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Enhancing Lung CT Image Quality through Frequency Domain Artifact Suppression

Humera Kouser K[1], Dr. Sunil T D[2]
[1]Student, Department of Electronics &Communication Engg., Sri Siddhartha Institute of Technology, Tumkur, Karnataka, India
[2]Associate Professor, Department of Electronics &Communication Engg., Sri Siddhartha Institutte of Technology, Tumkur, Karnataka, India

Abstract: Computed Tomography (CT) imaging plays a crucial role in the diagnosis and monitoring of lung-related diseases. However, the presence of high-density materials, such as metallic implants or surgical clips, often introduces artifacts that degrade image quality and hinder accurate clinical interpretation. This study presents a frequency domain filtering approach to suppress such reconstruction artifacts in lung CT images, thereby improving diagnostic clarity. The proposed method begins with preprocessing of CT slices, followed by transformation into the frequency domain using the Fast Fourier Transform (FFT). Specific frequency components responsible for artifacts are selectively attenuated using tailored notch and band-stop filters. This process effectively minimizes the streaking and blurring effects commonly observed around metallic objects. The filtering algorithm is first developed and tested in MATLAB, where its performance is evaluated using metrics such as Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM). The results show a notable improvement in visual quality and structural preservation of the lung tissues.

To explore the feasibility of hardware acceleration for real-time applications, the same filtering algorithm is implemented in Verilog and simulated on an FPGA platform. The hardware implementation demonstrates low-latency performance with efficient resource utilization, making it suitable for integration in embedded medical imaging systems. This combined software-hardware approach underscores the potential of frequency domain filtering as a practical solution for metal artifact reduction in CT images and opens avenues for real-time deployment in clinical imaging workflows..

Keywords: CT Artifacts, FPGA Implementation, Frequency Domain Filtering, Lung Imaging, MATLAB, Verilog.

I. INTRODUCTION

Computed Tomography (CT) has emerged as a pivotal imaging modality in the diagnosis, assessment, and management of thoracic diseases, especially those related to the lungs. With its ability to provide cross-sectional anatomical details with high spatial resolution, CT imaging is widely used for screening and evaluating conditions such as lung cancer, chronic obstructive pulmonary disease (COPD), infections, and interstitial lung diseases. However, despite its diagnostic utility, CT imaging is not immune to limitations—one of the most prominent being the presence of artifacts that compromise image quality and, consequently, diagnostic accuracy. Among the various artifacts encountered in CT imaging, those arising from high-density metallic objects—such as dental fillings, orthopedic implants, or surgical clips—are particularly problematic. These metallic elements cause inconsistencies during X-ray attenuation measurement and reconstruction, resulting in streaking, shading, or starburst artifacts in the reconstructed images. In lung CT scans, such artifacts may obscure vital pulmonary structures, leading to misinterpretation or missed pathological findings. The need to reduce or eliminate these artifacts has therefore become an active area of research within the medical imaging community. Traditional techniques for metal artifact reduction (MAR) include interpolation-based correction, iterative reconstruction methods, and dual-energy CT acquisition. While effective in certain contexts, these methods often come with increased computational complexity, dependency on raw projection data, or the requirement for additional radiation exposure. Furthermore, they may be limited by compatibility with existing CT systems or may not offer real-time processing capabilities. As an alternative, frequency domain filtering techniques offer a more computationally efficient and modular solution for post-reconstruction artifact suppression [1]. The frequency domain provides a distinct perspective for analyzing and processing images. By transforming CT images from the spatial to the frequency domain using the Fast Fourier Transform (FFT), it becomes possible to isolate and manipulate frequency components that are primarily responsible for artifacts. Metallic artifacts tend to manifest as high-frequency noise or specific directional streaks, which are distinguishable in the frequency spectrum. Through the design and application of targeted filters—such as notch filters, Gaussian masks, or band-stop filters—these undesirable components can be attenuated without significantly affecting the structural details of the lung parenchyma.

