Evolution and recent progress of Computed Tomography Scan (CT- Scan)

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Abstract

The CT Scan (Computed Tomography) has been an integral instrument for the medical field to observe and diagnose patients. Throughout time, the CT scan has been developed over generations; from the first and up to the seventh generation. These developments were to ensure a shorter duration of scan-time (from 25 minutes down to a matter of a few seconds), higher resolution of imaging with low levels of noise, simple and quick to calibrate, and reduce the radiation dosage on the patients. One key development of the CT scan is the invention of multi-slice. This generates clearer images with better resolution compared to the previous generations. The CT scan is still developing as a technology, and looking towards the future, more compact designs of the CT scanner are being developed and the design is being streamlined to allow automation of the process.

Keywords: CT Scan; Report; Liaison Journal of Engineering; International University Liaison Indonesia

1. INTRODUCTION

A diagnostic imaging process called computed tomography scanning (CT scanning) creates non-invasive cross-sectional images of the body using X-Rays for medical examination. Hounsfield was the first to introduce CT scanning. The first CT Scanner was developed by Godfrey Hounsfield, a British engineer with EMI Laboratories, alongside with Dr, Allan Cormack, and was marketed towards the public in 1972. Later, the 1979 Nobel Prize in Physiology and Medicine was shared amongst the two researchers. Hounsfield received a knighthood in 1981 and took the name, Sir Godfrey Hounsfield (Imaging, 2022). Although, the technology was first developed using Johann Radon's "Radon transform" mathematical theory, which was published in 1917. In Radon's description of a method for taking two-dimensional projections through a three-dimensional object and fully recreating it in space (Beatty, 2021).

The value of CT has been apparent ever since it was first introduced. CT Scanners are beneficial diagnostic devices to detect conditions that regular X-Rays unable to. Nearly every region of the body may be seen using a CT scan, which is also used to plan medical, surgical, or radiation treatments as well as detect diseases and injuries. Reasons for CT scan examination are usually for evaluating spinal fractures, chronic back pain, certain types of cancer, heart diseases, blood clots, and, bowel disorder.

Contrary to other radiography devices, CT Scanner can provide a clear image of the scanning result, making the diagnosis more precise than a regular X-Ray. The intensity of CT Scanner's radiation is lower than the regular X-Ray devices. In conclusion, the evolution of CT Scanners is impactful to the medical world with faster scan time, accurate pictures, and lower radiation spread.

2.1. Basic Principle of CT scan

"The interior structure of an item may be reconstructed from various projections of the object" is the basic principle of CT (Botz & Shetty, 2014). A thin cross section of the body is scanned with a focused X-Ray beam to create the ray projections, which are then measured using a sensitive radiation detector. Systematic data projections are collected and represented by CT scanning (T. Goyal, 2018).

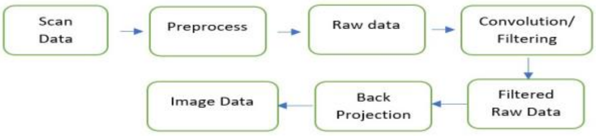

Figure 1. Data Processing of CT Scan (T. Goyal, 2018).

The CT Scanner's core principle consists of a source of X-Rays that are intended to pass through the body and be detected by detectors. Data collection, picture reconstruction, and image display are the three essential components of image processing. Data is obtained when an X-Ray beam travels through a patient and lands on a detector. During this stage of picture development, the gantry and patient table are the main elements utilized (Harmonay, 2021). The following components make up the CT scanning equipment: the generator, shielding components, photon detectors, the scanning unit (gantry), the medical desk, the imaging device, the console.

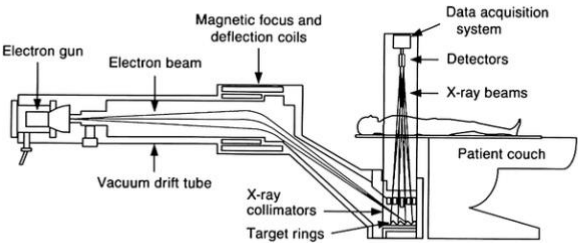

Figure 2. Electron Beam Tomography (Rutt, B., 1987)

