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Generative AI and Recent Advances for Medical Image Reconstruction in Positron Emission Tomography (PET)

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Extended Abstract

Positron-emission tomography (PET) image reconstruction has advanced over many decades, driven by the imperative to maximise image quality from inherently low-count, noisy data and limited spatial resolution. Historically, major progress has been achieved by (i) improving the data model — including forward-projection physics, modelling of scatter, attenuation, point-spread function, and the Poisson statistics of photon counts — and (ii) improving the image model — through the choice of basis functions, regularisation, or anatomical guidance to suppress noise and enhance spatial resolution. Within this framework, maximum a posteriori (MAP) reconstruction methods emerged as the state-of-the-art, combining improved data models with explicit image priors (for example, edge-preserving or MRI-informed) to achieve substantial noise reduction and spatial resolution recovery.

Yet such conventional priors remain limited: they are either overly simplistic (e.g. relative-difference smoothing, total-variation penalties) or overly prescriptive (e.g. anatomical image guidance, which can mislead when PET tracer uptake diverges from anatomical features). The most recent frontier has therefore been defined by deep learning and generative AI, spanning from supervised data-driven mappings, through physics-informed unrolled networks, to the cutting edge of generative modelling of the posterior distribution of PET images. In particular, score-based generative and diffusion-model frameworks for fully 3D PET reconstruction now enable the generation of multiple plausible reconstructions — samples from a learned posterior — offering improved robustness to domain shift and out-of-distribution pathologies. Rather than producing a single "best" image, these models generate a distribution of reconstructions, thereby quantifying uncertainty. Coupled with recent major advances in PET scanner technology, particularly total-body PET imaging, the integration of generative AI and deep learning promises a new era of clinical PET — one characterised by shorter scan times, lower radiation doses, enhanced quantitative accuracy, and ultimately, improved diagnostic and prognostic capability.