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Practice of domain knowledge towards robust and generalizable deep learning-based CT-free PET attenuation and scatter correction

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Deep learning (DL)-based methods have been proposed to substitute CT-based PET attenuation and scatter correction to achieve CT-free PET imaging. A critical bottleneck for these DL-based methods is their limited capability in the application in the heterogeneous domain of PET imaging, i.e. a variety of scanners and tracers. This study employs a simple way to integrate domain knowledge in deep learning for CT-free PET imaging. In contrast to conventional direct deep learning methods, we simplify the complex problem by a domain decomposition so that the learning of anatomy-dependent attenuation correction can be achieved robustly in a low-frequency domain while the original anatomy-independent high-frequency texture can be preserved during the processing. The effectiveness and robustness of our proposed approach was verified in tests of external imaging tracers on different scanners. Whole body PET images of 829 patients using 18F-FDG, 18F-PSMA, 68Ga-DOTA-TOC, 68Ga-DOTA-TATE, 68Ga-FAPI, acquired using clinical PET scanners, including Biograph Vision (Siemens Healthineers), United Imaging uMI 780 (United Imaging), Discovery MI (General Electric Healthcare) in Shanghai and Bern, were included for the development and testing of the proposed method. Although the method was developed using one tracer (18F-FDG) and one scanner, it achieved an average whole-body normalized root mean squared error (NRMSE) and peak signal-to-noise ratio (PSNR) of $0.3\% \pm 0.2\%$ and 51.5 ± 6.4 respectively for different scanners, and $0.6\% \pm 0.4\%$ and 47.5 ± 7.4 for different tracers, which have significantly improved over conventional deep learning methods. The proposed decomposition-based method provides a simple approach to incorporating domain knowledge in deep learning, which can significantly improve the performance and robustness of CT-free PET correction. The robust, generalizable and transparent DL development may enhance the potential of clinical translation.

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