Many of the parts required to generate and detect X-Rays are housed in the gantry, which is the ring-shaped portion of the CT Scanner. A variety of patients and examination regimens can be accommodated by tilting the gantry forward or backward as necessary. The gantry structure may revolve constantly thanks to slip rings. This avoids the need to straighten twisted system cables. The generator supplies the two different types of electrical current required to produce X-Rays. The highest intensity of the X-Rays that can be produced depends on the availability of a high voltage (20–150 Kilovolt) supply. Moving electrons, or electrical current, are transformed into X-Ray-like photons in the X-Ray tube by virtue of their energetic characteristics (wavelength and amplitude). A cathode assembly, an anode assembly, and a rotor are the three main components of an X-Ray tube. These components are all housed inside a tube envelope and together they make up a structure known as the tube insert. The vacuum created by the evacuation of all gas atoms from the interior of the tube envelope (Hermena & Young, 2022).

2.2. Application of CT Scanner

In a real case example, a 9-year-old male was presented to the Emergency Room with two days of non-bloody, non-bilious emesis and one day of abdominal distention. Radiographs were obtained on presentation and resulted in these pictures (see Figure 1 and 2). Based on the CT scan results, it was diagnosed that the boy had Large-bowel obstruction. Large-bowel obstruction (LBO) is much less common than small-bowel obstruction but is considered an abdominal emergency (Hamouda et al., 2018).

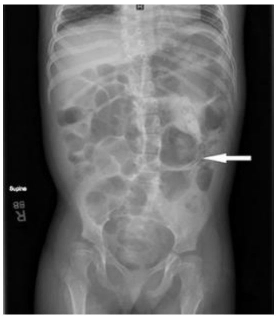

Figure 1. Supine radiograph shows central dilated loops of bowel with decompressed small bowel and distal colon, as well as pneumatosis intestinalis (arrow) (Hamouda, N. et al., 2018)

Figure 2. Decubitus radiograph demonstrates air-fluid levels in the colon (arrow (Hamouda, N. et al., 2018)).

2.3. Generation of CT Scanners

There are seven generations of CT Scanners in which higher generation number does not mean a higher performance system. The generation of CT Scanners are defined by the order of CT Scanner design that has been introduced. The classification of computed tomography is based on the arrangement of components and mechanical motion required to collect data.

The first-generation CT Scanner only measures one pencil beam at a time, rotates one degree, and then passes past the patient once more. This process is continued until the scanner has spun 180 degrees. The image is entirely recreated in this way. Due to patient movement, the resulting image is of poor quality, and it also took longer to acquire the data than expected—at least 4.5 to 5.5 minutes were required to obtain a slice's full scan (Richard, 2022). This kindled the creation of the second generation of scanners, which trace a semicircular path while scanning and modify the arrangement of the X-Ray source from a single pencil beam to numerous pencil beams. Additionally, there are more detectors on the patient's opposite side than just one. A shorter scan time is produced by the X-Ray tube's higher spin and the addition of more detectors (20 seconds-3.5 minutes) (Robb, 1982).

The third-generation scanner is one of the most widely used scanner models. A high number of detectors are placed on an arc that is centered on the X-Ray source, which has a fan-shaped beam arrangement to send more X-Rays to the patient. The X-Ray tube revolves constantly around the patient for 360 degrees while the X-Ray source and detector stay fixed; this eliminates linear motion and shortens the data acquisition time because there is no longer any translation but only rotation. In the fourth-generation CT Scanner, an X-Ray beam in the shape of a fan is constantly irradiating the detectors (Seeram, 2023). The related data acquisition circuits grow rather massive as more detectors are needed to construct a full ring. Fourth-generation scanners are likely to be phased out due to financial and practical considerations (Mikhaeil et al., 2020).

After the fourth generation, CT technology remained stable. However, a breakthrough happened when spiral CT Scanners solved temporal resolution and long procedure duration issues using a slip ring technology.

The Evolution of CT Scanners have made breakthrough mainly in their scan duration and resolution. The focused point of the development of CT scan are reducing the duration and making clearer image for more accurate diagnosis. The first generation of CT scan has only 1 detector and affect the duration of scan greatly. Knowing this limitation, the second generation of CT scan was made with multiple detectors to increase the duration of the scan. Unfortunately, the scatter radiation can not be contained perfectly. To improve the containment of the scatter radiation, Septa Ring was made within the third generation of CT Scanner. Although, this can cause ring artefacts due to a defective or miscalibrated detectors (Ramasamy et al., 2018).