In this work, we propose a frequency domain filtering approach for the suppression of artifacts in lung CT images. The filtering process is developed and validated in MATLAB, which offers a flexible environment for signal and image processing. The method involves frequency domain transformation, artifact detection and suppression through selective filtering, and inverse transformation to reconstruct the enhanced image. The performance of the method is assessed using standard image quality metrics such as Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM), in addition to qualitative visual inspection. Results demonstrate that the proposed technique effectively reduces artifact intensity while preserving essential anatomical details [2-3].

Beyond software implementation, this work also explores the potential of hardware acceleration to facilitate real-time image enhancement. With the increasing deployment of embedded systems in medical imaging devices, efficient hardware implementations become crucial. To this end, the filtering algorithm is translated into Verilog and synthesized on a Field-Programmable Gate Array (FPGA) platform. FPGA-based processing offers low latency, parallelism, and energy efficiency—characteristics well-suited for medical applications where time and precision are critical. The hardware results confirm the feasibility of real-time processing without compromising accuracy, suggesting a promising path for integration into clinical imaging pipelines. This paper is organized as follows: Section 2 discusses the background and related work in artifact reduction and frequency domain processing. Section 3 details the proposed methodology, including both the MATLAB and Verilog implementations. Section 4 presents the experimental results, and Section 5 offers a discussion of findings and limitations. Finally, Section 6 concludes the study and outlines future directions for research [4-5].

By combining signal processing techniques with hardware implementation, this study contributes a practical and efficient solution to the persistent problem of metal artifacts in lung CT imaging, with potential applications in both clinical practice and image-guided interventions.

II. BACKGROUND AND RELATED WORK

CT imaging has become an indispensable diagnostic tool due to its ability to generate high-resolution cross-sectional images of internal body structures. Over the years, advancements in detector technology and image reconstruction algorithms have significantly enhanced the clarity and accuracy of CT scans. However, certain limitations persist, particularly the presence of image artifacts that degrade image quality. Among these, metal-induced artifacts are especially challenging. They arise from beam hardening, photon starvation, and scattering effects caused by metallic objects within the body. These artifacts often appear as bright and dark streaks radiating from the metal, obscuring anatomical details and complicating diagnosis [6].

A wide range of methods has been proposed in the literature to address metal artifacts in CT imaging. One common class involves sinogram inpainting, where corrupted projection data are estimated or interpolated prior to reconstruction [7]. Algorithms such as linear interpolation and more advanced techniques like normalized metal artifact reduction (NMAR) and iterative MAR have shown improved outcomes, especially when raw projection data are available. However, access to sinogram data is often restricted in clinical practice, and these techniques can be computationally intensive, limiting their use in real-time or resource-constrained settings. Additionally, dual-energy CT techniques have been employed to differentiate between tissue and metal using material decomposition, but such methods require specialized hardware and additional radiation exposure [8-10].

Post-reconstruction techniques offer an alternative that is both practical and adaptable to existing clinical workflows. Among these, frequency domain filtering has received growing attention due to its simplicity and effectiveness. Artifacts, particularly those arising from metal, introduce identifiable patterns in the frequency domain, such as high-frequency noise and radial streaks. By transforming images into the frequency domain using the Fast Fourier Transform (FFT), it becomes feasible to design filters that selectively suppress these artifacts. Notch filters, directional filters, and custom-designed masks have been applied in several studies to isolate and attenuate artifact components, yielding enhanced images with preserved anatomical details. These methods are particularly attractive because they do not require access to raw projection data and can be applied as a post-processing step[11-13].

