Static CT Imaging Method Based on Multi-Line Array X-Ray Sources

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Abstract

Static computed tomography (CT) is an advanced 3D measurement technology. It offers key instrumentation advantages by reducing motion-induced artifacts, preserving measurement accuracy, and lowering radiation dosescritical factors for precision systems. This capability is particularly crucial for imaging moving organs such as the heart. This study introduces a novel Multi-Array Stationary CT (MASCT) imaging architecture.Utilizing cold-cathode carbon nanotube X-ray sources, the proposed architecture achieves dual innovations in temporal and spatial resolution, advancing stationary CT instrument design. Firstly, the X-ray sources rapid response allows for swift data acquisition. Coupled with its low power consumption and compact form factor, these characteristics collectively facilitate high temporal resolution, meeting the demands of dynamic imaging. Second, the densely arranged source array enhances angular resolution, while the z-axis MAS configuration ex tends scanning capacity for elongated objects, thereby expanding spatial resolution across multiple dimensions. To address practical implementation challenges, we incorporate iterative reconstruction algorithms to solve limited-angle problem, achieving diagnostically acceptable image quality. The feasibility of our multi-array X-ray source-based static CT system is rigorously validated through both numerical simulations and physical experiments.

Full Text

Preamble

Static CT Imaging Method Based on Multi-Line Array X-Ray Sources∗
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Static computed tomography (CT) represents an advanced 3D measurement technology that offers key instrumentation advantages by eliminating motion-induced artifacts, preserving measurement accuracy, and reducing radiation dose—critical factors for precision imaging systems. This capability is particularly crucial for imaging moving organs such as the heart. This study introduces a novel Multi-Array Stationary CT (MASCT) imaging architecture that leverages cold-cathode carbon nanotube X-ray sources to achieve dual innovations in temporal and spatial resolution, advancing stationary CT instrument design. The X-ray source' s rapid response enables swift data acquisition, while its low power consumption and compact form factor collectively facilitate high temporal resolution to meet the demands of dynamic imaging. Additionally, the densely arranged source array enhances angular resolution, and the z-axis MAS configuration extends scanning capacity for elongated objects, thereby expanding spatial resolution across multiple dimensions. To address practical implementation challenges, we incorporate iterative reconstruction algorithms to solve the limited-angle problem, achieving diagnostically acceptable image quality. The feasibility of our multi-array X-ray source-based static CT system is rigorously validated through both numerical simulations and physical experiments.

Keywords: Cold Cathode, Carbon Nanotube, mSTCT, Imaging System, Iterative Reconstruction

Introduction

Static computed tomography (CT) is an emerging measurement technology driven by demands for higher quantitative imaging efficiency, lower radiation exposure, and broader instrumentation applicability. Traditional cone-beam CT (CBCT) typically employs an X-ray source and flat panel detector (FPD), requiring a full set of angular views to collect sufficient data for high-quality image reconstruction. However, CBCT faces notable limitations in medical applications. First, dependence on high-speed rotation of X-ray sources and detectors leads to complex mechanical structures prone to wear and failure, significantly increasing maintenance costs and severely impacting system stability. Second, the rotating mechanism greatly limits imaging speed, hindering real-time monitoring of rapid physiological processes such as heartbeats and breathing. Third, dynamic or high-resolution imaging inevitably exposes patients to higher radiation doses through multiple scans, posing potential health risks that contradict the medical field' s pursuit of low-radiation, high-safety goals.

Industrial applications present additional challenges. Processes such as casting cooling defect formation [1], material deformation [2], and dynamic fluid infiltration [3] involve complex dynamic changes [4] that traditional CBCT fails to capture, compromising image quality and real-time monitoring precision. Consequently, reliable static CT architectures represent a critical innovation pathway for both medical and industrial sectors, with transformative potential for their respective technological landscapes.

In recent years, researchers have extensively explored diverse static CT system implementations, with multi-source-detector configurations emerging as particularly promising. A key advantage of increasing source-detector pairs is the effective reduction of data acquisition time and enhancement of temporal resolution [5]. The pioneering Dynamic Spatial Reconstructor (DSR), introduced in 1983, marked the advent of semi-static CT [6]. This system incorporated 14 X-ray tubes and 14 television cameras within a rotating gantry, acquiring projections through sequential activation of multiple X-ray sources despite relying on mechanical rotation for comprehensive data collection.

