# Local-Global Transformer Enhanced Unfolding Network for Pan-sharpening


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IJCAI/2023 MACAO

## Summary


- **Task description:** *Pan-sharpening* aims to increase the spatial resolution of the low-resolution multispectral (LrMS) image with the guidance of the corresponding panchromatic (PAN) image.
  - **Input:** The coupled LrMS image and PAN image.
  - **Output:** A high-resolution multispectral (HrMS) image.
- **Existing two-fold deficiency:**
  - Model Interpretability----
  - Local and Global Dependencies----
- **Our main contributions:**
  - We customize a transformer module LGT as an image denoiser to efficiently model local and global dependencies at the same time and sufficiently mine the potential of the proposed unfolding pan-sharpening framework.
  - We develop an interpretable transformer-based deep unfolding network, LGTEUN.
  - To the best of our knowledge, LGTEUN is the first transformer-based deep unfolding network for the MS pan-sharpening, and LGT is also the first transformer module to perform spatial and frequency dual-domain learning.
  - **Code:** https://github.com/ lms-07/LGTEUN


## Proposed Method

- **Model formulation and optimization**

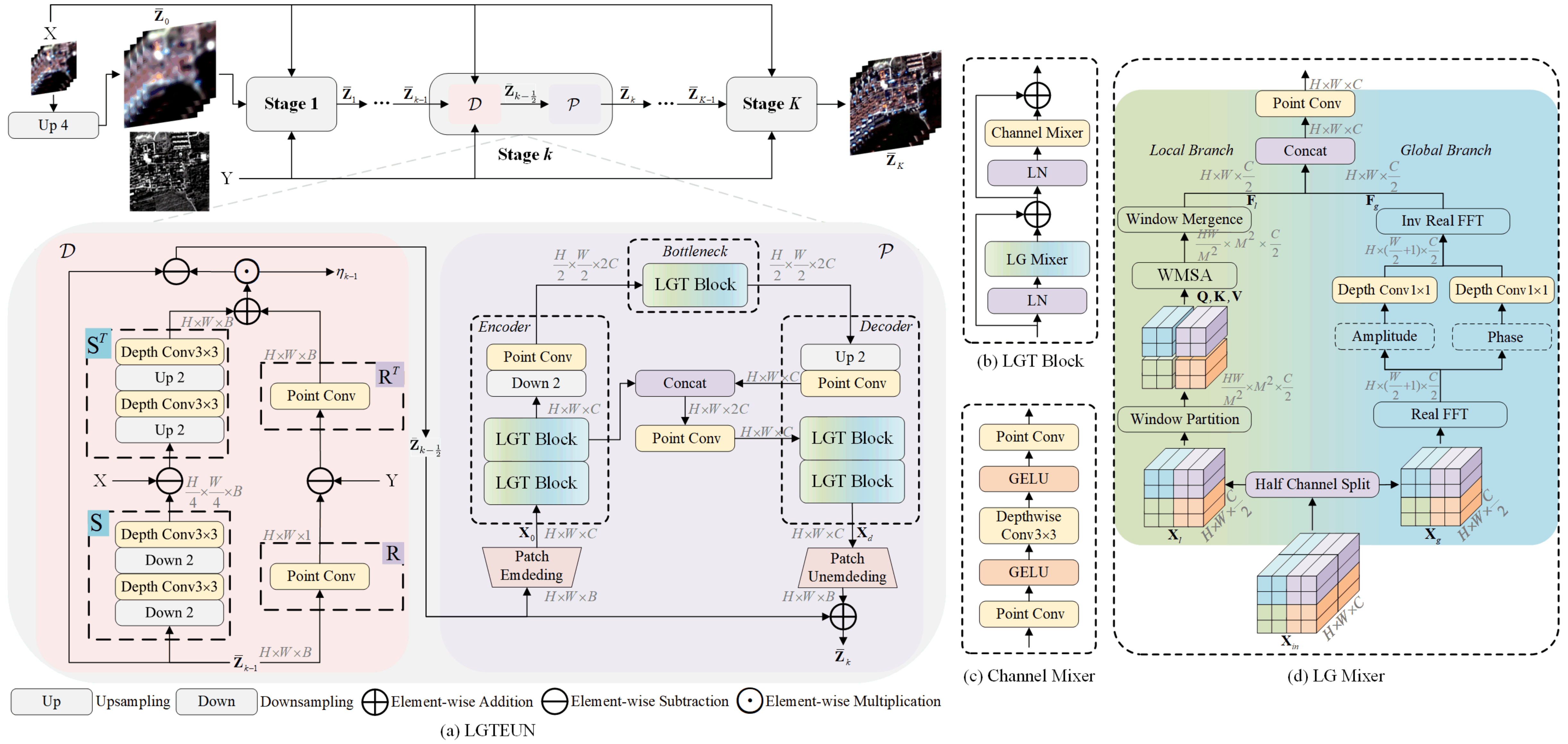
The degradation process of the HrMS image **Z**:

