Joint Reconstruction and Super-Resolution of Hyper-Spectral CTIS Images

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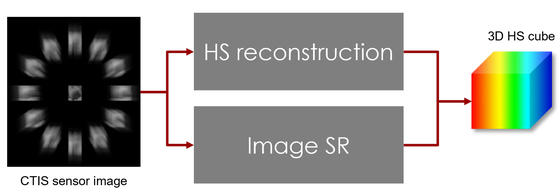
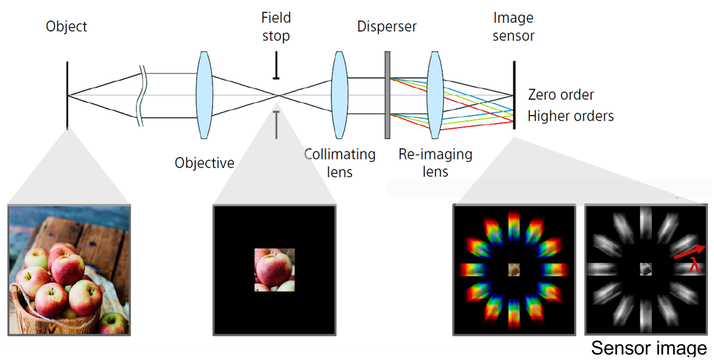
Abstract

Computed Tomography Imaging Spectrometers (CTIS) capture dense spectra of dynamic scenes as compressed 2D sensor measurements in a single shot. Model-based Hyper-Spectral (HS) image reconstruction algorithms devised for such systems are typically very slow and can only restore HS images with poor spatial resolution. We jointly address the issues of reconstruction speed and spatial resolution of CTIS through a simple and interpretable network architecture exploiting aliased pixel information in CTIS images to recover spatially super-resolved HS cubes.

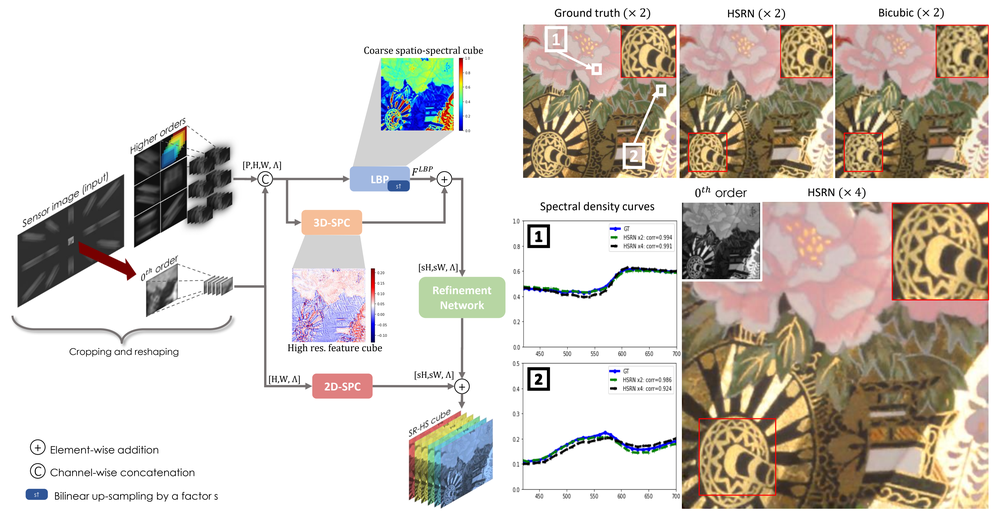


CTIS System



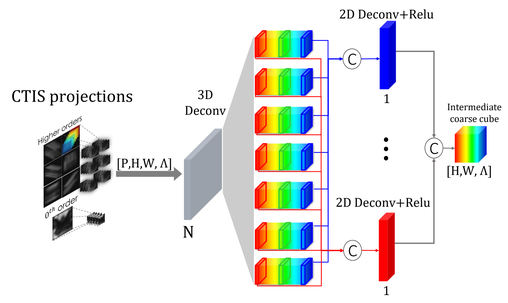
- The latent 3D HS cube is smeared and projected across multiple angles.
- Each projection in the sensor image carries distinct spatial and spectral information.
- The Spatial resolution is limited by that of the 0^{th} diffraction order.

Proposed Network HSRN



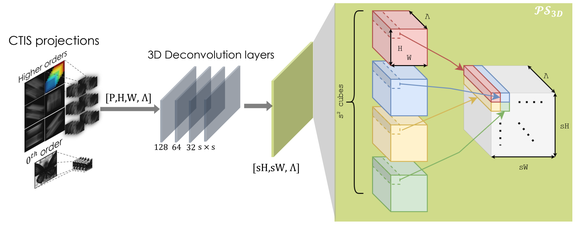
HSRN reconstructs coarse spatio-spectral cubes via LBP which are then added to a high resolution residual generated by 3D-SPC and are further fine-tuned via a dedicated CNN.

