

SwinIR: Image Restoration Using Swin Transformer

Jingyun Liang¹ Jiezhong Cao¹ Guolei Sun¹ Kai Zhang^{1,*} Luc Van Gool^{1,2} Radu Timofte¹
¹Computer Vision Lab, ETH Zurich, Switzerland ²KU Leuven, Belgium

{jinliang, jiezhong, guosun, kai.zhang, vangool, timofte}@vision.ee.ethz.ch

<https://github.com/JingyunLiang/SwinIR>

Abstract

Image restoration is a long-standing low-level vision problem that aims to restore high-quality images from low-quality images (e.g., downsampled, noisy and compressed images). While state-of-the-art image restoration methods are based on convolutional neural networks, few attempts have been made with Transformers which show impressive performance on high-level vision tasks. In this paper, we propose a strong baseline model SwinIR for image restoration based on the Swin Transformer. SwinIR consists of three parts: shallow feature extraction, deep feature extraction and high-quality image reconstruction. In particular, the deep feature extraction module is composed of several residual Swin Transformer blocks (RSTB), each of which has several Swin Transformer layers together with a residual connection. We conduct experiments on three representative tasks: image super-resolution (including classical, lightweight and real-world image super-resolution), image denoising (including grayscale and color image denoising) and JPEG compression artifact reduction. Experimental results demonstrate that SwinIR outperforms state-of-the-art methods on different tasks by up to 0.14~0.45dB, while the total number of parameters can be reduced by up to 67%.

1. Introduction

Image restoration, such as image super-resolution (SR), image denoising and JPEG compression artifact reduction, aims to reconstruct the high-quality clean image from its low-quality degraded counterpart. Since several revolutionary work [18, 40, 90, 91], convolutional neural networks (CNN) have become the primary workhorse for image restoration [43, 51, 43, 81, 92, 95, 24, 93, 46, 89, 88].

Most CNN-based methods focus on elaborate architecture designs such as residual learning [43, 51] and dense connections [97, 81]. Although the performance is significantly improved compared with traditional model-based

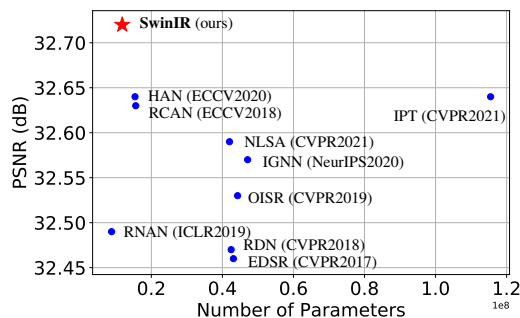


Figure 1: PSNR results v.s the total number of parameters of different methods for image SR ($\times 4$) on Set5 [3].

methods [73, 14, 28], they generally suffer from two basic problems that stem from the basic convolution layer. First, the interactions between images and convolution kernels are content-independent. Using the same convolution kernel to restore different image regions may not be the best choice. Second, under the principle of local processing, convolution is not effective for long-range dependency modelling.

As an alternative to CNN, Transformer [76] designs a self-attention mechanism to capture global interactions between contexts and has shown promising performance in several vision problems [6, 74, 19, 56]. However, vision Transformers for image restoration [9, 5] usually divide the input image into patches with fixed size (e.g., 48×48) and process each patch independently. Such a strategy inevitably gives rise to two drawbacks. First, border pixels cannot utilize neighbouring pixels that are out of the patch for image restoration. Second, the restored image may introduce border artifacts around each patch. While this problem can be alleviated by patch overlapping, it would introduce extra computational burden.

Recently, Swin Transformer [56] has shown great promise as it integrates the advantages of both CNN and Transformer. On the one hand, it has the advantage of CNN to process image with large size due to the local attention mechanism. On the other hand, it has the advantage of Transformer to model long-range dependency with the shifted window scheme.

*Corresponding author.

In this paper, we propose an image restoration model, namely SwinIR, based on Swin Transformer. More specifically, SwinIR consists of three modules: shallow feature extraction, deep feature extraction and high-quality image reconstruction modules. Shallow feature extraction module uses a convolution layer to extract shallow feature, which is directly transmitted to the reconstruction module so as to preserve low-frequency information. Deep feature extraction module is mainly composed of residual Swin Transformer blocks (RSTB), each of which utilizes several Swin Transformer layers for local attention and cross-window interaction. In addition, we add a convolution layer at the end of the block for feature enhancement and use a residual connection to provide a shortcut for feature aggregation. Finally, both shallow and deep features are fused in the reconstruction module for high-quality image reconstruction.

Compared with prevalent CNN-based image restoration models, Transformer-based SwinIR has several benefits: (1) content-based interactions between image content and attention weights, which can be interpreted as spatially varying convolution [13, 21, 75]. (2) long-range dependency modelling are enabled by the shifted window mechanism. (3) better performance with less parameters. For example, as shown in Fig. 1, SwinIR achieves better PSNR with less parameters compared with existing image SR methods.

2. Related Work

2.1. Image Restoration

Compared to traditional image restoration methods [28, 72, 73, 62, 32] which are generally model-based, learning-based methods, especially CNN-based methods, have become more popular due to their impressive performance. They often learn mappings between low-quality and high-quality images from large-scale paired datasets. Since pioneering work SRCNN [18] (for image SR), DnCNN [90] (for image denoising) and ARCNN [17] (for JPEG compression artifact reduction), a flurry of CNN-based models have been proposed to improve model representation ability by using more elaborate neural network architecture designs, such as residual block [40, 7, 88], dense block [81, 97, 98] and others [10, 42, 93, 78, 77, 79, 50, 48, 49, 92, 70, 36, 83, 30, 11, 16, 96, 64, 38, 26, 41, 25]. Some of them have exploited the attention mechanism inside the CNN framework, such as channel attention [95, 15, 63], non-local attention [52, 61] and adaptive patch aggregation [100].