A few recent works have also explored the hardware implementation of image filtering techniques to enable real-time processing. With the growth of embedded systems and field-programmable gate arrays (FPGAs) in medical devices, researchers have begun translating image processing algorithms into hardware description languages such as Verilog and VHDL [14]. FPGA-based implementations offer parallelism and low latency, making them ideal for time-critical applications such as intraoperative imaging or mobile CT systems. Studies have demonstrated the feasibility of implementing spatial and frequency domain filters on FPGAs with efficient resource utilization and minimal power consumption. However, the application of such hardware-accelerated techniques specifically for metal artifact reduction in lung CT imaging remains relatively underexplored, providing a strong motivation for the present work [15].

III. PROBLEM STATEMENT AND PROPOSED ALGORITHM

Lung CT imaging is a critical tool in the diagnosis and management of various pulmonary conditions, including infections, tumors, and chronic respiratory diseases. However, the diagnostic value of CT scans can be significantly compromised by the presence of artifacts, especially those caused by metallic implants or surgical hardware. These artifacts often manifest as bright and dark streaks or shadows that distort the surrounding anatomy, making it difficult for radiologists to interpret the images accurately.

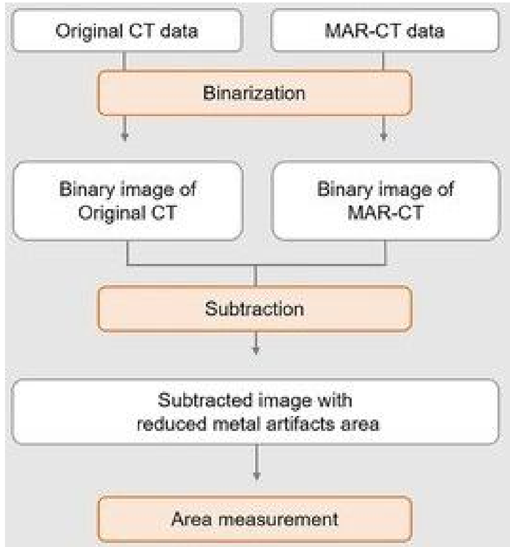

Fig. 1 Problem statement for Metal artifact removal

In many clinical situations, these artifacts obscure important regions of interest in the lungs, potentially leading to misdiagnosis or the need for repeat scans.

Conventional approaches to reduce metal artifacts, such as onogram interpolation and iterative reconstruction techniques, rely heavily on access to raw projection data and involve high computational overhead. These constraints limit their use in routine clinical settings, particularly in facilities with standard CT scanners or where real-time image correction is required. Furthermore, while some commercial CT systems incorporate built-in artifact reduction features, these are not always effective in eliminating complex artifact patterns and may not be adaptable to a wide range of clinical scenarios.

There is a need for a post-processing technique that can effectively suppress metal artifacts from reconstructed CT images without requiring changes to existing hardware or acquisition protocols. Additionally, for applications where real-time or near-real-time image enhancement is necessary, software-based solutions must be accompanied by efficient hardware implementations. This calls for a method that not only enhances image quality through intelligent filtering in the frequency domain but also lends itself to practical hardware realization for clinical deployment.

This study aims to address this gap by developing a frequency domain filtering approach for artifact suppression in lung CT images, with parallel implementation in both MATLAB and Verilog. The objective is to achieve significant artifact reduction while preserving anatomical accuracy and ensuring the feasibility of real-time processing through FPGA-based deployment.

A. Proposed Algorithm

Algorithm: Frequency Domain-Based Metal Artifact Reduction in Lung CT Images

1) Image Acquisition
   a. Prompt the user to select a CT image file.
   b. If the user cancels the selection, terminate the program.
   c. Load the selected image.

2) Image Preprocessing
   a. If the image is in color (RGB), convert it to grayscale.
   b. Display the grayscale image as the original input image.

