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Transfer learning empowers material Z classification with muon tomography

Cosmic-ray muon sources exhibit distinct scattering angle distributions when interacting with materials of different atomic numbers (Z values), facilitating the identification of various Z-class materials, particularly those radioactive high-Z nuclear elements. Most of the traditional identification methods are based on complex statistical iterative reconstruction or simple trajectory approximation. Supervised machine learning methods offer some improvement but rely heavily on prior knowledge of target materials, significantly limiting their practical applicability in detecting concealed materials. For the first time, transfer learning is introduced into the field of muon tomography in this work. We propose two lightweight neural network models for fine-tuning and adversarial transfer learning, utilizing muon scattering data of bare materials to predict the Z-class of materials coated by typical shieldings (e.g., aluminum or polyethylene), simulating practical scenarios like cargo inspection and arms control. By introducing a novel inverse cumulative distribution-based sampling method, more accurate scattering angle distributions could be obtained from data, leading to an improvement by nearly 4% in prediction accuracy compared with the traditional random sampling-based training. When applied to coated materials with limited labeled or even unlabeled muon tomography data, the proposed method achieves an overall prediction accuracy exceeding 96%, with high-Z materials reaching nearly 99%. Simulation results indicate that transfer learning improves prediction accuracy by approximately 10% compared to direct prediction without transfer. This study demonstrates the effectiveness of transfer learning in overcoming the physical challenges associated with limited labeled/unlabeled data, and highlights the promising potential of transfer learning in the field of muon tomography.

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