2.2. Vision Transformer

Recently, natural language processing model Transformer [76] has gained much popularity in the computer vision community. When used in vision problems such as image classification [66, 19, 84, 56, 45, 55, 75], ob-

ject detection [6, 53, 74, 56], segmentation [84, 99, 56, 4] and crowd counting [47, 69], it learns to attend to important image regions by exploring the global interactions between different regions. Due to its impressive performance, Transformer has also been introduced for image restoration [9, 5, 82]. Chen *et al.* [9] proposed a backbone model IPT for various restoration problems based on the standard Transformer. However, IPT relies on large number of parameters (over 115.5M parameters), large-scale datasets (over 1.1M images) and multi-task learning for good performance. Cao *et al.* [5] proposed VSR-Transformer that uses the self-attention mechanism for better feature fusion in video SR, but image features are still extracted from CNN. Besides, both IPT and VSR-Transformer are patch-wise attention, which may be improper for image restoration. In addition, a concurrent work [82] proposed a U-shaped architecture based on the Swin Transformer [56].

3. Method

3.1. Network Architecture

As shown in Fig. 2, SwinIR consists of three modules: shallow feature extraction, deep feature extraction and high-quality (HQ) image reconstruction modules. We employ the same feature extraction modules for all restoration tasks, but use different reconstruction modules for different tasks.

Shallow and deep feature extraction. Given a low-quality (LQ) input $I_{LQ} \in \mathbb{R}^{H \times W \times C_{in}}$ (H , W and C_{in} are the image height, width and input channel number, respectively), we use a 3×3 convolutional layer $H_{SF}(\cdot)$ to extract shallow feature $F_0 \in \mathbb{R}^{H \times W \times C}$ as

$$F_0 = H_{SF}(I_{LQ}), \quad (1)$$

where C is the feature channel number. The convolution layer is good at early visual processing, leading to more stable optimization and better results [86]. It also provides a simple way to map the input image space to a higher dimensional feature space. Then, we extract deep feature $F_{DF} \in \mathbb{R}^{H \times W \times C}$ from F_0 as

$$F_{DF} = H_{DF}(F_0), \quad (2)$$

where $H_{DF}(\cdot)$ is the deep feature extraction module and it contains K residual Swin Transformer blocks (RSTB) and a 3×3 convolutional layer. More specifically, intermediate features F_1, F_2, \dots, F_K and the output deep feature F_{DF} are extracted block by block as

$$\begin{aligned} F_i &= H_{RSTB_i}(F_{i-1}), \quad i = 1, 2, \dots, K, \\ F_{DF} &= H_{CONV}(F_K), \end{aligned} \quad (3)$$

where $H_{RSTB_i}(\cdot)$ denotes the i -th RSTB and H_{CONV} is the last convolutional layer. Using a convolutional layer at the

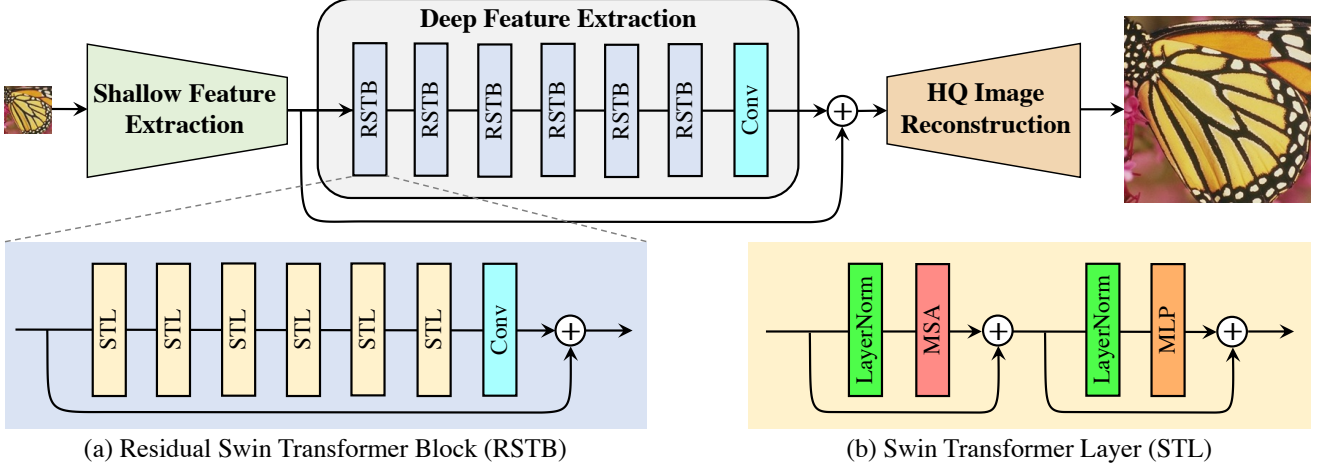


Figure 2: The architecture of the proposed SwinIR for image restoration.

end of feature extraction can bring the inductive bias of the convolution operation into the Transformer-based network, and lay a better foundation for the later aggregation of shallow and deep features.

Image reconstruction. Taking image SR as an example, we reconstruct the high-quality image I_{RHQ} by aggregating shallow and deep features as

$$I_{RHQ} = H_{REC}(F_0 + F_{DF}), \quad (4)$$

where $H_{REC}(\cdot)$ is the function of the reconstruction module. Shallow feature mainly contain low-frequencies, while deep feature focus on recovering lost high-frequencies. With a long skip connection, SwinIR can transmit the low-frequency information directly to the reconstruction module, which can help deep feature extraction module focus on high-frequency information and stabilize training. For the implementation of reconstruction module, we use the sub-pixel convolution layer [68] to upsample the feature.

For tasks that do not need upsampling, such as image denoising and JPEG compression artifact reduction, a single convolution layer is used for reconstruction. Besides, we use residual learning to reconstruct the residual between the LQ and the HQ image instead of the HQ image. This is formulated as

$$I_{RHQ} = H_{SwinIR}(I_{LQ}) + I_{LQ}, \quad (5)$$

where $H_{SwinIR}(\cdot)$ denotes the function of SwinIR.

