Supplementary Material: Joint Patch-Group Based Sparse Representation for Image Inpainting

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To further verify the feasibility of the proposed joint patch-group based sparse representation (JPG-SR) model, we have applied it to another two low-level vision tasks, i.e., image deblocking and image compressive sensing (CS) recovery.

Particularly, in image deblocking, we verify the proposed algorithm for restoring JPEG-compressed images on 14 widely used images shown in Fig. 1.

Figure 1: Test images used in the image deblocking. Top row: from left to right, Bahoon, Barbara, Airplane, Straw, Lake, Girl, Bridge; bottom row: from left to right, Fingerprint, Fence, Goldhill, Man, Pentagon, Tank, House.

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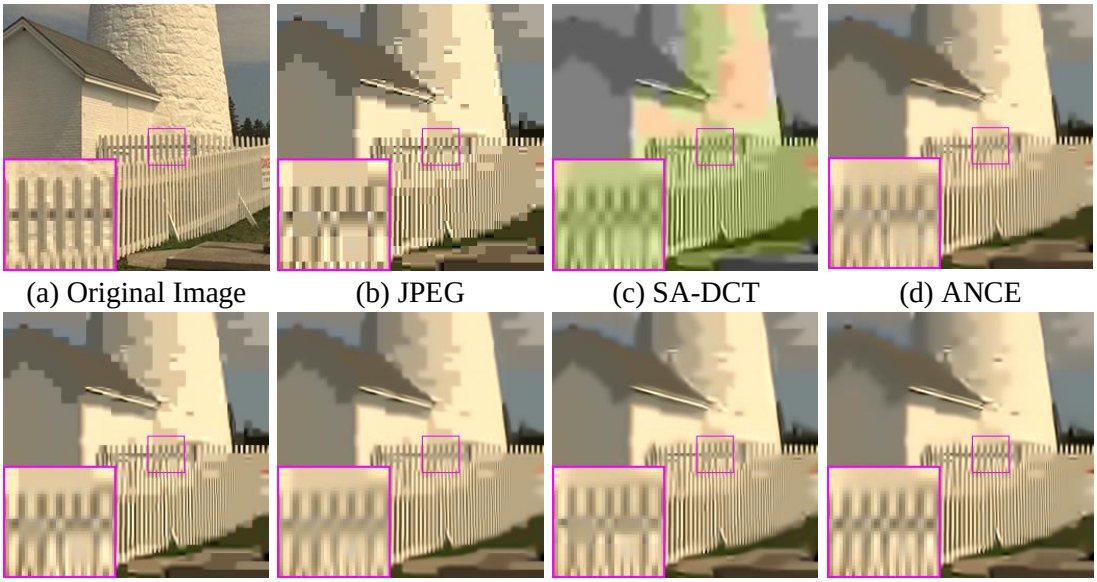
We compare the proposed JPG-SR with advanced image deblocking methods including SA-DCT (Foi et al., 2007), ANCE (Zhang et al., 2013c), BM3D (Dabov et al., 2007), WNNM (Gu et al., 2014) and SSR-QC (Zhao et al., 2017). Note that BM3D and WNNM are the well-known image restoration methods that deliver state-of-the-art denoising results. SA-DCT, ANCE and SSR-QC are the state-of-the-art deblocking methods and SSR-QC utilize the group sparse representation for image deblocking. The PSNR and SSIM result comparisons for all test images in the case of quality factor (QF) =1, 5, 10, 20, 30 and 40 are shown in Table 1 and Table 2, respectively. The proposed JPG-SR achieves {1.32dB, 0.46dB, 0.29dB, 0.48dB, 0.30dB and 0.19dB} gains in PSNR and {0.0361, 0.0141, 0.0119, 0.0138, 0.0147 and 0.0096} gains in SSIM over SA-DCT, ANCE, BM3D, WNNM and SSR-QC on average, respectively.

The visual quality comparisons in the case of QF =1 for image *Fence* and *Airplane* are demonstrated in Fig. 2 to Fig. 3, respectively. One can observe that the blocking artifacts are obvious in the images reconstructed directly by the standard JPEG decoder. SA-DCT, ANCE, BM3D and WNNM methods can only suppress the blocking artifacts partially, but many blocking artifacts are still visible in the reconstructed image. SSR-QC usually generate better results than JPEG, SA-DCT, ANCE, BM3D and WNNM methods. However, it often produces noticeable zigzag artifacts and blur effects along image edges. By contrast, the proposed JPG-SR not only removes blocking or ringing artifacts across the image, but also preserves large-scale sharp edges and small-scale fine image details.