Following DSR, various fully static CT strategies have been developed. Liu et al. demonstrated improved image quality in a simulated five-source cone-beam micro-CT system using Feldkamp-type reconstruction algorithms [7]. Similarly, Gong et al. [8] proposed a static CT architecture employing over 80 X-ray sources, utilizing three fixed X-ray source arrays paired with detectors operating in interior tomography mode. However, high-quality data acquisition and interior CT reconstruction remain significant technical challenges in multi-source X-ray imaging systems [9], particularly regarding reconstruction instability in specific regions of interest (ROI) caused by limited measurement data [10][11]. While a recent dynamic CT system with 29 X-ray sources and corresponding detectors achieved stable high-quality ROI reconstruction and state-of-the-art temporal resolution [12], it still faces critical engineering limitations, including a small field-of-view (FOV) radius insufficient for most applications, bulky system size hindering mobility, and prohibitively high cost. These persistent challenges underscore that substantial barriers remain for the practical engineering implementation of multi-source static CT systems despite their technical promise.

Recent technological advancements have positioned field-emission cold cathode X-ray sources as highly promising candidates for static CT systems due to their rapid response, low energy consumption, controllable electron emission direction, and ease of beam focusing [13]. Several studies have reported novel static CT designs employing linearly arranged carbon nanotube (CNT) cold cathode X-ray source arrays [14]. For instance, Yang et al. [15] developed a static digital breast tomosynthesis system utilizing CNT cold cathode X-ray sources. Quan et al. [16] proposed square and hexagonal geometric configurations for multi-source X-ray micro-CT systems, while Gonzales et al. [17] introduced a rectangular static-gantry CT system for airport security inspection. These implementations offer simplified mechanical structures and superior temporal performance. However, challenges persist: the inherent low density of X-ray sources and spatial constraints limit the integration of sufficient sources for comprehensive data acquisition.

Our team previously conducted simulation studies on a static CT system using an addressable cold-cathode flat-panel X-ray source with ZnO nanowire-based emitters, validating its viability as a novel imaging instrument [18–20]. Although this design demonstrated potential for cost-effective static imaging, its over-idealized hardware requirements currently hinder practical high-quality data acquisition. Furthermore, pursuing a large FOV introduces data sparsity issues during reconstruction, primarily due to insufficient angular sampling coverage.

CNT linear-array X-ray source technology, a promising next-generation platform, has demonstrated significant potential in diverse applications, including low-dose medical imaging [21], preclinical small animal imaging [22], and high-speed imaging systems achieving microsecond-scale temporal resolution through rapid electronic switching [23, 24]. Modern implementations utilize multiple vacuum-sealed focal spots engineered for specialized functions, encompassing CNT-based field emitters [25], tungsten dispenser cathodes [26], and Spindt-type emitters [27]. Cold cathode electron emission mechanisms exhibit unique advantages over traditional thermionic sources: the electron tunneling process occurs on sub-femtosecond timescales, enabling ultrafast response characteristics, while low-energy divergence of emitted electron beams simplifies beam focusing requirements, leading to cost-effective system designs. Importantly, the absence of thermal activation eliminates preheating delays and facilitates device miniaturization, making them particularly suitable for portable and conformable imaging systems. These attributes have driven substantial research efforts toward developing high-performance cold cathode X-ray tubes [28–30]. Recent progress in spatially distributed X-ray source array technology using CNT field emitters has demonstrated enhanced capabilities for three-dimensional imaging, with mechanical-free architectures achieving multidirectional projection acquisition through electronic scanning [31–34].

In this paper, leveraging the advantages of addressable cold cathode CNT linear-array sources, we propose a novel stationary imaging architecture called the Multi-Array Static (MAS) system. CNT-based sources can achieve high integration density in limited space, with center-to-center distances as small as 5 mm [35], providing the necessary angular resolution for image reconstruction. Additionally, an optimized source activation sequence enables millisecond-level temporal resolution. Spronk et al. [36, 37] developed a stationary CT imaging system for head/brain imaging (s-HCT) using CNT-based field-emission X-ray source array technology [38]. Their design incorporates axial scanning by translating the imaged object or patient along the z-axis, with reliability and reproducibility verified under application-specific imaging geometries and power/energy requirements.