Loss function. For image SR, we optimize the parameters of SwinIR by minimizing the L_1 pixel loss

$$\mathcal{L} = \|I_{RHQ} - I_{HQ}\|_1, \quad (6)$$

where I_{RHQ} is obtained by taking I_{LQ} as the input of SwinIR, and I_{HQ} is the corresponding ground-truth HQ image. For

classical and lightweight image SR, we only use the naive L_1 pixel loss as same as previous work to show the effectiveness of the proposed network. For real-world image SR, we use a combination of pixel loss, GAN loss and perceptual loss [81, 89, 80, 27, 39, 81] to improve visual quality.

For image denoising and JPEG compression artifact reduction, we use the Charbonnier loss [8]

$$\mathcal{L} = \sqrt{\|I_{RHQ} - I_{HQ}\|^2 + \epsilon^2}, \quad (7)$$

where ϵ is a constant that is empirically set to 10^{-3} .

3.2. Residual Swin Transformer Block

As shown in Fig. 2(a), the residual Swin Transformer block (RSTB) is a residual block with Swin Transformer layers (STL) and convolutional layers. Given the input feature $F_{i,0}$ of the i -th RSTB, we first extract intermediate features $F_{i,1}, F_{i,2}, \dots, F_{i,L}$ by L Swin Transformer layers as

$$F_{i,j} = H_{STL_{i,j}}(F_{i,j-1}), \quad j = 1, 2, \dots, L, \quad (8)$$

where $H_{STL_{i,j}}(\cdot)$ is the j -th Swin Transformer layer in the i -th RSTB. Then, we add a convolutional layer before the residual connection. The output of RSTB is formulated as

$$F_{i,out} = H_{CONV_i}(F_{i,L}) + F_{i,0}, \quad (9)$$

where $H_{CONV_i}(\cdot)$ is the convolutional layer in the i -th RSTB. This design has two benefits. First, although Transformer can be viewed as a specific instantiation of spatially varying convolution [21, 75], convolutional layers with spatially invariant filters can enhance the translational equivariance of SwinIR. Second, the residual connection provides a identity-based connection from different blocks to the reconstruction module, allowing the aggregation of different levels of features.

Swin Transformer layer. Swin Transformer layer (STL) [56] is based on the standard multi-head self-attention of the original Transformer layer [76]. The main differences lie in local attention and the shifted window mechanism. As shown in Fig. 2(b), given an input of size $H \times W \times C$, Swin Transformer first reshapes the input to a $\frac{HW}{M^2} \times M^2 \times C$ feature by partitioning the input into non-overlapping $M \times M$ local windows, where $\frac{HW}{M^2}$ is the total number of windows. Then, it computes the standard self-attention separately for each window (*i.e.*, local attention). For a local window feature $X \in \mathbb{R}^{M^2 \times C}$, the *query*, *key* and *value* matrices Q , K and V are computed as

$$Q = XP_Q, \quad K = XP_K, \quad V = XP_V, \quad (10)$$

where P_Q , P_K and P_V are projection matrices that are shared across different windows. Generally, we have $Q, K, V \in \mathbb{R}^{M^2 \times d}$. The attention matrix is thus computed by the self-attention mechanism in a local window as

$$\text{Attention}(Q, K, V) = \text{SoftMax}(QK^T/\sqrt{d} + B)V, \quad (11)$$

where B is the learnable relative positional encoding. In practice, following [76], we perform the attention function for h times in parallel and concatenate the results for multi-head self-attention (MSA).

Next, a multi-layer perceptron (MLP) that has two fully-connected layers with GELU non-linearity between them is used for further feature transformations. The LayerNorm (LN) layer is added before both MSA and MLP, and the residual connection is employed for both modules. The whole process is formulated as

$$\begin{aligned} X &= \text{MSA}(\text{LN}(X)) + X, \\ X &= \text{MLP}(\text{LN}(X)) + X. \end{aligned} \quad (12)$$

However, when the partition is fixed for different layers, there is no connection across local windows. Therefore, regular and shifted window partitioning are used alternately to enable cross-window connections [56], where shifted window partitioning means shifting the feature by $(\lfloor \frac{M}{2} \rfloor, \lfloor \frac{M}{2} \rfloor)$ pixels before partitioning.

4. Experiments

4.1. Experimental Setup

For classical image SR, real-world image SR, image denoising and JPEG compression artifact reduction, the RSTB number, STL number, window size, channel number and attention head number are generally set to 6, 6, 8, 180 and 6, respectively. One exception is that the window size is set to 7 for JPEG compression artifact reduction, as we observe significant performance drop when using 8, possibly because JPEG encoding uses 8×8 image

partitions. For lightweight image SR, we decrease RSTB number and channel number to 4 and 60, respectively. Following [95, 63], when self-ensemble strategy [51] is used in testing, we mark the model with a symbol “+”, *e.g.*, SwinIR+. Due to page limit, training and evaluation details are provided in the supplementary.

4.2. Ablation Study and Discussion

For ablation study, we train SwinIR on DIV2K [1] for classical image SR ($\times 2$) and test it on Manga109 [60].

Impact of channel number, RSTB number and STL number. We show the effects of channel number, RSTB number and STL number in a RSTB on model performance in Figs. 3(a), 3(b) and 3(c), respectively. It is observed that the PSNR is positively correlated with these three hyper-parameters. For channel number, although the performance keeps increasing, the total number of parameters grows quadratically. To balance the performance and model size, we choose 180 as the channel number in rest experiments. As for RSTB number and layer number, the performance gain becomes saturated gradually. We choose 6 for both of them to obtain a relatively small model.