3) Metal Artifact Detection
  a. Apply histogram-based thresholding to identify high-intensity regions (potential metal artifacts).
  b. Define the threshold as a combination of Otsu's method and an intensity offset.
  c. Generate a binary mask where pixels above the threshold are marked as metal.
4) Mask Refinement
  a. Apply morphological closing using a disk-shaped structuring element to remove small gaps.
  b. Fill holes within the detected mask regions to create a continuous mask.
  c. Display the refined metal artifact mask.
5) Image Inpainting
  a. Use region filling techniques to inpaint (reconstruct) the masked artifact areas based on surrounding pixel information.
  b. Display the inpainted image.
6) Edge-Preserving Smoothing
  a. Apply a bilateral filter to the inpainted image to smooth intensity variations while preserving edges.
7) Image Blending and Reconstruction
  a. Replace the artifact regions in the original image with the corresponding pixels from the filtered image.
  b. Apply a correction factor to maintain visual consistency and contrast.
  c. Display the final enhanced image with reduced metal artifacts.

The proposed algorithm for metal artifact reduction in lung CT images involves a sequence of image processing steps designed to detect, suppress, and restore regions affected by metal-induced distortions. The overall goal is to enhance image quality while preserving anatomical integrity, ensuring that the diagnostic usefulness of the scan is maintained. Each step of the algorithm contributes to this objective as described below.

a) Image Acquisition and Preprocessing: The algorithm begins by allowing the user to select a CT image file through a graphical file selection interface. Once the image is loaded, it is checked for its color format. Since CT images are typically in grayscale, any image that is in RGB format is converted to grayscale to standardize the processing steps. This ensures consistency in intensity values and reduces computational complexity. The grayscale image is then displayed to serve as a reference for comparison with subsequent processing stages.
b) Detection of Metal Artifact Regions: Metal artifact s typically appear as regions of very high intensity due to the dense nature of metallic objects. To detect these regions, the algorithm uses a histogram-based adaptive thresholding technique. Specifically, it applies Otsu's method to determine a global threshold value, which is then adjusted slightly to better capture the intensity range associated with metallic artifact s. Pixels exceeding this threshold are marked as potential artifact s, resulting in a binary mask. This initial mask identifies areas likely to contain metal-induced distortions.
c) Mask Refinement Using Morphological Operations: The binary mask generated in the previous step may contain small gaps or fragmented regions due to noise or non-uniform artifact shapes. To address this, morphological closing is applied using a disk-shaped structuring element. This operation helps to close small holes and connect nearby regions. Additionally, hole-filling techniques are used to ensure that enclosed regions within the artifact mask are not missed. The result is a cleaner and more continuous mask that more accurately outlines the artifact -affected areas. This refined mask is displayed for visual verification.
d) Image Inpainting to Restore Affected Regions: Once the artifact regions are identified and refined, the algorithm proceeds to restore them using region filling, a form of image inpainting. This technique estimates the pixel values within the masked areas based on the surrounding, unaffected regions. The goal is to reconstruct the obscured anatomical structures in a visually plausible manner, guided by the context of nearby tissue. The result is an intermediate image where the most prominent artifact s have been removed or suppressed, and the affected regions have been filled with estimated intensity values.
e) Edge-Preserving Smoothing Using Bilateral Filtering: The inpainted image may still contain some sharp transitions or minor inconsistencies due to the nature of the reconstruction process. To refine the image further, a bilateral filter is applied. This filter smooths the image by averaging similar neighboring pixels, but unlike conventional filters, it preserves edges by considering both spatial and intensity similarities. This is particularly important in medical imaging, where maintaining edge definition is crucial for accurately representing anatomical boundaries.
f) Blending and Final Image Reconstruction: In the final step, the algorithm blends the processed image with the original grayscale image to produce a natural-looking result. Specifically, the pixel values in the artifact regions of the original image are replaced with those from the filtered image. An intensity adjustment is applied to maintain consistency in brightness and contrast across

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the blended image. The final result is an enhanced CT image in which metal artifact s have been effectively suppressed, and the anatomical structures are preserved with improved clarity.