Building on FANS [18], we introduce a novel z-axis linear array deployment to alleviate sparse-view artifacts, complemented by an augmented planar array configuration inspired by mSTCT [39] to provide essential angular sampling for tomographic reconstruction. To broaden application scenarios and optimize cost efficiency, we deliberately retain limited-angle imaging with 150° angular coverage—a limitation that is no longer insurmountable with current technology.

Notably, the method for calculating angular coverage in MASCT is unique.

Four key advantages characterize the proposed MAS system. First, integrating affordable carbon nanotube (CNT) X-ray sources within a simplified, compact design yields superior cost-effectiveness and portability compared to conventional thermal-source systems. Second, the absence of mechanical motion during scanning inherently simplifies geometric calibration, enhancing imaging accuracy. Third, the unique planar distribution of X-ray sources achieves better in-plane spatial resolution and mitigates cone-beam artifacts through uniform projection sampling. Finally, capitalizing on the rapid response of cold cathode sources, our optimized activation sequence delivers high temporal resolution, making the system well-suited for demanding applications like small animal imaging.

This study offers three significant contributions to CT imaging. First, we developed a novel static CT imaging architecture that overcomes efficiency limitations imposed by mechanical motion in conventional systems. Based on addressable carbon nanotube (CNT) linear array X-ray sources, this architecture eliminates mechanical rotation, enabling rapid, high-quality image reconstruction and greatly enhancing imaging efficiency. Second, we rigorously analyzed data distribution characteristics in Radon transform space and conducted a comparative evaluation of the MAS system against conventional architectures, conclusively demonstrating superior image reconstruction performance that confirms the technical advantages of our innovative design. Finally, leveraging the unique capabilities of CNT-based X-ray sources, we theoretically quantified the data acquisition time for MASCT, revealing exceptional temporal resolution compared to traditional systems and underscoring its profound potential for rapid imaging applications.

The remainder of this paper is organized as follows. Section 2 details the MAS system architecture, including comparative analysis of Radon space data distribution patterns and development of a dedicated image reconstruction model. Section 3 validates the feasibility of the MAS-based static CT imaging framework through numerical simulations and experiments employing clinical and phantom datasets. Finally, Section 4 summarizes key findings, discusses current limitations of MASCT, and outlines directions for future research.

II. Methods

A. MASCT Imaging Model

This study proposes MASCT, which innovatively integrates cold cathode CNT linear array X-ray sources with FPD technology to achieve high-quality imaging. Fig. 1 Figure 1: see original paper illustrates the schematic diagram of MASCT, comprising five paired source arrays and FPDs. Each source array is meticulously designed with adjustable numbers and positions of focal spots. After in-depth analysis of resource optimization and image quality, we uniformly deploy focal spots on each source array, as depicted in Fig. 1(b). During data acquisition, all components remain stationary while the object under inspection is securely placed on a platform near the FPD and remains motionless throughout the procedure. This layout ensures that X-ray cone beams fully and unobstructedly cover and penetrate the object, avoiding data truncation and ensuring integrated imaging.

Due to the limited size of the X-ray source array, MASCT collects incomplete data. Therefore, accurately characterizing the distribution of collected data in Radon space is critical to guide optimal system architecture design. To describe MASCT' s imaging geometry, we establish a Cartesian coordinate system o-xyz with the object as the center, as shown in Fig. 2 Figure 2: see original paper. Let denote the angle between the line connecting the detector center and source array center and the y-axis, positive counterclockwise. For any detector-source array pair with arbitrary angle , the detector unit position can be expressed as:

$$S_\theta(\lambda, \nu) = (l \sin\theta + \lambda\cos\theta, -l\cos\theta + \lambda\sin\theta, \nu)$$

with $\lambda \in [-s_\lambda, s_\lambda]$, $\nu \in [-s_\nu, s_\nu]$, where s_λ and s_ν denote half-width and half-height of the source array, and l represents the object-to-source array distance. Assuming the object' s density function has circular support with radius R, we obtain $f(x, y, z) = 0$ for $\sqrt{x^2 + y^2 + z^2} > R$, where $R < \min(a, b)$. The line integral of the density function f along the X-ray directed from $S_\theta(\lambda, \nu)$ to $D_\theta(u, v)$ can be formulated as:

$$p(S_\theta, D_\theta) = \int_{-\infty}^{+\infty} f(S_\theta + t\hat{e})\, dt$$

where

$$D_\theta(u, v) = (-h\sin\theta + u\cos\theta, h\cos\theta + u\sin\theta, v)$$

with $u \in [-d_u, d_u]$, $v \in [-d_v, d_v]$, where d_u and d_v denote half-width and half-height of the detector, and h represents the object-to-detector distance. The coordinate of a focal spot on the source array can be formulated as:

$$\hat{e} = \frac{D_\theta - S_\theta}{|D_\theta - S_\theta|} = \frac{(-(h+l)\sin\theta + (u-\lambda)\cos\theta, (h+l)\cos\theta + (u-\lambda)\sin\theta, 0)}{\sqrt{(u-\lambda)^2 + (h+l)^2}}$$

Here, $p(S_\theta, \cdot)$ represents a cone-beam projection. The parallel projection in the y-z plane is given by:

$$\bar{p}(\phi_z, r_z) = p(S_\theta(0, \nu), D_\theta(0, v))$$

with

$$r_z = \sqrt{\nu^2 + l^2}\sin(\beta_z - \phi_z), \quad \phi_z = \arctan\left(\frac{h+l}{v-\nu}\right)$$

where $\beta_z = \arctan(-l/\nu)$. $\bar{p}(\phi_z, r_z)$ represents the parallel projection in the y-z plane, and ϕ_z denotes the angle of the line from the z-axis, as depicted in Fig. 3 Figure 3: see original paper. Finally, the distribution of projections collected by MASCT in the x-y plane within Radon space can be obtained, as illustrated in Fig. 3(b).

B. Data Distribution in Radon Space

The Radon transform maps the density function f to Radon space through line integration, defined by parameters r (distance from the origin) and ϕ (angle of the line). We first examine MASCT' s collected data in the x-y plane. The fan-beam projection can be converted to parallel projection by:

$$p(S_\theta(\lambda, 0), D_\theta(u, 0)) = \bar{p}(\phi_x, r_x)$$

with

$$r_x = \sqrt{\lambda^2 + l^2}\sin(\beta_x - \phi_x), \quad \phi_x = \arctan\left(\frac{h+l}{u-\lambda}\right)$$

where $\beta_x = \arctan(-l/\lambda)$. $\bar{p}(\phi_x, r_x)$ represents the parallel projection in the x-y plane, ϕ_x denotes the angle from the x-axis, and r_x represents the signed distance from the origin. Fig. 2(b) illustrates the distribution of MASCT' s collected data in the x-y plane within Radon space.

In the y-z plane, the relationship between fan-beam and parallel projections is:

$$p(S_\theta(0, \nu), D_\theta(0, v)) = \bar{p}(\phi_z, r_z)$$

To intuitively understand our data acquisition capabilities, we analyze the distribution of MASCT' s collected data in the x-y plane within Radon space. Unlike the previously proposed multi-segment linear X-ray source translation CT (mSTCT) [40], we focus solely on non-truncated regions in the x-y plane. A single linear array source covers an angular range of:

$$\Delta\phi_x = 2\arctan\left(\frac{d_u}{s_\lambda h - d_u l}\right), \quad |r| \le R_1$$

where

$$R_1 = \frac{\sqrt{(l+h)^2 + (s_\lambda + d_u)^2}}{2}$$

Through careful design, each CNT source is optimized to maximize its contribution. As illustrated in Fig. 2(b), projections are acquired starting from the central detector, where each adjacent detector pair in MASCT is offset by angle $\Delta\theta$. R_1 represents the radius of the central circle of acquired projection data. The five detectors correspond to five parallel linear array X-ray sources, forming paired combinations that sequentially collect data. To address diverse application scenarios, we intentionally retain certain limited-angle challenges. In practice, considering physical source sizes, our data distribution also exhibits sparsity. A key innovation of this paper is introducing source arrangements along the z-axis, which provides enhanced angular resolution and significantly mitigates sparse-angle impacts. This design also enables imaging of "long objects." By adding four additional rows to a single-row mSTCT configuration, our system can cover more data than conventional STCT systems—in other words, mSTCT can only collect a subset of the data acquired by our system.