Impact of patch size and training image number; model convergence comparison. We compare the proposed SwinIR with a representative CNN-based model RCAN to compare the difference of Transformer-based and CNN-based models. From Fig. 3(d), one can see that SwinIR performs better than RCAN on different patch sizes, and the PSNR gain becomes larger when the patch size is larger. Fig. 3(e) shows the impact of the number of training images. Extra images from Flickr2K are used in training when the percentage is larger than 100% (800 images). There are two observations. First, as expected, the performance of SwinIR rises with the training image number. Second, different from the observation in IPT that Transformer-based models are heavily relied on large amount of training data, SwinIR achieves better results than CNN-based models using the same training data, even when the dataset is small (*i.e.*, 25%, 200 images). We also plot the PSNR during training for both SwinIR and RCAN in Fig. 3(f). It is clear that SwinIR converges faster and better than RCAN, which is contradictory to previous observations that Transformer-based models often suffer from slow model convergence.

Impact of residual connection and convolution layer in RSTB. Table 1 shows four residual connection variants in RSTB: no residual connection, using 1×1 convolution layer, using 3×3 convolution layer and using three 3×3 convolution layers (channel number of the intermediate layer is set to one fourth of network channel number). From the table, we can have following observations. First, the residual connection in RSTB is important as it improves the PSNR by 0.16dB. Second, using 1×1 convolution brings little improvement maybe because it cannot

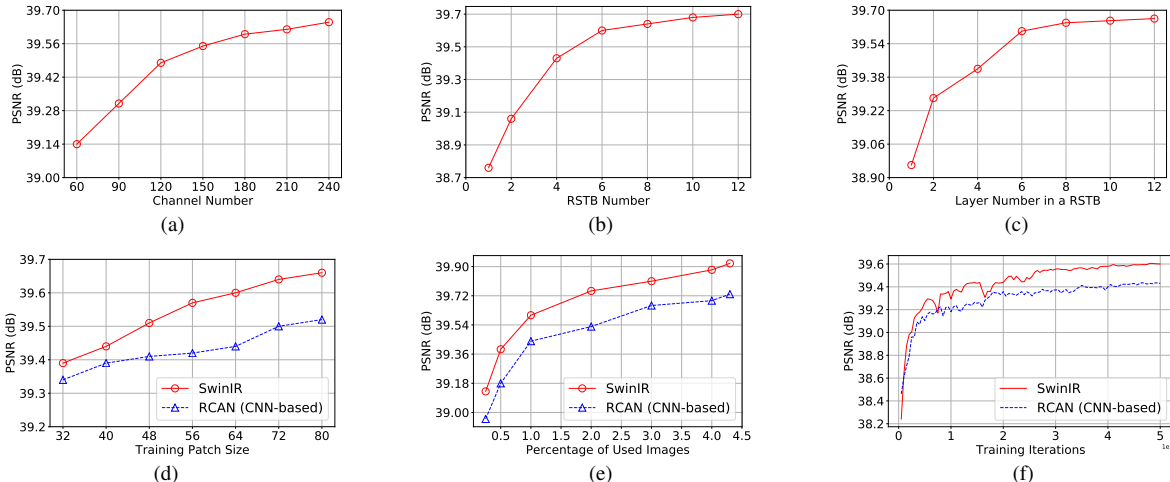


Figure 3: Ablation study on different settings of SwinIR. Results are tested on Manga109 [60] for image SR ($\times 2$).

Table 1: Ablation study on RSTB design.

Design	No residual	1×1 conv	3×3 conv	Three 3×3 conv
PSNR	39.42	39.45	39.58	39.56

extract local neighbouring information as 3×3 convolution does. Third, although using three 3×3 convolution layers can reduce the number of parameters, the performance drops slightly.

4.3. Results on Image SR

Classical image SR. Table 2 shows the quantitative comparisons between SwinIR (middle size) and state-of-the-art methods: DBPN [31], RCAN [95], RRDB [81], SAN [15], IGNN [100], HAN [63], NLSA [61] and IPT [9]. As one can see, when trained on DIV2K, SwinIR achieves best performance on almost all five benchmark datasets for all scale factors. The maximum PSNR gain reaches 0.26dB on Manga109 for scale factor 4. Note that RCAN and HAN introduce channel and spatial attention, IGNN proposes adaptive patch feature aggregation, and NLSA is based on the non-local attention mechanism. However, all these CNN-based attention mechanisms perform worse than the proposed Transformer-based SwinIR, which indicates the effectiveness of the proposed model. When we train SwinIR on a larger dataset (DIV2K+Flickr2K), the performance further increases by a large margin (up to 0.47dB), achieving better accuracy than the same Transformer-based model IPT, even though IPT utilizes ImageNet (more than 1.3M images) in training and has huge number of parameters (115.5M). In contrast, SwinIR has a small number of parameters (11.8M) even compared with state-of-the-art CNN-based models (15.4~44.3M). As for runtime, representative CNN-based model RCAN, IPT and SwinIR take about 0.2, 4.5s and 1.1s to test on a $1,024 \times 1,024$ image, respectively. Visual comparisons are show in Fig. 4. SwinIR can restore high-frequency details and alleviate the

blurring artifacts, resulting in sharp and natural edges. In contrast, most CNN-based methods produces blurry images or even incorrect textures. IPT generates better images compared with CNN-based methods, but it suffers from image distortions and border artifact.

Lightweight image SR. We also provide comparison of SwinIR (small size) with state-of-the-art lightweight image SR methods: CARN [2], FALSAR-A [12], IMDN [35], LAPAR-A [44] and LatticeNet [57]. In addition to PSNR and SSIM, we also report the total numbers of parameters and multiply-accumulate operations (evaluated on a 1280×720 HQ image) to compare the model size and computational complexity of different models. As shown in Table 3, SwinIR outperforms competitive methods by a PSNR margin of up to 0.53dB on different benchmark datasets, with similar total numbers of parameters and multiply-accumulate operations. This indicates that the SwinIR architecture is highly efficient for image restoration.