$$\mathbf{X} = \mathbf{SZ} + \mathbf{N}_x,\ \mathbf{Y} = \mathbf{ZR} + \mathbf{N}_y,$$

The energy function under MAP framework:

$$\bar{\mathbf{Z}} = \underset{\mathbf{Z}}{argmin} \frac{1}{2} \| \mathbf{X} - \mathbf{SZ} \|^2 + \frac{1}{2} \| \mathbf{Y} - \mathbf{ZR} \|^2 + \lambda J(\mathbf{Z}),$$

Fig: Illustration of the proposed LGTEUN.




Employing proximal gradient descent (PGD) algorithm:

$$\bar{\mathbf{Z}}_k = \underset{\mathbf{Z}}{argmin} \frac{1}{2} \| \mathbf{Z} - (\bar{\mathbf{Z}}_{k-1} - \eta \nabla f(\bar{\mathbf{Z}}_{k-1})) \|^2 + \lambda J(\mathbf{Z}),$$

The data terms oriented differentiable operator:

$$\nabla f(\bar{\mathbf{Z}}_{k-1}) = \mathbf{S}^T(\mathbf{S}\bar{\mathbf{Z}}_{k-1} - \mathbf{X}) + (\bar{\mathbf{Z}}_{k-1}\mathbf{R} - \mathbf{Y})\mathbf{R}^T.$$

The data subproblem and the prior subproblem:

$$\bar{\mathbf{Z}}_{k-\frac{1}{2}} = \bar{\mathbf{Z}}_{k-1} - \eta \nabla (\bar{\mathbf{Z}}_{k-1}),$$

$$\bar{\mathbf{Z}}_k = prox_{\eta, J}(\bar{\mathbf{Z}}_{k-\frac{1}{2}}),$$

- **Deep unfolding network**

Data module: $\bar{\mathbf{Z}}_{k-\frac{1}{2}} = \mathcal{D}(\bar{\mathbf{Z}}_{k-1}, \mathbf{X}, \mathbf{Y}, \eta_{k-1}).$

Prior module: $\bar{\mathbf{Z}}_k = \mathcal{P}(\bar{\mathbf{Z}}_{k-\frac{1}{2}}).$

- **Local-Global Transformer: LGT**
- **Local branch** calculates local window based self-attention in spatial domain.

$$\mathbf{F}_a^i = Softmax(\frac{\mathbf{Q}^i \mathbf{K}^{iT}}{\sqrt{d}} + \mathbf{P}^i)\mathbf{V}^i, \quad i = 1, ..., h,$$

- **Global branch** extracts global contextual feature representation in frequency domain.

