PHYSICALLY CONSISTENT IMAGE AUGMENTATION FOR DEEP LEARNING IN MUELLER MATRIX POLARIMETRY

Christopher HAHNE*,[1] Omar RODRÍGUEZ-NUÑEZ,[2] Éléa GROS,[3] Théotim LUCAS,[5] Ekkehard HEWER,[4] Tatiana NOVIKOVA,[5] Theoni MARAGKOU,[3] Philippe SCHUCHT,[2] Richard MCKINLEY,[5]

[1]Support Center for Advanced Neuroimaging, University of Bern, 3012 Bern, Switzerland;
[2]Department of Neurosurgery, Inselspital, University of Bern, 3010 Bern, Switzerland;
[3]Institute of Pathology, Lausanne University Hospital, 1011 Lausanne, Switzerland;
[4]Institute of Pathology Lausanne University Hospital, Lausanne, Switzerland;
[5]LPICM, CNRS, Ecole Polytechnique, 91128 Palaiseau, France;
**christopher.hahne@unibe.ch*

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Image augmentations are essential for enhancing dataset diversity and improving the generalization of deep learning models. Conventional geometric transforms fail to preserve the polarization properties encoded in Mueller matrix images. We introduce a physics-based augmentation framework that couples spatial isometric mappings (rotations, flips) with corresponding polarimetric transformations in the Mueller domain. Spatial operations are represented by orthogonal matrices in O(2), while polarimetric changes are modeled via the special orthogonal transform on Stokes vectors, ensuring physical consistency. By integrating augmentation at the calibration stage, we enable efficient, on-the-fly generation of augmented data within PyTorch data loaders. An image-based validation using brain tissue samples rotated in 10° increments demonstrates that our method achieves the lowest mean absolute error in linear retardance azimuth alignment, outperforming spatial-only and an angle of polarization offset method [1]. A semantic segmentation task for tumor delineation in brain tissue samples shows that polar-aware augmentations surpass absent augmentation and spatial-only techniques by means of Dice score and an intersection-over-union (IoU). Computational overhead remains moderate (210 ms per frame) and is readily parallelized during training. Our results underscore the necessity of embedding polarization physics into augmentation pipelines for Mueller matrix polarimetry, particularly in data-constrained biomedical imaging scenarios. This approach promotes robust feature learning and offers a cost-effective strategy to mitigate limited sample availability, paving the way for advanced polarimetric deep learning applications.

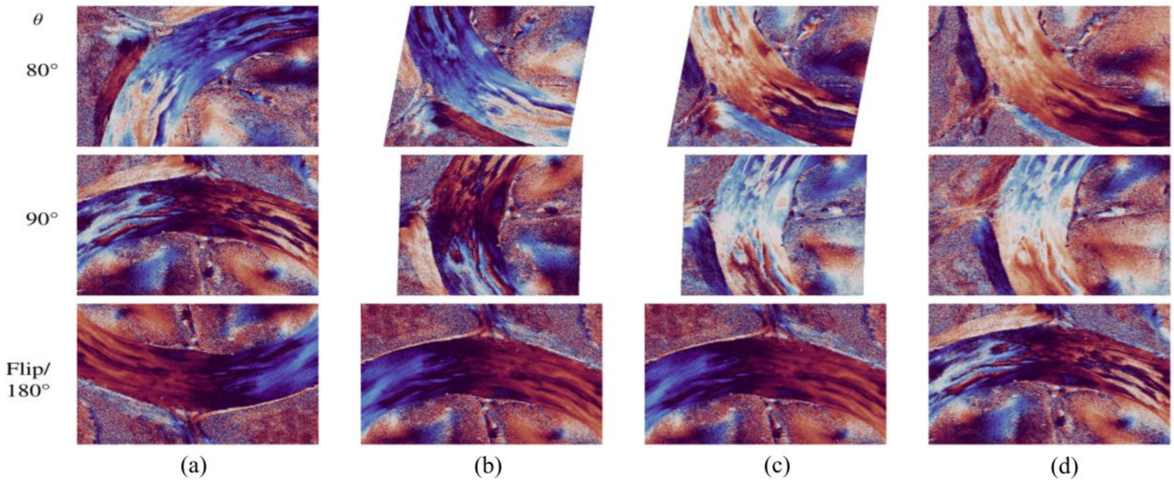

Fig. 1: Schematic illustration of polarimetric data augmentation: a) input image of the azimuth; rotation/flip in b) spatial and c) polarimetric domain; d) experimental ground truth images.

[1]. C. Hahne et al., "Physically Consistent Image Augmentation for Deep Learning in Mueller Matrix Polarimetry," IEEE Trans. on Image Processing, (under review)