High-Frequency Prior Neural Radiance Field for CBCT Reconstruction

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Abstract

Implicit Neural Representations (INR) have emerged as a promising framework for medical imaging reconstruction, particularly in Cone Beam Computed Tomography (CBCT). Unlike traditional explicit voxel-based representations, INR models continuous volumetric signals using neural networks, enabling high-resolution reconstruction from sparse or incomplete projections. However, achieving accurate and detailed reconstructions with INR often requires extensive training time, and high-frequency details may be lost during optimization due to spectral bias. Traditional analytical methods such as Filtered Back Projection (FDK) preserve high-frequency structures but are prone to cone-beam artifacts and noise amplification. To address these limitations, we propose a novel approach called High-Frequency Prior Implicit Neural Representation (HFPINR) for CBCT reconstruction.

HFPINR effectively combines the strengths of FDK and INR through a two-stage training strategy. In the first stage, the FDK reconstruction is embedded into the network as a high-frequency prior by initializing the implicit representation with structural details extracted from the FDK result. In the second stage, the network is refined by enforcing projection consistency, where the rendered projections from the current volume are compared against the measured sinogram data and used to update the network parameters. This progressive optimization suppresses cone-beam artifacts and improves convergence, leading to high-fidelity CBCT reconstructions.

Experimental results demonstrate that HFPINR significantly improves reconstruction accuracy and image quality compared to conventional methods, offering a robust solution for high-fidelity CBCT imaging. This work highlights the potential of synergizing classical reconstruction techniques with modern implicit neural representations to overcome longstanding challenges in medical imaging.

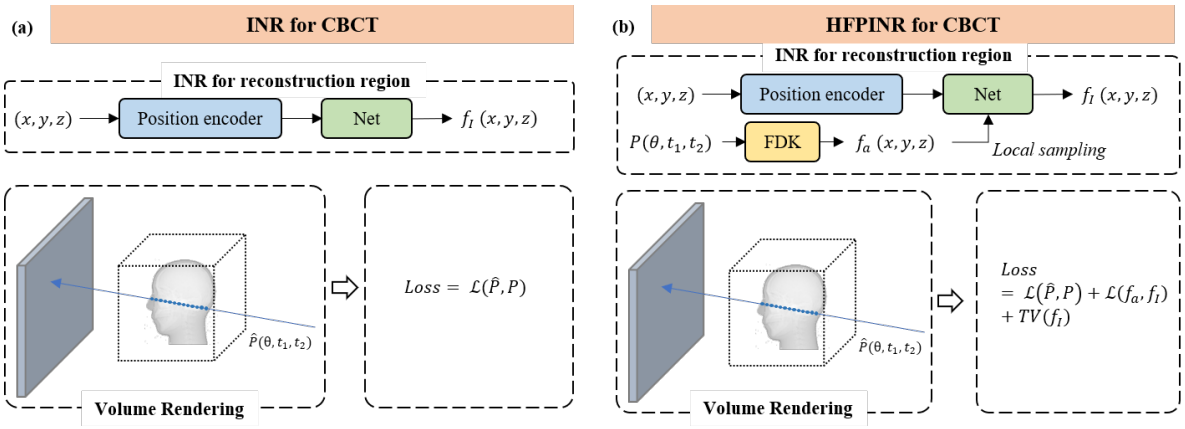

Figure 1: (a) INR for CBCT; (b) High-Frequency Prior INR (HFPINR) for CBCT. HFPINR integrates the strengths of FDK and INR by incorporating a FDK result into the INR framework, effectively balancing the preservation of fine details and the reduction of artifacts. The loss function of HFPINR consists of three components: the projection item, FDK item and TV item.

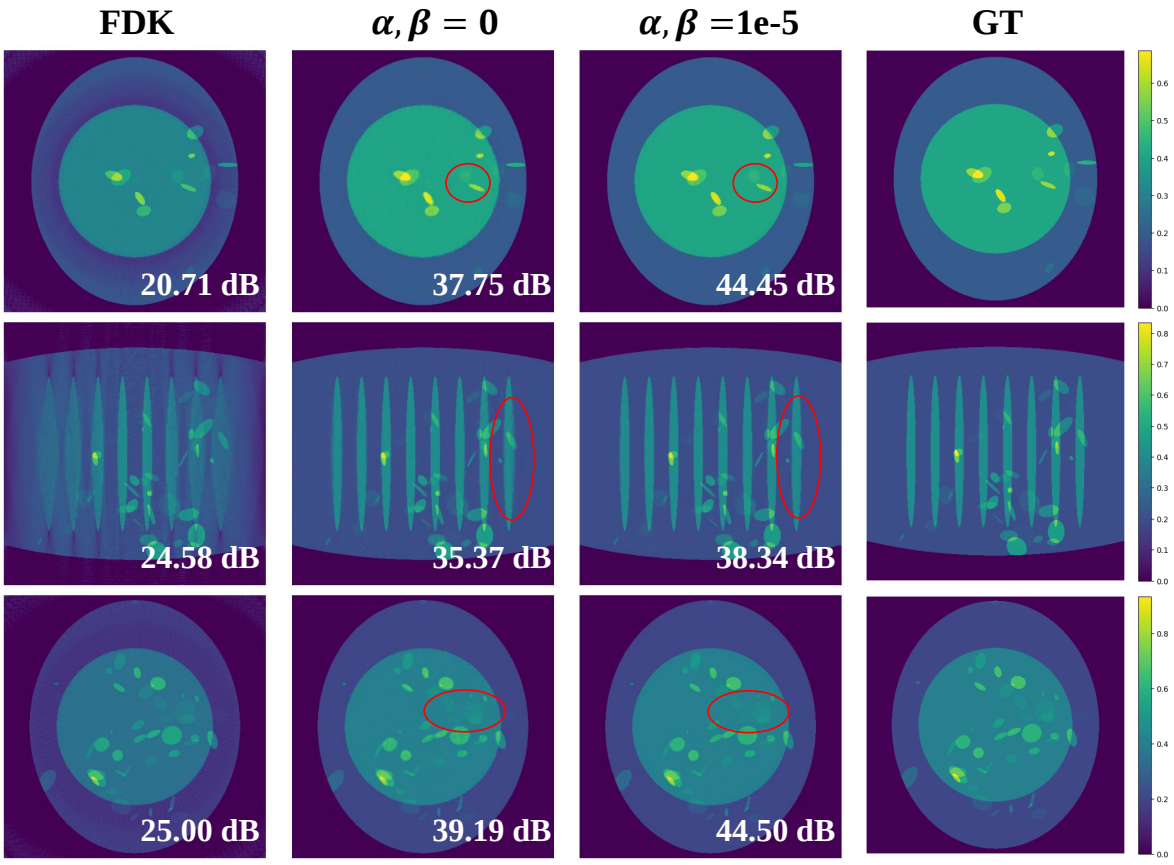

Figure 2: Qualitative results of different methods. From left to right: FDK reconstructions, HFPINR with $\alpha = 0$ and $\beta = 0$, HFPINR with $\alpha = 10^{-5}$ and $\beta = 10^{-5}$, and the ground truth CT slices. The first row is CT slice with $z = 138$, the second row is CT slice with $x = 228$, and the third row is CT slice with $z = 328$.