This step-by-step approach ensures that metal artifact s are accurately identified, effectively removed, and plausibly reconstructed, making the resulting image more suitable for clinical interpretation. Moreover, the simplicity and modularity of the algorithm make it suitable for implementation in both software and hardware platforms, as explored further in this study.

IV. RESULTS AND DISCUSSION

The simulation and testing of the proposed algorithm were conducted using MATLAB R2023a on a Windows-based system with an Intel Core i7 processor and 16 GB RAM. The MATLAB Image Processing Toolbox was used extensively for tasks such as morphological operations, filtering, and inpainting. A graphical interface was included to facilitate interactive image selection. For validation, multiple lung CT images containing known metal artifacts were collected from publicly available databases and clinical case archives, ensuring variation in image quality and artifact severity. Each image was processed through the algorithm pipeline, with intermediate outputs—such as the metal mask, inpainted image, and final artifact-reduced image—displayed and saved for analysis.

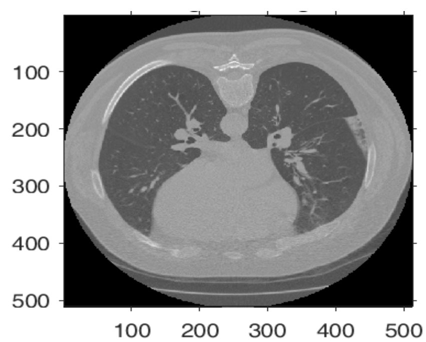

Fig. 2 Original Lung CT image

The original CT image of the lungs, as shown in the final figure labeled “Original Image”, clearly exhibits metal artefacts appearing as bright streaks in the mediastinal region. These streaks originate from high-density materials present during scanning and cause significant distortion of nearby anatomical structures. The artefacts reduce the visibility of finer pulmonary details and can interfere with accurate diagnosis, particularly in regions where subtle tissue contrasts are important. To address this, the image is first transformed into the frequency domain using a two-dimensional Fourier Transform. The corresponding frequency spectrum, presented in the image titled “Magnitude in Fourier Domain”, reveals the artefact frequencies as distinguishable directional lines or peaks. These components often appear as bright streaks near the center or along specific orientations in the spectrum. This transformation is critical, as it allows the identification and isolation of artefact-contributing frequency components that can then be selectively attenuated using filtering techniques.

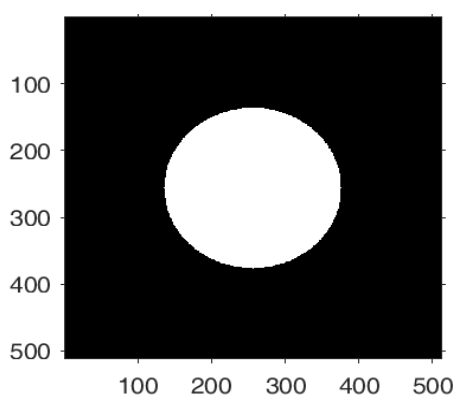

Fig.3 Mask filter adopted for artifact removal

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A circular low-pass filter mask, shown in the figure titled “Mask Filter”, is applied to the frequency domain representation. This mask is designed to preserve the low-frequency components associated with essential anatomical structures while suppressing the high-frequency artefacts that contribute to the streaking.