Learned Back Projection (LBP)



The Learned Back Projection (LBP) layer combines spatio-spectral information across all higher diffraction orders and the 0^{th} order.

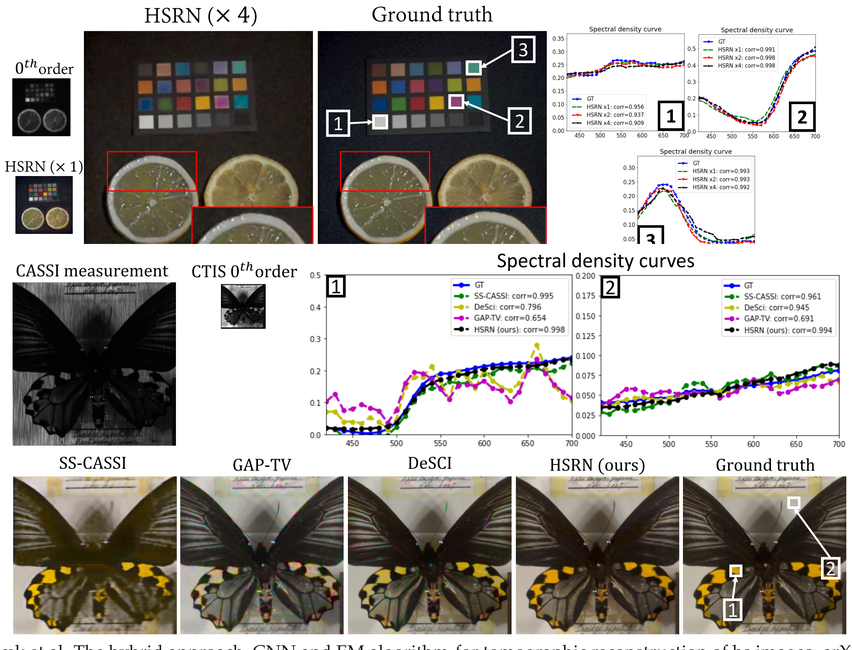
3D Sub-Pixel Convolution (3D-SPC)



- 3D Sub-Pixel Convolution (3D-SPC) module performs image super-resolution via 3D periodic reshuffling.
- Processing is carried out in low-resolution space.

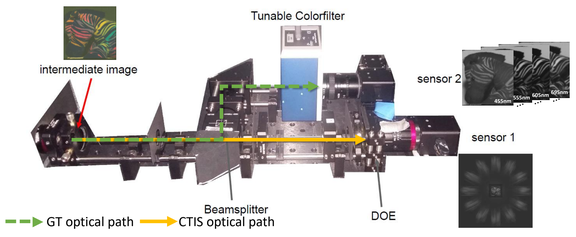
Results on Synthetic Data

Method	#Params (M)	Time (s) (CNN/EM)	TokyoTech-31 RMSE↓	TokyoTech-31 PSNR↑	TokyoTech-31 SSIM↑	CAVE RMSE↓	CAVE PSNR↑	CAVE SSIM↑	ICVL RMSE↓	ICVL PSNR↑	ICVL SSIM↑
Ahlebæk [1]	26.6	0.05 / ≥ 10	0.035	28.849	0.872	0.039	28.708	0.823	0.021	33.896	0.881
Zimmermann [2]	1.5	0.017 / -	0.028	33.033	0.917	0.024	34.448	0.941	0.005	47.497	0.991
HSRN (ours)	**0.9**	0.010 / -	**0.025**	**33.809**	**0.941**	**0.018**	**37.282**	**0.964**	**0.004**	**48.470**	**0.995**



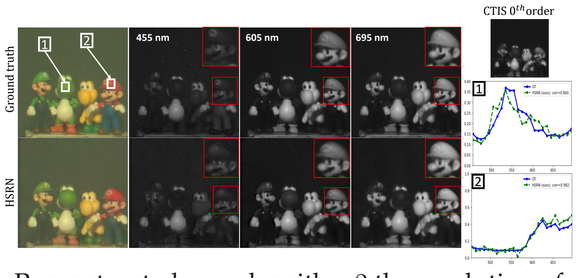
[1] Ahlebæk et al. The hybrid approach–CNN and EM algorithm-for tomographic reconstruction of hs images. arXiv, 2022.
[2] Zimmermann et al. DL-based HS image reconstruction from emulated and real ctis data. Optical Engineering, 2022.

Real CTIS Prototype



- GT data are captured in a secondary optical path by using a tunable color filter (*Varispec*).
- We capture 25 spectral bands in the range $[455nm, 695nm]$ with $10nm$ steps.

Results on Real Data



Reconstructed sample with $\times 2$ the resolution of the 0^{th} diffraction order: $278 \times 278 \times 25$.