Physics-Aware AI for Early Disease Detection

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Hyperspectral imaging is a powerful medical tool capable of detecting cellular chemical shifts before visible symptoms arise. However, the efficacy of this technology is currently throttled by a rigid physical limitation where clinicians are forced to choose between the speed of image acquisition, the spatial clarity of the picture, and the spectral depth required for accurate chemical analysis.

This limitation often leaves vital metabolic indicators for conditions ranging from multiple sclerosis to breast cancer obscured by data that is either too blurry to interpret or too cumbersome for live clinical settings. I have dismantled this barrier by engineering HyReS, a Physics-Aware Deep Learning model. Unlike conventional AI that often hallucinates missing data, HyReS integrates the imaging system's governing physical laws directly into its learning architecture.

By mathematically aligning the neural network with optical physics, HyReS solves the complex inverse problem of resolution loss, ensuring that restored images remain biologically faithful rather than becoming artifacts of machine learning. HyReS delivers a 16-fold increase in spatial resolution while making the imaging process 12 times quicker. This performance leap significantly lowers barriers to entry, making high-quality diagnostics both cheaper and faster to deploy. HyReS has led to the discovery of previously undetectable metabolic signatures associated with Down's syndrome and the characterisation of breast cancer micro-calcifications and myelin degradation in multiple sclerosis.

The release of this software as an open-source tool equips clinicians with a cost-effective capability that transcends hardware limits, ensuring the earliest mathematical signs of disease are no longer invisible.

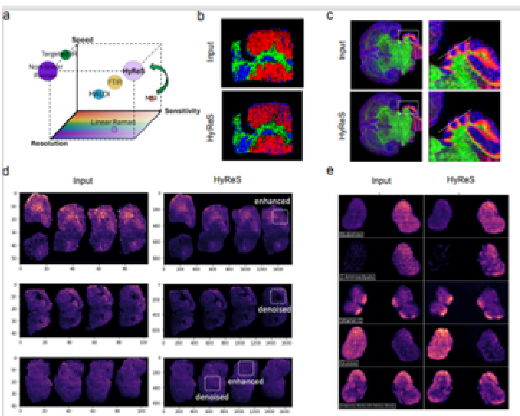

Figure 1. (a) Traditional imaging methods are confined to a strict compromise between Speed, Sensitivity, and Resolution. HyReS leaps outside the conventional limits to achieve high performance in all three dimensions. (b) The segmentation of the input image of breast cancer tissues is noisy and scattered, HyReS clearly defines tissue boundaries and accurately differentiates between fatty (blue) and muscular (green) regions, aligning with ground truth obtained from optical image. (c) Pseudo-colored images highlight that HyReS sharpens edges and offers visibly improved SNR. (d) The low-resolution inputs of Down syndrome mouse brains obscure key anatomy HyReS reveals sharp structures, enabling the extraction of metabolic patterns that were previously impossible. (e) Comparison of key metabolites before and after restoration for the mouse brains with multiple sclerosis shows that HyReS preserves accurate chemical signatures without introducing false artifacts.