In fourth generation of CT scan, self-calibration detectors were generated to fix this problem. The fourth generation’s detectors were also made to surround the entire circle and significantly increase the contrast of the reconstructed CT results. Later, The Septa Ring for rejecting scatter radiation in the third generation can also cause patient’s dose drawback which its indication is shown in the fourth generation. To solve all these issues, the fifth generation of CT scan is created. The fifth generation CT scan is also made with more than 2000 detectors for ultrafast scan and it was designed for the electron in X-tube to be steered magnetically to allow fast cardiac scanning (Lell et al., 2015). Alas, multiple detectors produce louder sounds and lower its spatial resolution.

The sixth generation solves this issue by using detectors that can move freely and able to create 3D image. Thereafter, flat-top sampling issues occurred. It causes amplitude distortion and delay in the sixth generation CT Scanner. In the seventh generation, the flat-top sampling issues were solved and the duration of scan is improved. Although, the cost of using the seventh generation is the most expensive.

Generation of Scanners	**First Gen**	**Second Gen**	**Third Gen**	**Fourth Gen**	**Fifth Gen**	**Sixth Gen**	**Seventh Gen**
Detectors	one	Multiple (up to 30)	Multiple (up to 250)	More than 2000	More than 2000 (Stationary Ring)	Multiple in 3G/4G	Multiple array of detectors
Beam	pencil-like X-Ray beam	fan-shaped X-Ray beam	fan-shaped X-Ray beam	fan-shaped X-Ray beam	fan beam	3G/4G	cone beam
Movement	translate-rotate	translate-rotate	rotate-rotate	rotate-fixed	fixed-fixed	slip-ring	slip-ring
Number of Slice per Duration	one	one	multiple	2 or more	2 or more	2 or more	multi-slice
Duration of Scan	25-30 Minutes	Less than 90 seconds	5 seconds	Few seconds	Few seconds	Few seconds	Few seconds

Table 1. Evolution of CT Scanners per Generation. (References: (Nett, 2020); (Abdulla, 2021))

CT Scanners Generations	Limitation	Improvement
First Generation	Slow scanning and only one detector	First clinical CT Scanner
Second Generation	Increasing of scatter radiation	More detectors
Third Generation	Drawback of ring artefacts	SEPTA installation to reject scatter of radiation
Fourth Generation	Patient dose drawback (non-focusable X-Ray source to make use of SEPTA to reject scatter radiation)	Self-calibration
Fifth Generation	Higher noise level and lower spatial resolution	Ultrafast CT Scanner
Sixth Generation	Flat top sampling (requires a properly synchronized communication system to detect digital signals)	X-Ray source and detectors can move freely (allow 3D image)
Seventh Generation	Very expensive	Increasing z-resolution and reducing scan duration

Table 2. Limitation and Improvement per Generation (References: (Garvey, 2002); (Flohr, 2013))

2.4. Comparison of CT scan results

As it is shown in Figure 5., the result image of the first gen CT Scanner is still blurry because of the lack of pixel in the monitor and the lack of detectors in the tube. Knowing this weakness, the result image is becoming the focus point as it can produce clearer images in the future generations. As it can be seen in Figure 6., the result of the CT scan is nearly produced in 3D-Image. After the fifth generation, the multi-slice is implemented. It can produce a clear image of blood clotting, spinal fractures, etc.

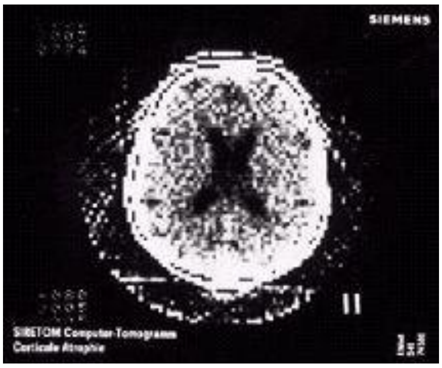

Figure 3. The first CT scan image. (Atkinson Morley's Hospital, October 1971)

Figure 4. The latest CT scan image using fifth generation.