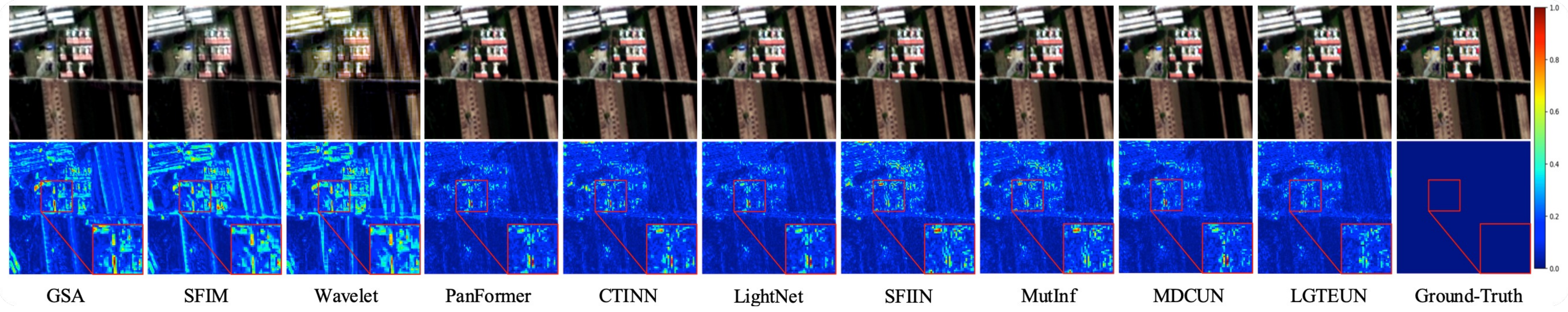
$$\mathcal{F}(\mathbf{X}_g)(u, v) = \frac{1}{\sqrt{HW}} \sum_{h=0}^{H-1} \sum_{w=0}^{W-1} \mathbf{X}_g(h, w) e^{-j2\pi(\frac{h}{H}u + \frac{w}{W}v)},$$

$$\mathcal{A}(\mathbf{X}_g)(u, v) = \sqrt{R^2(\mathbf{X}_g)(u, v) + I^2(\mathbf{X}_g)(u, v)},$$

$$\mathcal{P}(\mathbf{X}_g)(u, v) = arctan[\frac{I(\mathbf{X}_g)(u, v)}{R(\mathbf{X}_g)(u, v)}],$$

$$\mathbf{F}_g = \mathcal{F}^{-1}(DConv(\mathcal{A}(\mathbf{X}_g)), DConv(\mathcal{P}(\mathbf{X}_g))),$$