Real-world image SR. The ultimate goal of image SR is for real-world applications. Recently, Zhang *et al.* [89] proposed a practical degradation model BSRGAN for real-world image SR and achieved surprising results in real scenarios¹. To test the performance of SwinIR for real-world SR, we re-train SwinIR by using the same degradation model as BSRGAN for low-quality image synthesis. Since there is no ground-truth high-quality images, we only provide visual comparison with representative bicubic model ESRGAN [81] and state-of-the-art real-world image SR models RealSR [37], BSRGAN [89] and Real-ESRGAN [80]. As shown in Fig. 5, SwinIR produces visually pleasing images with clear and sharp edges, whereas other compared methods may suffer from unsatisfactory artifacts. In addition, to exploit the full potential of SwinIR for real applications, we further propose a

¹<https://github.com/csxn/BSRGAN>

Table 2: Quantitative comparison (average PSNR/SSIM) with state-of-the-art methods for **classical image SR** on benchmark datasets. Best and second best performance are in **red** and **blue** colors, respectively. Results on $\times 8$ are provided in supplementary.

Method	Scale	Training Dataset	Set5 [3]		Set14 [87]		BSD100 [58]		Urban100 [34]		Manga109 [60]	
			PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
RCAN [95]	$\times 2$	DIV2K	38.27	0.9614	34.12	0.9216	32.41	0.9027	33.34	0.9384	39.44	0.9786
SAN [15]	$\times 2$	DIV2K	38.31	0.9620	34.07	0.9213	32.42	0.9028	33.10	0.9370	39.32	0.9792
IGNN [100]	$\times 2$	DIV2K	38.24	0.9613	34.07	0.9217	32.41	0.9025	33.23	0.9383	39.35	0.9786
HAN [63]	$\times 2$	DIV2K	38.27	0.9614	34.16	0.9217	32.41	0.9027	33.35	0.9385	39.46	0.9785
NLSA [61]	$\times 2$	DIV2K	38.34	0.9618	34.08	0.9231	32.43	0.9027	33.42	0.9394	39.59	0.9789
SwinIR (Ours)	$\times 2$	DIV2K	38.35	0.9620	34.14	0.9227	32.44	0.9030	33.40	0.9393	39.60	0.9792
SwinIR+ (Ours)	$\times 2$	DIV2K	38.38	0.9621	34.24	0.9233	32.47	0.9032	33.51	0.9401	39.70	0.9794
DBPN [31]	$\times 2$	DIV2K+Flickr2K	38.09	0.9600	33.85	0.9190	32.27	0.9000	32.55	0.9324	38.89	0.9775
IPT [9]	$\times 2$	ImageNet	38.37	-	34.43	-	32.48	-	33.76	-	-	-
SwinIR (Ours)	$\times 2$	DIV2K+Flickr2K	38.42	0.9623	34.46	0.9250	32.53	0.9041	33.81	0.9427	39.92	0.9797
SwinIR+ (Ours)	$\times 2$	DIV2K+Flickr2K	38.46	0.9624	34.61	0.9260	32.55	0.9043	33.95	0.9433	40.02	0.9800
RCAN [95]	$\times 3$	DIV2K	34.74	0.9299	30.65	0.8482	29.32	0.8111	29.09	0.8702	34.44	0.9499
SAN [15]	$\times 3$	DIV2K	34.75	0.9300	30.59	0.8476	29.33	0.8112	28.93	0.8671	34.30	0.9494
IGNN [100]	$\times 3$	DIV2K	34.72	0.9298	30.66	0.8484	29.31	0.8105	29.03	0.8696	34.39	0.9496
HAN [63]	$\times 3$	DIV2K	34.75	0.9299	30.67	0.8483	29.32	0.8110	29.10	0.8705	34.48	0.9500
NLSA [61]	$\times 3$	DIV2K	34.85	0.9306	30.70	0.8485	29.34	0.8117	29.25	0.8726	34.57	0.9508
SwinIR (Ours)	$\times 3$	DIV2K	34.89	0.9312	30.77	0.8503	29.37	0.8124	29.29	0.8744	34.74	0.9518
SwinIR+ (Ours)	$\times 3$	DIV2K	34.95	0.9316	30.83	0.8511	29.41	0.8130	29.42	0.8761	34.92	0.9526
IPT [9]	$\times 3$	ImageNet	34.81	-	30.85	-	29.38	-	29.49	-	-	-
SwinIR (Ours)	$\times 3$	DIV2K+Flickr2K	34.97	0.9318	30.93	0.8534	29.46	0.8145	29.75	0.8826	35.12	0.9537
SwinIR+ (Ours)	$\times 3$	DIV2K+Flickr2K	35.04	0.9322	31.00	0.8542	29.49	0.8150	29.90	0.8841	35.28	0.9543
RCAN [95]	$\times 4$	DIV2K	32.63	0.9002	28.87	0.7889	27.77	0.7436	26.82	0.8087	31.22	0.9173
SAN [15]	$\times 4$	DIV2K	32.64	0.9003	28.92	0.7888	27.78	0.7436	26.79	0.8068	31.18	0.9169
IGNN [100]	$\times 4$	DIV2K	32.57	0.8998	28.85	0.7891	27.77	0.7434	26.84	0.8090	31.28	0.9182
HAN [63]	$\times 4$	DIV2K	32.64	0.9002	28.90	0.7890	27.80	0.7442	26.85	0.8094	31.42	0.9177
NLSA [61]	$\times 4$	DIV2K	32.59	0.9000	28.87	0.7891	27.78	0.7444	26.96	0.8109	31.27	0.9184
SwinIR (Ours)	$\times 4$	DIV2K	32.72	0.9021	28.94	0.7914	27.83	0.7459	27.07	0.8164	31.67	0.9226
SwinIR+ (Ours)	$\times 4$	DIV2K	32.81	0.9029	29.02	0.7928	27.87	0.7466	27.21	0.8187	31.88	0.9423
DBPN [31]	$\times 4$	DIV2K+Flickr2K	32.47	0.8980	28.82	0.7860	27.72	0.7400	26.38	0.7946	30.91	0.9137
IPT [9]	$\times 4$	ImageNet	32.64	-	29.01	-	27.82	-	27.26	-	-	-
RRDB [81]	$\times 4$	DIV2K+Flickr2K	32.73	0.9011	28.99	0.7917	27.85	0.7455	27.03	0.8153	31.66	0.9196
SwinIR (Ours)	$\times 4$	DIV2K+Flickr2K	32.92	0.9044	29.09	0.7950	27.92	0.7489	27.45	0.8254	32.03	0.9260
SwinIR+ (Ours)	$\times 4$	DIV2K+Flickr2K	32.93	0.9043	29.15	0.7958	27.95	0.7494	27.56	0.8273	32.22	0.9273