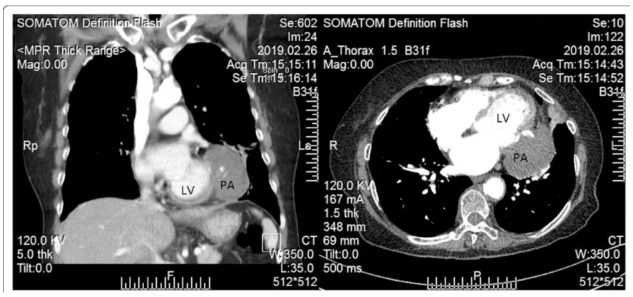

Figure 5. The result of Cardiac multislice computed tomography (MSCT) confirmed the formation of the pseudoaneurysm and thrombus filling with pseudoaneurysm. (Li et al., 2020)

2.5. Future Development

The advancement of artificial intelligence (AI) has been hailed as a huge advantage for pathologists and radiologists all around the world, with the medical imaging sector being one of the most likely beneficiaries. The most recent study, which showed that an AI platform can be capable of recognizing acute neurologic events in CT scan pictures within 1.2 seconds, is a perfect illustration of this. The experiment involved 37,000 head CT scans, and the findings indicated that an AI system could diagnose and identify neurological conditions like a stroke more quickly than a human radiologist (Strindlund, 2021).

Another future development of CT scan that could happen is mobile and portable CT scanning. The dangers of intrahospital travel, such as the compromising of monitoring devices, intravenous lines, or intubation tubes, can be reduced by doctors. The use of portable CT Scanners has benefited the treatment of head injuries because they enable quick CT deployment to radiology departments and hospitals while lowering patient risk both during transit and treatment. Because faster imaging for patients in the ICU and outside the ICU is made possible by optimizing the workflow of regular scanners, portable CT Scanners allow physicians to make the most of the stationary CT equipment that is available at a hospital (Cofone, 2022).

Figure 6. Mobile CT Scanner (Khedri, 2022)

Iterative reconstruction could also be the future of CT scanning. Iterative reconstruction is the name given to a CT image reconstruction algorithm that starts with an image assumption and compares it to real-time observed values while making continuous revisions until the two are in sync. The computed tomography image reconstruction market has been greatly impacted by its capacity to eliminate noise caused by filtered back projection without boosting radiation exposure. Early scanners were unable to undertake iterative reconstruction due to computer technology. With technological advancements, it might be feasible to employ it widely (Gajera & Murphy, 2017).

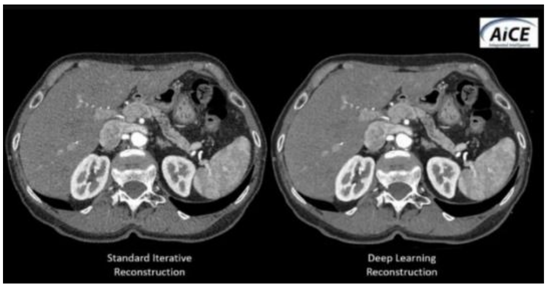

Figure 7. Iterative Reconstruction with AI Technology (Book, 2021)

Basically, Future CT Scanners should be quicker, more automated, and simpler to use. Technology will advance from being an effective interpretive tool to a machine with more quantification and a quick and direct diagnosis.

3. CONCLUSION

Since the early 1970s, when the technique was first developed, computed tomography technology has made enormous strides. CT scans are often viewed on a computer screen and are stored as electronic data files. These pictures are interpreted by a radiologist, who then reports back to your doctor. The technology advancements have produced images of outstanding and consistent quality, which has in turn led to their widespread usage in clinical care. It is possible to predict the future with accuracy by examining historical tendencies such as temporal resolution. Enhancement in each generation of CT Scanners is the solution of drawbacks in the generation before. The future of CT Scanners is expected to remain stable. It means there will be no breakthrough for the next generation, until new materials and new inventions in mechanical aspects are found.

4. References

Abdulla, S. (2021) *CT equipment*, *Radiology Cafe*. Available at: https://www.radiologycafe.com/frcr-physics-notes/ct-imaging/ct-equipment/ (Accessed: February 20, 2023).

Beatty, J. (2021) *The Radon Transform and the Mathematics of Medical Imaging*. thesis.

Book, C. (2021) *Canon medical introduces deep learning-based CT Image Reconstruction*, *Imaging Technology News*. Available at: https://www.itnonline.com/content/canon-medical-introduces-deep-learning-based-ct-image-reconstruction (Accessed: February 20, 2023).