Fig: Qualitative comparison




## Experiments

- **Quantitative comparison**

| Method | WorldView-3 | | | | | WorldView-2 | | | | | GaoFen-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PSNR↑ | SSIM↑ | Q8↑ | SAM↓ | ERGAS↓ | PSNR↑ | SSIM↑ | Q4↑ | SAM↓ | ERGAS↓ | PSNR↑ | SSIM↑ | Q4↑ | SAM↓ | ERGAS↓ |
| GSA | 22.5164 | 0.6343 | 0.5742 | 0.1106 | 7.8267 | 33.5975 | 0.8899 | 0.5681 | 0.0573 | 2.5402 | 36.0557 | 0.8838 | 0.5517 | 0.0641 | 3.5758 |
| SFIM | 21.4154 | 0.5415 | 0.4525 | 0.1147 | 8.8553 | 32.6334 | 0.8728 | 0.5159 | 0.0597 | 3.1919 | 34.7715 | 0.8572 | 0.4584 | 0.0657 | 4.2073 |
| Wavelet | 21.4464 | 0.5656 | 0.5271 | 0.1503 | 9.1545 | 32.1992 | 0.8500 | 0.4577 | 0.0638 | 3.3799 | 33.9208 | 0.8197 | 0.4033 | 0.0695 | 4.6445 |
| PanFormer | 30.4772 | 0.9368 | 0.9316 | 0.0672 | 3.1830 | 41.3581 | 0.9731 | 0.8236 | 0.0241 | 1.0617 | 44.8540 | 0.9805 | 0.8865 | 0.0271 | 1.3334 |
| CTINN | 31.8564 | 0.9518 | 0.9460 | 0.0660 | 2.7421 | 41.2015 | 0.9735 | 0.8149 | 0.0246 | 1.0880 | 44.2942 | 0.9784 | 0.8716 | 0.0293 | 1.4148 |
| LightNet | 32.0018 | 0.9525 | 0.9472 | 0.0639 | 2.6853 | 41.5589 | 0.9739 | 0.8220 | 0.0237 | 1.0382 | 44.6876 | 0.9787 | 0.8741 | 0.0279 | 1.3510 |
| SFIIN | 31.6587 | 0.9492 | 0.9435 | 0.0652 | 2.8016 | 41.9489 | 0.9752 | 0.8108 | 0.0229 | 1.0084 | 44.7248 | 0.9802 | 0.8721 | 0.0280 | 1.3361 |
| MutInf | 31.8298 | 0.9523 | 0.9469 | 0.0636 | 2.7526 | 41.9522 | 0.9760 | 0.8258 | 0.0227 | 1.0153 | 44.8305 | 0.9800 | 0.8836 | 0.0277 | 1.3394 |
| MDCUN | 31.2978 | 0.9429 | 0.9363 | 0.0661 | 2.9295 | 42.3351 | 0.9772 | 0.8370 | 0.0216 | 0.9638 | 45.5677 | 0.9825 | 0.8915 | 0.0252 | 1.2249 |
| LGTEUN | 32.2188 | 0.9545 | 0.9494 | 0.0605 | 2.6286 | 42.6837 | 0.9786 | 0.8415 | 0.0208 | 0.9280 | 45.8364 | 0.9840 | 0.8973 | 0.0247 | 1.1824 |

