:10.1187/cbe.12-09-0142.

[9] M. Toida *et al*: "The first demonstration of laser computed tomography achieved by coherent detection imaging method for biomedical applications" *IEICE Trans. Electron* E74-C (1991) 1692.

[10] H. M. Thomas, *et al*.: “Three-dimensional image reconstruction for CCD camera based optical computed tomography scanner,” *IEEE Nucl. Sci. Symp. Conf. Rec*., (2007) 2965 DOI:10.1109/NSSMIC.2007.4436756.

[11] E. Mylott, *et al*.: “An easily assembled laboratory exercise in computed tomography,” *Eur. J. Phys* (2011) 1227 DOI: 10.1088/0143-0807/32/5/010.

[12] S. Rode *et al*.: "Design and Fabrication of a 3-D scanning system using Optical Computed Tomography and Photogrammetry", *International Conference on Nascent Technologies in Engineering (ICNTE)*, (2021) DOI: 10.1109/ICNTE51185.2021.9487696.

[13] W. G. Campbell *et al*.: “A prototype fan-beam optical CT scanner for 3D dosimetry,” *Med. Phys.* (2013) DOI: 10.1118/1.4805111.

[14] R. P. Johnson *et al*.: “Results from a prototype proton-CT head scanner,” *Phys. Procedia* (2017) 209 DOI: 10.1016/j.phpro.2017.09.060.

[15] J. G. Wolodzko *et al*.: “CCD imaging for optical tomography of gel radiation dosimeters” *Med Physics*. 26 (1999) 2508 DOI:10.1118/1.598772.

[16] M. Oldham *et al*.: "Optical-CT gel-dosimetry I: basic investigations", *Med Phys*. 30 2(2003) 623 DOI: 10.1118/1.1559835.

[17] S. J. Doran, "The history and principles of optical computed tomography for scanning 3-D radiation dosimeters: 2008 update", *J. Phys.: Conf. Ser*. 164 (2009) 012020 DOI:10.1088/1742-6596/164/1/012020.

[18] T. Olding *et al*.: "Cone beam optical computed tomography for gel dosimetry I: scanner characterization", *Phys Med Biol*. 55 (2010) 2819 DOI: 10.1088/0031-9155/55/10/003.

[19] B. P. Ravindran *et al*."A simple optical cone beam CT set-up for gel `readout'", *J. Phys.: Conf. Ser*. 3 (2004) 268 DOI:10.1088/1742-6596/3/1/044.

[20] O. Ennemoser, *et al*.: “Computerised tomography (CT) in education: a demonstration experiment for students,” *Eur. J. Phys* (1986) 88 DOI: 10.1088/0143-0807/7/2/002.

[21] J. M. Fagerstrom: "Computed tomography, sinograms, and image reconstruction in the classroom" *Phys. Educ*. (2020) DOI: 10.1088/1361-6552/ab753c.

[22] I. G. Darvey, "A simple inexpensive procedure for illustrating some principles of tomography," *Phys. Teach*. 51, (2013) 298 DOI:10.1119/1.1488640.

[23] Modus Medical Device, “DeskCAT™ Optical CT scanner for biophysics education”, retrieved from https://modusqa.com/products/deskcat-optical-ct-scanner-for-biophysics-education/.

[24] Y. D. Deene: “Optical CT scanning for experimental demonstration of medical x-ray CT and SPECT,” *Eur. J. Phys* (2019) DOI:10.1088/1361-6404/aaf94c.

[25] V. Daley *et al*.: "Index matching computerized tomography" *Am. J. Phys*. (2021) 220 DOI:10.1119/10.000).

[26] T. Watanabe *et al*. "A digital-data-preservation system featuring LED-light computer tomography", *IEICE Electron. Express* 6 (2009) 1569 DOI:10.1587/elex.6.1569.

[27] O. Zietz *et al*.: "Infrared radiography: Modeling X-ray imaging without harmful radiation," *Phys. Teach*. 53 (2015) 46 DOI:0.1119/1.4928355).

[28] A. Kostenko *et al*.: "Prototyping X-ray tomographic reconstruction pipelines with FleXbox", SoftwareX, (2020) DOI: 10.1016/j.softx.2019.100364

[29] Livermore tomography tools for image reconstruction, https://nci.llnl.gov/content/assets/docs/ChampleyALSmeeting.pdf. [Accessed 01 Nov 2023].

[30] W. V. Aarle *et al*.: "Fast and flexible X-ray tomography using the ASTRA toolbox," *Opt. Express* 24, (2016) 25129 DOI:10.1364/OE.24.025129.

[31] M. J. Willemink and P. B, Noël: "The evolution of image reconstruction for CT-from filtered back projection to artificial intelligence", *Eur Radiol*. (2019) 2185 DOI: 10.1007/s00330-018-5810-7.

[32] H. F. W. Sadrozinski *et al.*, “Development of a head scanner for proton CT,” in *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, (2013) 205 DOI: 10.1016/j.nima.2012.04.029.