Botz, B. and Shetty, A. (2014) “CT Scanner (evolution),” *Radiopaedia.org* [Preprint]. Available at: https://doi.org/10.53347/rid-29733.

Cofone, L. (2022) *Recent advances in CT Scan Technology*, *NeuroLogica*. Available at: https://www.neurologica.com/blog/advances-ct-scan-technology (Accessed: February 10, 2023).

Flohr, T. (2013) “CT Systems,” *Current Radiology Reports*, 1(1), pp. 52–63. Available at: https://doi.org/10.1007/s40134-012-0005-5.

Gajera, J. and Murphy, A. (2017) “Iterative Reconstruction (CT),” *Radiopaedia.org* [Preprint]. Available at: https://doi.org/10.53347/rid-51925.

Garvey, C.J. (2002) “Computed Tomography in clinical practice,” *BMJ*, 324(7345), pp. 1077–1080. Available at: https://doi.org/10.1136/bmj.324.7345.1077.

Hamouda, N. *et al.* (2018) *Large-bowel obstruction*, *Applied Radiology*. Available at: https://appliedradiology.com/communities/Pediatric-Imaging/large-bowel-obstruction (Accessed: February 14, 2023).

Harmonay, V. (2021) *CT Scanner components: What does what?*, *CT Scanner Components: What Does What?* Atlantis Worldwide. Available at: https://info.atlantisworldwide.com/blog/ct-scanner-components-what-does-what (Accessed: February 10, 2023).

Hermena, S. and Young, M. (2022) *CT-scan Image Production Procedures*. Treasure Island, Florida: StatPearls Publishing.

Imaging, C. (2022) *History of the CT scan: Catalina Imaging, Mobile CT Rental - Mobile Imaging Rental And Lease*. Available at: https://catalinaimaging.com/history-ct-scan/#:~:text=The%20first%20commercially%20available%20CT,Prize%20in%20Physiology%20and%20Medicine. (Accessed: February 10, 2023).

Khedri, R. (2022) *Portable CT Scanner: An overview for RTS, Medical Professionals*. Available at: https://www.medical-professionals.com/en/portable-ct-scanner/ (Accessed: February 20, 2023).

Lell, M.M. *et al.* (2015) "Evolution in Computed Tomography," *Investigative Radiology*, 50(9), pp. 629–644. Available at: https://doi.org/10.1097/rli.0000000000000172.

Li, X. *et al.* (2020) "The evolution of left ventricular pseudoaneurysm from the rupture of left ventricular free wall following acute myocardial infarction: A case report," *BMC Cardiovascular Disorders*, 20(1). Available at: https://doi.org/10.1186/s12872-019-01321-2.

Mikhaeil, E. *et al.* (2020) *X-Ray Sensors in Computed Tomography* [Preprint]. Available at: https://doi.org/10.13140/RG.2.2.30444.39045.

Nett, B. (2020) *Animated CT generations [1st, 2nd, 3rd, 4th, 5th gen CT] for Radiologic Technologists • How Radiology Works, How Radiology Works*. Available at: https://howradiologyworks.com/ctgenerations/ (Accessed: February 20, 2023).

Ramasamy, A., Madhan, B. and Krishnan, B. (2018) *Ring artefacts in cranial CT, BMJ Case Reports*. BMJ Publishing Group. Available at: https://casereports.bmj.com/content/2018/bcr-2018-226097 (Accessed: February 15, 2023).

Richard, K. (2022) *X-Ray computed tomography (CT), Techniques*. Available at: https://serc.carleton.edu/research_education/geochemsheets/techniques/CT.html (Accessed: February 20, 2023).

Robb, R.A. (1982) "X-Ray computed tomography: From basic principles to applications," *Annual Review of Biophysics and Bioengineering*, 11(1), pp. 177–201. Available at: https://doi.org/10.1146/annurev.bb.11.060182.001141.

Rutt, B. (1987) "Three dimensional scanned projection radiography using high speed computed tomographic scanning system."

Seeram, E. (2023) *Computed Tomography: Physical principles, clinical applications, and Quality Control*. Maryland Heights, MO, Missouri: Elsevier.

Strindlund, M. (2021) *The impact of artificial intelligence on CT Imaging, The Impact of Artificial Intelligence on CT imaging*. Available at: https://www.itnonline.com/article/impact-artificial-intelligence-ct-imaging (Accessed: February 10, 2023