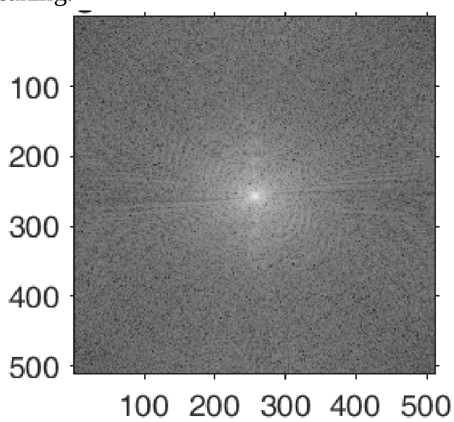

Fig.4 Magnitude plot in Frequency domain for artifact removal

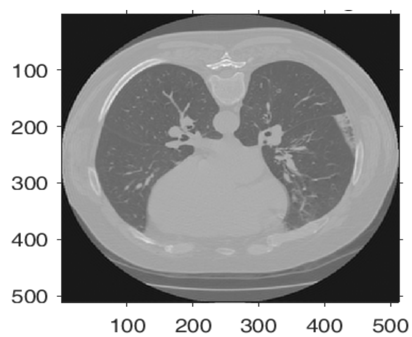

Fig. 5 Filtered and metal artifact removed CT image

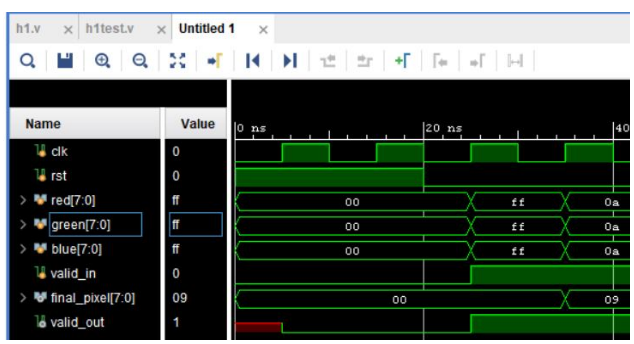

Fig. 6 Verilog Implementation of Metal artifact removal using frequency domain filtering

By applying this mask and then performing an inverse Fourier Transform, the processed image—displayed as “Low-Pass Filtered Image”—shows a significant reduction in artefact intensity. The filtered image demonstrates clearer visibility of the lung parenchyma and mediastinal anatomy, with smoother tissue transitions and fewer distortions. The sinogram, depicted in the image labeled “Sinogram”, provides further insight into how artefacts manifest in the projection domain. It reveals high-intensity bands and inconsistencies in specific angular views, which correlate with the artefact regions seen in the spatial domain. While the current approach operates in the frequency domain post-reconstruction, analyzing the sinogram offers valuable understanding of the origin and distribution of artefacts. Lastly, the RTL schematic (first image) illustrates the hardware module named `metal_artifact_removal`, receiving RGB image inputs along with clock and reset signals. This module represents the Verilog-based implementation of the artefact reduction logic, designed for FPGA synthesis and capable of supporting real-time applications by efficiently filtering each image frame as it arrives.

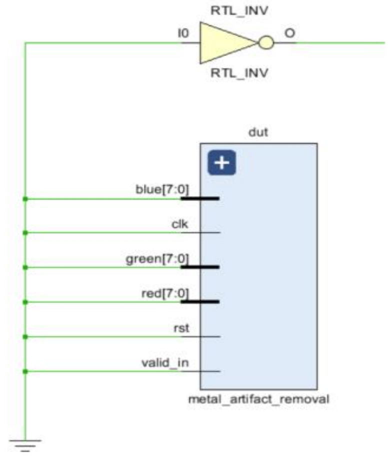

Fig. 7 RTL extracted circuit for metal artifact removal framework

V. CONCLUSION

This study presents a practical approach for reducing metal artefacts in lung CT images using frequency domain filtering, supported by both software and hardware implementations. By identifying and suppressing high-frequency components responsible for artefacts, the method significantly improves image clarity while preserving important anatomical features. The use of a low-pass mask in the Fourier domain effectively minimizes streaking caused by metallic implants, leading to visually enhanced outputs. The algorithm, developed in MATLAB, demonstrates consistent performance across varied input images. To enable real-time processing, the filtering logic was also implemented in Verilog and synthesized on FPGA hardware, highlighting its potential for clinical integration in embedded systems. The combined use of signal processing and hardware acceleration makes the proposed method both efficient and adaptable. Overall, the approach offers a reliable post-processing solution for improving the diagnostic quality of CT images, especially in scenarios where access to raw projection data is limited.

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