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A Hybrid CNN and Reinforcement Learning Approach for Parameter Estimation from Magnetic Tweezer Images

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Extracting algorithm parameters based on visual outputs presents a significant challenge, as the relationship between the appearance of an image and the underlying parameters that generated it is often non-linear and lacks clear statistical correlation. Traditional supervised learning approaches, such as Convolutional Neural Networks, struggle with this task due to their reliance on direct feature-to-parameter mapping and can be harmed by noisy inputs which is detrimental especially in magnetic tweezer experiment data, where the images are both noisy and low resolution. While powerful, transformer-based models are often impractical for this domain due to their demand for large datasets.

To address these limitations, we propose a hybrid framework that combines Convolutional Neural Networks with Reinforcement Learning for precise parameter regression. The method follows a multi-stage pipeline: first, a DnCNN-based denoising block is used to enhance the quality of the input image. By adaptively adjusting denoising parameters based on validation loss, this block achieved better performance than traditional denoising techniques in the context of analyzing diffraction ring images from magnetic tweezers experiments. Next, a feature extraction CNN then processes this cleaned image to encode its characteristics into a compact representation. It serves as the initial state for a reinforcement learning model, specifically a policy gradient reinforcement learning approach, which predicts and refines the parameter vector. The agent is fine-tuned through a feedback loop where its predictions are executed by the external algorithm, and the resulting performance metric is used as a reward signal to guide further learning.

Experimental results demonstrate that our framework achieves superior regression accuracy compared to conventional CNN models, showing consistently lower error and greater prediction stability, while avoiding the data requirements of transformer models, making it suitable for a wide range of applications with limited training data. Due to the denoising stage the proposed method is especially effective in domains dealing with low-resolution or noisy visual data such as microscopy.

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