Abstract

Low-dose computed tomography (CT) imaging has revolutionised medical diagnostics by significantly reducing radiation exposure during examinations. This crucial advancement comes with the inherent challenge of increased noise levels in acquired images, which can degrade the accuracy and utility of diagnostic information. To mitigate this issue, effective denoising techniques are essential to enhance the quality of low-dose CT images.

This doctoral thesis addresses the challenges and limitations of CNN-based denoising in low-dose CT imaging. In the first section of the thesis, we demonstrated the exploitation of the intrinsic characteristics of CT images, such as intra-slice and inter-slice similarity, to achieve improved denoising. Through innovative architectural modifications, we substantially enhanced the denoising performance of state-of-the-art methods. These architectural enhancements were designed to leverage the inherent characteristics CT images, leading to superior outcomes. Additionally, we proposed a novel self-supervised denoising approach that utilises inter-slice similarity to train a deep denoising network using clean CT images. The self-supervised approach overcomes the limitation of requiring paired training data by utilising unpaired, low-dose, and clean CT images.

The intricate characteristics of CT images, marked by varying noise levels linked to tissue density and a wide dynamic range, introduce a significant challenge to the optimal performance of CNN-based denoising techniques. There exists a pressing need for a thorough investigation into the impact of these factors on the efficacy of CNN-based denoising. Yet, this critical exploration remains relatively unexplored. To bridge this gap, the second section of the thesis undertakes an extensive analysis of the influence of this attribute on CNN-based denoisers. Additionally, we have introduced inventive methodologies aimed at alleviating these complexities, thereby ensuring robust performance even when confronted with such intricate challenges. Concretely, we have suggested a novel CT slicing technique to mitigate the challenges posed by large dynamic ranges. This approach involves partitioning the input image into various intensity ranges and utilising these sub-images as input for the neural network. Additionally, we have introduced a noise-conditioned dynamic weight modulation method to handle variations in noise levels present in low-dose CT images.

The third section of this thesis introduces a novel approach for low-dose CT denoising using CNN based denoisers and a reinforcement learning (RL) based agent. Specifically, we trained an RL agent to choose an optimal Gaussian denoiser to denoise a real low-dose CT image. The Gaussian denoisers were trained to remove synthetic Gaussian noise from the clean normal-dose CT images. The thesis's final section assessed how well the CNN based denoisers handle out-of-distribution test data. Like other computer vision tasks, the network's performance in this scenario also suffered when dealing with images from different distributions than its training data. To handle this challenge, we proposed an innovative strategy tailored to augment the denoising proficiency of the neural networks, particularly concerning out-of-distribution test data. This approach involves the application of domain adversarial learning coupled with cross-consistency-based training, aiming to enhance the model's adaptability to diverse and previously unencountered data distributions.

In summary, this research offers a thorough investigation of new approaches to tackle the challenges of CNN-based low-dose CT denoising. It introduces various innovations, such as non-local neural network modules, memory networks leveraging inter-slice coherence, self-supervised denoising methods, and domain adaptation techniques. Together, these advancements have the capacity to transform low-dose CT denoising, enhancing diagnostic accuracy and image quality for the benefit of medical professionals and patients alike. By addressing critical gaps in low-dose CT imaging, this work paves the way for more effective techniques in the future. As low-dose CT imaging progresses, the findings presented here have the potential to shape the landscape of medical diagnostics.

Keywords: Image denoising; Low-Dose CT; Computed tomography imaging; Convolutional neural network; Low-dose CT denoising; Self supervised denoising; Low-dose CT restoration; Image restoration