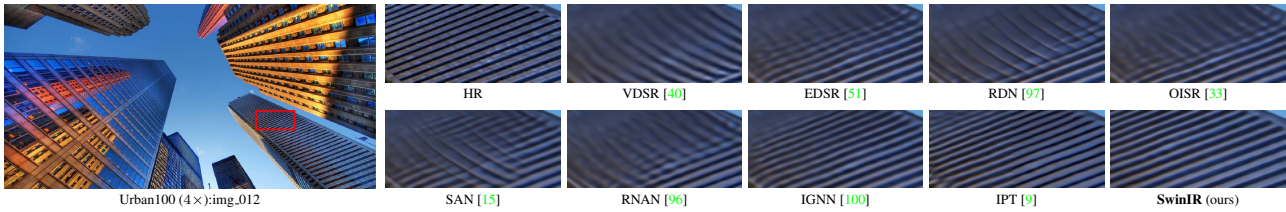


Figure 4: Visual comparison of **bicubic image SR** ($\times 4$) methods. Compared images are derived from [9]. Best viewed by zooming.

Table 3: Quantitative comparison (average PSNR/SSIM) with state-of-the-art methods for **lightweight image SR** on benchmark datasets. Best and second best performance are in **red** and **blue** colors, respectively.

Method	Scale	#Params	#Mult-Adds	Set5 [3]		Set14 [87]		BSD100 [58]		Urban100 [34]		Manga109 [60]	
				PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
CARN [2]	$\times 2$	1,592K	222.8G	37.76	0.9590	33.52	0.9166	32.09	0.8978	31.92	0.9256	38.36	0.9765
FALSR-A [12]	$\times 2$	1,021K	234.7G	37.82	0.959	33.55	0.9168	32.1	0.8987	31.93	0.9256	-	-
IMDN [35]	$\times 2$	694K	158.8G	38.00	0.9605	33.63	0.9177	32.19	0.8996	32.17	0.9283	38.88	0.9774
LAPAR-A [44]	$\times 2$	548K	171.0G	38.01	0.9605	33.62	0.9183	32.19	0.8999	32.10	0.9283	38.67	0.9772
LatticeNet [57]	$\times 2$	756K	169.5G	38.15	0.9610	33.78	0.9193	32.25	0.9005	32.43	0.9302	-	-
SwinIR (Ours)	$\times 2$	878K	195.6G	38.14	0.9611	33.86	0.9206	32.31	0.9012	32.76	0.9340	39.12	0.9783
CARN [2]	$\times 3$	1,592K	118.8G	34.29	0.9255	30.29	0.8407	29.06	0.8034	28.06	0.8493	33.50	0.9440
IMDN [35]	$\times 3$	703K	71.5G	34.36	0.9270	30.32	0.8417	29.09	0.8046	28.17	0.8519	33.61	0.9445
LAPAR-A [44]	$\times 3$	544K	114.0G	34.36	0.9267	30.34	0.8421	29.11	0.8054	28.15	0.8523	33.51	0.9441
LatticeNet [57]	$\times 3$	765K	76.3G	34.53	0.9281	30.39	0.8424	29.15	0.8059	28.33	0.8538	-	-
SwinIR (Ours)	$\times 3$	886K	87.2G	34.62	0.9289	30.54	0.8463	29.20	0.8082	28.66	0.8624	33.98	0.9478
CARN [2]	$\times 4$	1,592K	90.9G	32.13	0.8937	28.60	0.7806	27.58	0.7349	26.07	0.7837	30.47	0.9084
IMDN [35]	$\times 4$	715K	40.9G	32.21	0.8948	28.58	0.7811	27.56	0.7353	26.04	0.7838	30.45	0.9075
LAPAR-A [44]	$\times 4$	659K	94.0G	32.15	0.8944	28.61	0.7818	27.61	0.7366	26.14	0.7871	30.42	0.9074
LatticeNet [57]	$\times 4$	777K	43.6G	32.30	0.8962	28.68	0.7830	27.62	0.7367	26.25	0.7873	-	-
SwinIR (Ours)	$\times 4$	897K	49.6G	32.44	0.8976	28.77	0.7858	27.69	0.7406	26.47	0.7980	30.92	0.9151