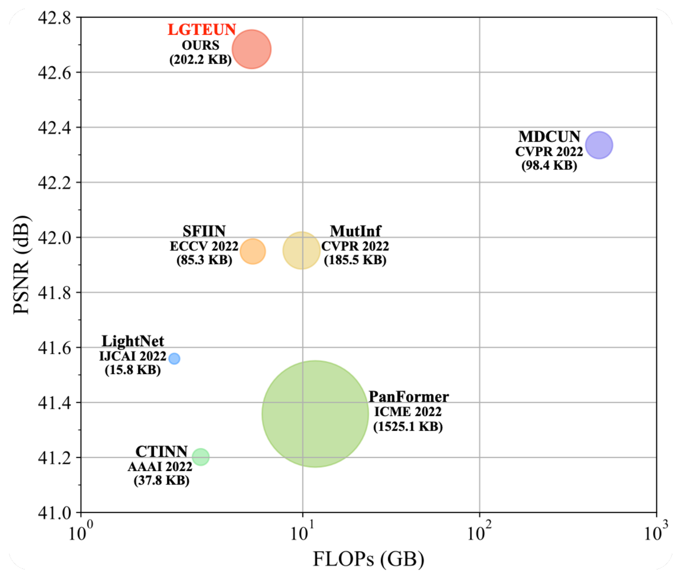
- **A key hyperparameter setting**

| Data Set | Metric | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
|---|---|---|---|---|---|
| WorldView-3 | PSNR↑ | 32.0339 | 32.2188 | 32.068 | 32.0042 |
| | SSIM↑ | 0.9532 | 0.9545 | 0.9535 | 0.9527 |
| | Q8↑ | 0.9481 | 0.9494 | 0.9487 | 0.9480 |
| | SAM↓ | 0.0605 | 0.0605 | 0.0603 | 0.0612 |
| | ERGAS↓ | 2.6765 | 2.6286 | 2.6678 | 2.6898 |
| | Time (s/img) | 0.0070 | 0.0133 | 0.0205 | 0.0262 |
| | Params (KB) | 270.2 | 540.0 | 809.9 | 1079.7 |
| | FLOPs (GB) | 9.52 | 19.04 | 28.56 | 38.08 |
| WorldView-2 | PSNR↑ | 42.600 | 42.6837 | 42.4771 | 42.1634 |
| | SSIM↑ | 0.9784 | 0.9786 | 0.9781 | 0.9767 |
| | Q4↑ | 0.8398 | 0.8415 | 0.8383 | 0.8329 |
| | SAM↓ | 0.0209 | 0.0208 | 0.0213 | 0.0222 |
| | ERGAS↓ | 0.9358 | 0.928 | 0.9573 | 0.9787 |
| | Time (s/img) | 0.0065 | 0.0137 | 0.0204 | 0.0254 |
| | Params (KB) | 101.2 | 202.2 | 303.2 | 404.2 |
| | FLOPs (GB) | 2.57 | 5.14 | 7.71 | 10.28 |

- **Full-resolution test**

| Method | Full-resolution Test | | |
|---|---|---|---|
| | $D_\lambda$↓ | $D_S$↓ | QNR↑ |
| GSA | 0.0094 | 0.1076 | 0.8839 |
| SFIM | 0.0094 | 0.1061 | 0.8854 |
| Wavelet | 0.0552 | 0.1330 | 0.8193 |
| PanFormer | 0.0191 | 0.0416 | 0.9400 |
| CTINN | 0.0123 | 0.0442 | 0.9440 |
| LightNet | 0.0185 | 0.0282 | 0.9539 |
| SFIIN | 0.0198 | 0.0352 | 0.9457 |
| MutInf | 0.0163 | 0.0420 | 0.9423 |
| MDCUN | 0.0747 | 0.1673 | 0.7708 |
| LGTEUN | 0.0162 | 0.0310 | 0.9532 |

- **Performance-efficiency comparison**




- **Efficiency comparison**

| Data Set | Metric | GSA | SFIM | Wavelet | PanFormer | CTINN | LightNet | SFIIN | MutInf | MDCUN | LGTEUN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WorldView-3 | Time (s/img) | 0.0482 | 0.0591 | 0.0562 | 0.0160 | 0.0426 | 0.0019 | 0.0529 | 0.1083 | 0.1747 | 0.0133 |
| | Params (KB) | – | – | – | 1532.8 | 38.3 | 16.3 | 85.8 | 185.8 | 140.9 | 540.0 |
| | FLOPs (GB) | – | – | – | 11.92 | 2.68 | 2.02 | 5.25 | 9.87 | 479.54 | 19.04 |
| GaoFen-2 | Time (s/img) | 0.0216 | 0.0301 | 0.0271 | 0.0257 | 0.0431 | 0.0017 | 0.0528 | 0.1141 | 0.1017 | 0.0129 |
| | Params (KB) | – | – | – | 1530.3 | 37.8 | 15.8 | 85.3 | 185.5 | 98.3 | 202.2 |
| | FLOPs (GB) | – | – | – | 11.77 | 2.65 | 1.95 | 5.22 | 9.85 | 473.19 | 5.14 |

- **Ablation study**

| Setting | | Reduced-resolution Test | | | | | Full-resolution Test | | |
|---|---|---|---|---|---|---|---|---|---|
| *Local Branch* | *Global Branch* | PSNR↑ | SSIM↑ | Q8↑ | SAM↓ | ERGAS↓ | $D_\lambda$↓ | $D_S$↓ | QNR↑ |
| ✗ | ✓ | 31.9309 | 0.9519 | 0.9468 | 0.0636 | 2.7102 | 0.0177 | 0.0364 | 0.9465 |
| ✓ | ✗ | 31.9742 | 0.9525 | 0.9468 | 0.0618 | 2.7029 | 0.0170 | 0.0349 | 0.9486 |
| ✓ | ✓ | 32.2188 | 0.9545 | 0.9494 | 0.0605 | 2.6286 | 0.0162 | 0.0310 | 0.9532 |

## Contact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Codebase

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