Deep Learning-Based Microstructure Reconstruction for Characterizing the Electromechanical Property of Nanomaterial Networks

Cameron J. Maloney[a], Lucas Taliaferro[b], Jonathan D. Ventura[a], and Long Wang[c,*]

[a]Department of Computer Science & Software Engineering, California Polytechnic State University, 1 Grand Ave., San Luis Obispo, CA, USA 93407;
[b]Department of Biomedical Engineering, California Polytechnic State University, 1 Grand Ave., San Luis Obispo, CA, USA 93407;
[c]Department of Civil and Environmental Engineering, California Polytechnic State University, 1 Grand Ave., San Luis Obispo, CA, USA 93407
*E-mail: lwang38@calpoly.edu

ABSTRACT

Various microscopic imaging techniques, such as optical microscopy, scanning electron microscopy, and X-ray microscopy, are currently essential for characterizing multi-scale material behavior and for understanding the structure-property relationships. However, to establish a large enough microstructural image library of target materials through experimental imaging, the process can be expensive, time-consuming, and inaccessible. On the other hand, there is an emerging trend of leveraging computational techniques (e.g., traditional statistical approach and machine learning/artificial intelligence) to more efficiently generate microstructural images that can be utilized in material studies. Therefore, this study focuses on developing deep learning (DL) approaches for reconstructing and artificially generating microstructures of strain-sensing nanomaterial networks based on microscopic images. Here, the nanomaterial networks are fabricated using a novel manufacturing technique, namely corona-enabled electrostatic printing (CEP), to attract carbon nanotubes (CNTs) onto flexible substrates. The fabricated CNT networks were previously found to exhibit strain sensing performance. To better understand this electromechanical behavior, optical microscopic images of CNT networks under different tensile strains are first experimentally obtained and used for developing the DL models. In this study, we employ a Generative Adversarial Network (GAN) that imitates the FastGAN architecture, incorporating skip-layer excitation and differentiable augmentation. The GAN model is conditioned on specific microstructure metrics, such as porosity, and uses the Learned Perceptual Image Patch Similarity (LPIPS) as part of its loss function to ensure realistic image generation. The model is trained on 2048x2048 images, allowing it to accurately replicate complex microstructural patterns. Furthermore, to compare the electrical properties associated with the experimentally and artificially generated images, finite element analyses are performed using the corresponding microstructural images. Overall, this study establishes a DL-based technique for generating a large database for characterizing the electrical properties of nanomaterial networks at micro-scale in a low-cost and efficient manner.

Keywords: flexible electronics, generative artificial intelligence, image reconstruction, microstructure, nanomaterials, strain sensing