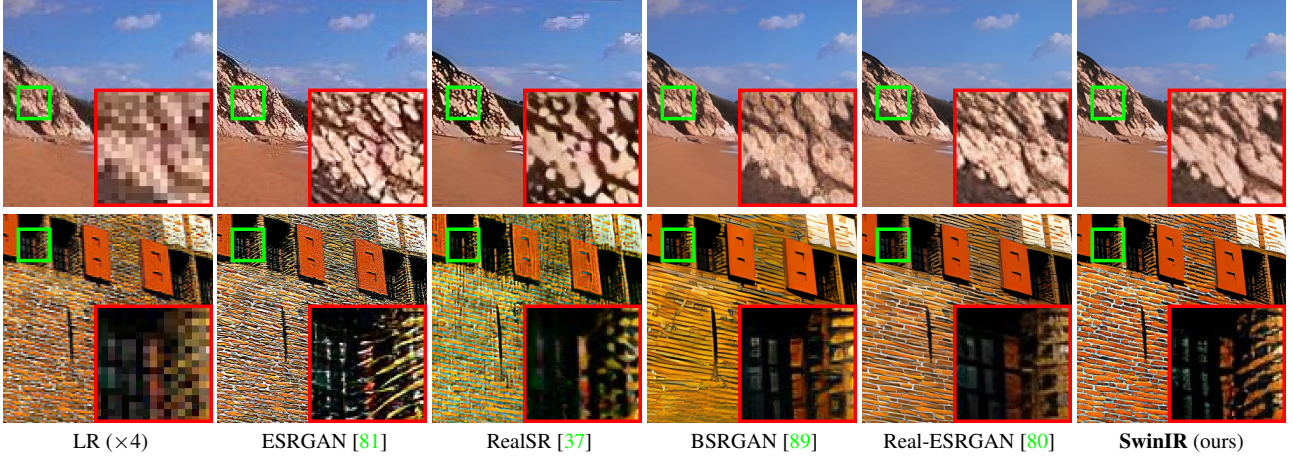


Figure 5: Visual comparison of real-world image SR ($\times 4$) methods on real-world images.

Table 4: Quantitative comparison (average PSNR/SSIM/PSNR-B) with state-of-the-art methods for JPEG compression artifact reduction on benchmark datasets. Best and second best performance are in red and blue colors, respectively.

Dataset	q	ARCNN [17]	DnCNN-3 [90]	QGAC [20]	RNAN [96]	RDN [98]	DRUNet [88]	SwinIR (ours)
Classic5 [22]	10	29.03/0.7929/28.76	29.40/0.8026/29.13	29.84/0.8370/29.43	29.96/0.8178/29.62	30.00/0.8188/-	30.16/0.8234/29.81	30.27/0.8249/29.95
	20	31.15/0.8517/30.59	31.63/0.8610/31.19	31.98/0.8850/31.37	32.11/0.8693/31.57	32.15/0.8699/-	32.39/0.8734/31.80	32.52/0.8748/31.99
	30	32.51/0.8806/31.98	32.91/0.8861/32.38	33.22/0.9070/32.42	33.38/0.8924/32.68	33.43/0.8930/-	33.59/0.8949/32.82	33.73/0.8961/33.03
	40	33.32/0.8953/32.79	33.77/0.9003/33.20	-	34.27/0.9061/33.4	34.27/0.9061/-	34.41/0.9075/33.51	34.52/0.9082/33.66
LIVE1 [67]	10	28.96/0.8076/28.77	29.19/0.8123/28.90	29.53/0.8400/29.15	29.63/0.8239/29.25	29.67/0.8247/-	29.79/0.8278/29.48	29.86/0.8287/29.50
	20	31.29/0.8733/30.79	31.59/0.8802/31.07	31.86/0.9010/31.27	32.03/0.8877/31.44	32.07/0.8882/-	32.17/0.8899/31.69	32.25/0.8909/31.70
	30	32.67/0.9043/32.22	32.98/0.9090/32.34	33.23/0.9250/32.50	33.45/0.9149/32.71	33.51/0.9153/-	33.59/0.9166/32.99	33.69/0.9174/33.01
	40	33.63/0.9198/33.14	33.96/0.9247/33.28	-	34.47/0.9299/33.66	34.51/0.9302/-	34.58/0.9312/33.93	34.67/0.9317/33.88

large model and train it on much larger datasets. Experiments show that it can deal with more complex corruptions and achieves even better performance on real-world images than the current model. Due to page limit, the details are given in our project page <https://github.com/JingyunLiang/SwinIR>.

4.4. Results on JPEG Compression Artifact Reduction

Table 4 shows the comparison of SwinIR with state-of-the-art JPEG compression artifact reduction methods: ARCNN [17], DnCNN-3 [90], QGAC [20], RNAN [96], RDN [98] and DRUNet [88]. All of compared methods are CNN-based models. Following [98, 88], we test different methods on two benchmark datasets (Classic5 [22] and LIVE1 [67]) for JPEG quality factors 10, 20, 30 and 40. As we can see, the proposed SwinIR has average PSNR gains of at least 0.11dB and 0.07dB on two testing datasets for different quality factors. Besides, compared with the previous best model DRUNet, SwinIR only has 11.5M parameters, while DRUNet is a large model that has 32.7M parameters.

4.5. Results on Image Denoising

We show grayscale and color image denoising results in Table 5 and Table 6, respectively. Com-

pared methods include traditional models BM3D [14] and WNNM [29], CNN-based models DnCNN [90], IRCNN [91], FFDNet [92], N3Net [65], NLRN [52], FOCNet [38], RNAN [96], MWCNN [54] and DRUNet [88]. Following [90, 88], the compared noise levels include 15, 25 and 50. As one can see, our model achieves better performance than all compared methods. In particular, it surpasses the state-of-the-art model DRUNet by up to 0.3dB on the large Urban100 dataset that has 100 high-resolution testing images. It is worth pointing out that SwinIR only has 12.0M parameters, whereas DRUNet has 32.7M parameters. This indicates that the SwinIR architecture is highly efficient in learning feature representations for restoration. The visual comparison for grayscale and color image denoising of different methods are shown in Figs. 6 and 7. As we can see, our method can remove heavy noise corruption and preserve high-frequency image details, resulting in sharper edges and more natural textures. By contrast, other methods suffer from either over-smoothness or over-sharpness, and cannot recover rich textures.

5. Conclusion

In this paper, we propose a Swin Transformer-based image restoration model SwinIR. The model is composed of three parts: shallow feature extraction, deep feature extrac-

Table 5: Quantitative comparison (average PSNR) with state-of-the-art methods for **grayscale image denoising** on benchmark datasets. Best and second best performance are in red and blue colors, respectively.