Fig. 3(a) aids in analyzing MASCT' s data distribution along the z-axis. The arrangement height of sources along the z-axis is not constrained by system structure, eliminating stitching concerns and allowing significant extension. To demonstrate our system design advantages, we added only four additional rows of linear array sources along the z-axis, focusing on truncated regions. As shown in Fig. 3(b), which illustrates z-direction projection data distribution in Radon space, we can calculate:

$$\Delta\phi_z = 2\arctan\left(\frac{d_v}{s_\nu h - d_v l}\right), \quad |r| \le R_3$$

In Fig. 3(b), points A and B represent data collected by L1 and L2, respectively, where:

$$\Delta\phi_{AB} = 2\arctan\left(\frac{s_\nu + d_v}{h + l}\right)$$

As shown in Fig. 3(a), R_3 represents the distance from the origin to the line connecting the leftmost source position and leftmost detector:

$$R_3 = \frac{\sqrt{(l+h)^2 + (s_\nu + d_v)^2}}{2}$$

Evidently, incorporating y-z plane data effectively adds depth to x-y plane data. Compared to mSTCT, both MAS and fan-beam systems exhibit exponential data volume increases. The y-z plane data correlates with parameter ϕ_{AB}.

When the cone-beam angle is sufficiently large, h can extend further, allowing ϕ_{AB} to increase accordingly and enabling scanning of longer objects. This advantage is highly significant for CT equipment utilizing conveyor belts, as it simplifies system complexity, enhances temporal resolution, and enables rapid imaging.

Leveraging cold cathode CNT source benefits, we analyzed the system' s temporal resolution. Electronic source switching can achieve microsecond-level temporal resolution [23, 24]. Considering stability, we assume a 1 ms response time interval between adjacent sources. As shown in Fig. 2(b), we sequentially numbered each detector-linear array source pair. Assuming each linear array contains 17 carbon nanotube sources divided into three groups (e.g., 1-4, 2-5, 3), each group achieves $5\$\times 17 mstemporalresolution.Thus, theentiresystemachieves 3\times 5\times \$17$ ms temporal resolution. A more optimized activation sequencing strategy could further improve system resolution.

C. Reconstruction Method for MAS System

MASCT collects data from multiple linear array X-ray sources, with image reconstruction aiming to recover high-quality CT images from limited scan data. The imaging model can be formulated as:

$$AX = P$$

where A represents the system matrix and P represents the projections. The reconstruction task minimizes the Frobenius norm:

$$\min \|AX - P\|_F^2$$

where $\|\cdot\|_F$ denotes the Frobenius norm. To solve this optimization problem, various iterative methods can be employed, including Algebraic Reconstruction Technique (ART) [41], Simultaneous ART (SART) [42], and Simultaneous Iterative Reconstruction Technique (SIRT) [43]. This study adopts the method described in [43].

III. Experiments and Results

To verify MASCT' s performance advantages over mSTCT and FANS systems, we conducted simulation experiments and constructed prototype systems for FANS, mSTCT, and MAS. The reconstruction process was implemented in MATLAB with GPU acceleration on a computer equipped with an NVIDIA GeForce RTX 3090 GPU. Reconstructing a $256\$\times 256\times 2563Dmatrixfrom 512\times \$512$ projections required 3.7 seconds per iteration. Since results after 1000 iterations were visually indistinguishable, SIRT was set to terminate after 1000 iterations to balance efficiency and accuracy.

A. Numerical Data Results

To further verify MASCT' s advantages, we conducted simulation experiments using the Shepp-Logan phantom. MASCT was configured with a 5\$$\times 5linear - arrayX - raysourcesetupandfiveFPDs, eachwith512\times$\$512 pixel resolution. The FPDs were square-shaped with 51.2 mm width. The source array was square-shaped with 100 mm width. The object-to-source array distance was 200 mm, and the object-to-detector distance was 100 mm. Table 1 summarizes MASCT' s detailed parameters.

In the x-y plane, MASCT' s collected data exhibits gap-free distribution in Radon space, theoretically equivalent to a reconstruction problem with a 150° limited angle. For fair comparison, we adjusted the mSTCT system by setting the linear-array source height to zero, effectively removing the additional four z-axis source rows while keeping other parameters identical to MASCT. The FANS system was configured with parameters consistent with MASCT.

Through quantitative calculations using equations (10), (12), and (13), coupled with detailed angular data analysis, we theoretically demonstrated MASCT' s superiority in three-dimensional object imaging. Experimental results presented below reveal remarkably effective outcomes.