Dataset	σ	BM3D [14]	WNNM [29]	DnCNN [90]	IRCNN [91]	FFDNet [92]	N3Net [65]	NLRN [52]	FOCNet [38]	RNAN [96]	MWCNN [54]	DRUNet [88]	SwinIR (ours)
Set12 [90]	15	32.37	32.70	32.86	32.76	32.75	-	33.16	33.07	-	33.15	33.25	33.36
	25	29.97	30.28	30.44	30.37	30.43	30.55	30.80	30.73	-	30.79	30.94	31.01
	50	26.72	27.05	27.18	27.12	27.32	27.43	27.64	27.68	27.70	27.74	27.90	27.91
BSD68 [59]	15	31.08	31.37	31.73	31.63	31.63	-	31.88	31.83	-	31.86	31.91	31.97
	25	28.57	28.83	29.23	29.15	29.19	29.30	29.41	29.38	-	29.41	29.48	29.50
	50	25.60	25.87	26.23	26.19	26.29	26.39	26.47	26.50	26.48	26.53	26.59	26.58
Urban100 [34]	15	32.35	32.97	32.64	32.46	32.40	-	33.45	33.15	-	33.17	33.44	33.70
	25	29.70	30.39	29.95	29.80	29.90	30.19	30.94	30.64	-	30.66	31.11	31.30
	50	25.95	26.83	26.26	26.22	26.50	26.82	27.49	27.40	27.65	27.42	27.96	27.98

Table 6: Quantitative comparison (average PSNR) with state-of-the-art methods for **color image denoising** on benchmark datasets. Best and second best performance are in red and blue colors, respectively.

Dataset	σ	BM3D [14]	DnCNN [90]	IRCNN [91]	FFDNet [92]	DSNet [64]	RPCNN [85]	BRDNet [71]	RNAN [96]	RDN [98]	IPT [9]	DRUNet [88]	SwinIR (ours)
CBSD68 [59]	15	33.52	33.90	33.86	33.87	33.91	-	34.10	-	-	-	34.30	34.42
	25	30.71	31.24	31.16	31.21	31.28	31.24	31.43	-	-	-	31.69	31.78
	50	27.38	27.95	27.86	27.96	28.05	28.06	28.16	28.27	28.31	28.39	28.51	28.56
Kodak24 [23]	15	34.28	34.60	34.69	34.63	34.63	-	34.88	-	-	-	35.31	35.34
	25	32.15	32.14	32.18	32.13	32.16	32.34	32.41	-	-	-	32.89	32.89
	50	28.46	28.95	28.93	28.98	29.05	29.25	29.22	29.58	29.66	29.64	29.86	29.79
McMaster [94]	15	34.06	33.45	34.58	34.66	34.67	-	35.08	-	-	-	35.40	35.61
	25	31.66	31.52	32.18	32.35	32.40	32.33	32.75	-	-	-	33.14	33.20
	50	28.51	28.62	28.91	29.18	29.28	29.33	29.52	29.72	-	29.98	30.08	30.22
Urban100 [34]	15	33.93	32.98	33.78	33.83	-	-	34.42	-	-	-	34.81	35.13
	25	31.36	30.81	31.20	31.40	-	31.81	31.99	-	-	-	32.60	32.90
	50	27.93	27.59	27.70	28.05	-	28.62	28.56	29.08	29.38	29.71	29.61	29.82

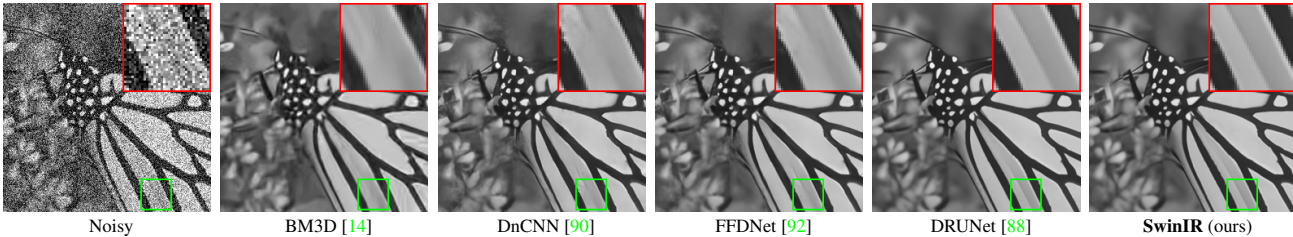


Figure 6: Visual comparison of **grayscale image denoising** (noise level 50) methods on image “Monarch” from Set12 [90]. Compared images are derived from [88].

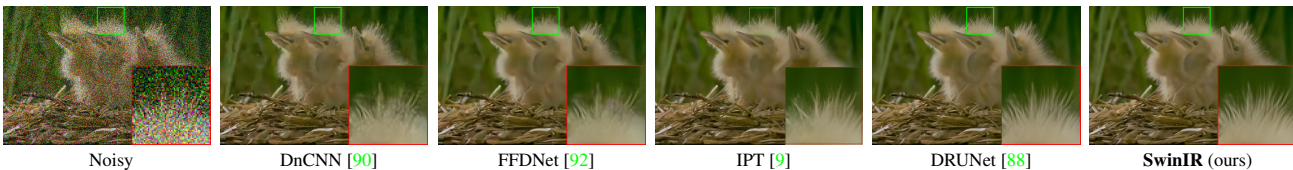


Figure 7: Visual comparison of **color image denoising** (noise level 50) methods on image “163085” from CBSD68 [59]. Compared images are derived from [88].

tion and HR reconstruction modules. In particular, we use a stack of residual Swin Transformer blocks (RSTB) for deep feature extraction, and each RSTB is composed of Swin Transformer layers, convolution layer and a residual connection. Extensive experiments show that SwinIR achieves state-of-the-art performance on three representative image restoration tasks and six different settings: classic image SR, lightweight image SR, real-world image SR, grayscale image denoising, color image denoising and JPEG com-

pression artifact reduction, which demonstrates the effectiveness and generalizability of the proposed SwinIR. In the future, we will extend the model to other restoration tasks such as image deblurring and deraining.

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