Fig. 4 [Figure 4: see original paper] displays our research findings. Columns (a)-(d) represent reconstruction results for slice number 128 across different systems, (e)-(h) show intermediate slices, and (i)-(l) depict slice number 384. Evidently, FANS exhibits severe limited-angle artifacts even under identical equipment conditions. Compared with mSTCT, MAS demonstrates significantly reduced sparse artifacts due to its additional four z-axis rows. Furthermore, from both slices 128 and 384, MAS clearly outperforms both mSTCT and FANS, indicating superior imaging capabilities especially when objects deviate from center—in other words, our system can effectively image longer objects.

The three-dimensional Shepp-Logan volume reconstructed using FDK from circular scanning is generally considered satisfactory and is presented in Fig. 3. From both coronal and sagittal views, MAS produces images with clearer details, fewer artifacts, and more perfect contours than those obtained through circular scanning—an unexpected yet remarkable outcome demonstrating superior performance over traditional FDK-based reconstructions and alternative approaches like mSTCT/FANS, highlighting potential advantages for future high-quality volumetric imaging applications.

Fig. 5 [Figure 5: see original paper] presents green-line profiles from axial, coronal, and sagittal views for all four systems. As shown in Fig. 5(b), which focuses on edge structures, mSTCT and FANS exhibit significant errors, further demonstrating the feasibility of the proposed MAS system and its reconstruction method.

As shown in Fig. 6 [Figure 6: see original paper], we investigated reconstruction results across different MAS systems by varying the number of planar arrays while keeping other conditions constant. The details highlighted by elliptical circles exhibit superior quality, and Shepp-Logan phantom edge structures improve as the number of planar arrays increases. Clearly, while ensuring capability to image elongated objects, more planar arrays yield better imaging quality. However, the number of planar arrays cannot increase indefinitely, as it must satisfy $\Delta\theta \times n < 180$ degrees, where n represents the number of planar arrays. Therefore, maximizing performance in MAS system design requires setting appropriate parameters to achieve more rational imaging outcomes.

B. Thumb Corn Data Experimental Validation

To further validate MASCT' s practical feasibility, we built an experimental platform shown in Fig. 7 [Figure 7: see original paper]. The platform consists of a micro-focus cone-beam X-ray source (Hamamatsu), rotation stage (Newport), flat-panel detector (iRay), translation stage (Newport), vertical lifting system, control system (Newport), and data acquisition system. The detector and object heights were fixed, while the X-ray source was mounted on the vertical lifting system for vertical movement. The lifting system was further mounted on the translation stage, enabling precise simulation of MASCT source positions. The object was placed on the rotation stage, allowing the platform to collect data for mSTCT, FANS, and MAS systems without configuration changes.

To avoid truncation artifacts, each linear-array source was designed with 17 sources, resulting in 80 mm total length. Five rows of linear-array sources were arranged along the z-axis with 50 mm total height. Each linear-array source covered a 17° angle. The MASCT detector maintained a 30° offset, meaning the object rotated 30° per projection. A 3D reconstruction of the corn kernel was performed at 512$×512×$512 resolution, with experimental geometric parameters detailed in Table 2 . Primary parameters for circular scanning, mSTCT, and FANS systems were configured consistently with MASCT for comparison.

Fig. 8 [Figure 8: see original paper] illustrates reconstruction results, highlighting MASCT' s advantages. For the same object, circular scanning is generally accepted as providing the best reconstruction due to complete angular information. To validate this, we acquired 720 projections at 1536$×$1536 resolution using circular scanning and reconstructed the corn kernel in 3D using the FDK algorithm as our quantitative RMSE reference.

From the central axial slice, focusing on arrow-indicated regions, MASCT' s reconstructed bottle appears closer to a perfect circle than other systems. Additionally, in red-ellipse-marked regions, corn structural details and edge sharpness are significantly better in MAS reconstruction. Among all systems, MAS results are closest to the RMSE reference.

In the 128th and 384th slices, MASCT demonstrates superior ability to reconstruct elongated objects compared to mSTCT. Furthermore, from coronal plane representative slices, MASCT outperforms even the RMSE reference in red-circled regions, delivering noticeably better results. Similarly, in sagittal plane slices, MASCT captures finer corn kernel details within red-rectangled regions. In the x-y plane, while projection data distribution in Radon space belongs to the gap-inclusive type mentioned earlier, the 3D reconstruction results are unexpectedly impressive. This indicates that with more optimal parameter design and leveraging the fast response and low-radiation advantages of cold cathode CNT sources, MASCT holds tremendous potential for applications like dental CT.

These results suggest MASCT excels in reconstructing objects where fine details are not overly critical, demonstrating high tolerance for lower-precision imaging tasks. Furthermore, its versatility allows resource-optimized designs tailored to different scenarios, reinforcing MASCT' s feasibility as a cost-effective, portable solution and paving the way for broader practical applications.

C. Duck Neck Data Experimental Validation

To further demonstrate the MAS system' s effectiveness, we conducted experiments using a duck neck featuring more structural details and resembling animal anatomy. Specific experimental geometric parameters are detailed in Table 3 . Primary parameters for circular scan, mSTCT, and FANS systems were kept consistent with MASCT for fair comparison.

Table 3 . Geometric Parameters of the Duck Neck Experiment under MASCT

The data shows that adjusting parameter $\Delta\theta$ to approach $\Delta\phi_x$ enables MASCT to achieve 140° limited-angle reconstruction—a considerable challenge for samples with complex details like duck neck. Using parameters $R_1 = 30.9$ mm and $R_3 = 55.5$ mm, we infer that MASCT' s field of view (FOV) is well-suited to diverse application scenarios, particularly beneficial for small animal imaging in veterinary medicine and biological research.

Fig. 9 [Figure 9: see original paper] further demonstrates MASCT's capability in reconstructing off-center slices. For more intuitive observation, we magnified the duck neck cross-sectional view. As shown in the red rectangular region of interest in (e), our system' s results are closer to circular scanning. In the red elliptical region of (q), highlighting duck neck bone structure, our system' s imaging exhibits finer details. To substantiate our claims, Fig. 9 presents quantitative profile comparisons along the green line. Clearly, duck neck reconstruction results validate MASCT' s clinical potential. All results robustly confirm our MAS CT imaging system' s advantages. To ensure reconstruction reliability, all results were obtained from 8,000 iterations.

To evaluate different system configurations, we conducted comparative experiments using 5$\times 18\times 4, 5\times 18\times 5, and 5\times 18\times$6 sources while keeping source spacing constant. As shown in Fig. 10 [Figure 10: see original paper], increasing the number of sources significantly improves image quality and eliminates noticeable truncation artifacts. These results validate MASCT' s effectiveness and clinical potential while highlighting the importance of system configuration optimization for superior imaging performance.

IV. Discussions and Conclusion

This paper developed a multi-array static CT imaging system based on carbon nanotube (CNT) X-ray sources, consisting of multiple linear-array sources and a fixed flat-panel detector (FPD). The system operates entirely stationary without rotation or movement. Using existing hardware, we successfully collected projection data with MASCT and completed image reconstruction with real data. High-quality results demonstrate the proposed system' s feasibility and effectiveness. Through mathematical analysis, we examined MASCT' s angular data coverage in both x-y and y-z planes, highlighting advantages over mSTCT and FANS systems. Experimental results further validated these advantages using various datasets, with reconstruction performance evaluated under different parameter configurations.

However, several challenges remain for future exploration. One challenge is optimizing CNT source arrangement within each linear array and multiple array layout to achieve improved reconstruction performance and higher image quality. Additionally, although the SIRT iterative reconstruction method achieved satisfactory results, significant potential exists for enhancement by incorporating advanced prior knowledge, including state-of-the-art techniques like deep tomographic networks that can reduce required CNT sources while improving image quality. Transformer-based deep learning reconstruction methods, which have recently gained attention in medical imaging, also show promise [44, 45]. Furthermore, cold cathode CNT sources theoretically offer microsecond-level temporal resolution, and optimizing activation sequences and geometric configurations may achieve even higher temporal resolution without sacrificing power —critical for applications like small animal imaging and dynamic human tissue imaging, such as cardiac imaging. Future work will also include evaluating MASCT performance in different scenarios, particularly its ability to focus on specific regions of interest (ROI) and adapt to varying imaging requirements. We also plan to estimate the maximum object length the system can accommodate based on device performance, crucial for applications like security screening and full-body scans.

Overall, MASCT demonstrates significant advantages: potential as a real-time CT system due to microsecond-level temporal resolution, excellent imaging capabilities for elongated objects, and high-precision image quality due to fully stationary operation. We believe MASCT has substantial potential for practical applications in various fields and anticipate its near-future implementation.

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