In image CS recovery, we verify the proposed algorithm for image CS recovery on 14 widely used images shown in Fig. 4. We compare the proposed JPG-SR with eight other competing methods including BCS (Mun and Fowler, 2009), MH (Chen et al., 2011), TV-NLR (Zhang et al., 2013a), RCOS (Zhang et al., 2012), ALSB (Zhang et al., 2014), SGSR (Zhang et al., 2013b), NGS (Liu et al., 2017) and PMDSE (Wu et al., 2017). Note that ALSB is the PSR-based method, while RCOS, SGSR and NGS methods are the GSR-based methods. The PSNR results are shown in Table 3. One can observe that the proposed JPG-SR consistently outperforms other competing methods (The only exception is the image *House* and *Parrot* with $0.4N$ measurements for which ALSB and SGSR slightly outperform the proposed JPG-SR, respectively.). In terms of PSNR, the proposed JPG-SR achieves {4.91dB, 2.80dB, 3.65dB, 1.65dB, 1.05dB, 0.89dB, 2.41dB and 5.33dB} improvement in average over BCS, MH, TV-NLR, RCOS, ALSB, SGSR, NGS and PMDSE, respectively. The SSIM results are shown in Table 4. It can be seen that the proposed JPG-SR outperforms the other competing methods in most case. The average gains of the proposed JPG-SR over BCS, MH, TV-NLR, RCOS, ALSB, SGSR, NGS and PMDSE methods are as much as {0.1340, 0.0590, 0.0749, 0.0361, 0.0135, 0.0134, 0.0614 and 0.1046}, respectively. The visual comparisons of image *Leaves*, image *Monarch* and image *Starfish* with $0.1N$ measurements are shown in Fig. 5, Fig. 6 and Fig. 7, respectively. One can observe that BCS and PMDSE methods cannot obtain the well perceptual results. The MH, TV-NLR, RCOS, ALSB, SGSR and NGS methods still suffer from some undesirable artifacts or over-smooth phenomena. By contrast, the proposed JPG-SR not only removes most of the visual artifacts, but also preserves large-scale sharp edges and small-scale fine image details.



(a) Original Image (b) JPEG (c) SA-DCT (d) ANCE

(e) BM3D (f) WNNM (g) SSR-QC (h)JPG-SR

Figure 2: Visual comparison of *Fence* for image deblocking with QF = 1. (a) Original image; (b) JPEG (PSNR = 21.63dB, SSIM = 0.6240); (c) SA-DCT (PSNR = 22.80dB, SSIM = 0.6604); (d) ANCE (PSNR = 22.91dB, SSIM = 0.6576); (e) BM3D (PSNR = 22.56dB, SSIM = 0.6532); (f) WNNM (PSNR = 23.17dB, SSIM = 0.6670); (g) SSR-QC (PSNR= 23.19dB, SSIM = 0.6699); (h) JPG-SR (PSNR= **23.61dB**, SSIM = **0.6869**).

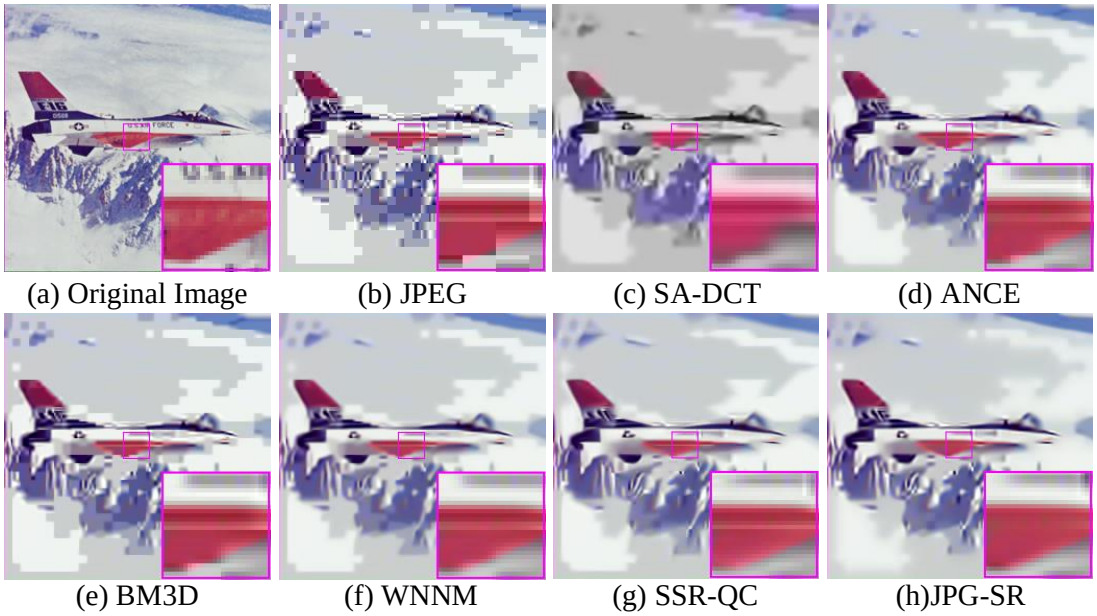


Figure 3: Visual comparison of *Airplane* for image deblocking with QF = 1. (a) Original image; (b) JPEG (PSNR = 22.01dB, SSIM = 0.6601); (c) SA-DCT (PSNR = 23.27dB, SSIM = 0.7298); (d) ANCE (PSNR = 23.25dB, SSIM = 0.7269); (e) BM3D (PSNR = 22.97dB, SSIM = 0.7040); (f) WNNM (PSNR = 23.31dB, SSIM = 0.7220); (g) SSR-QC (PSNR = 23.22dB, SSIM = 0.7235); (h) JPG-SR (PSNR= **23.67dB**, SSIM = **0.7495**).

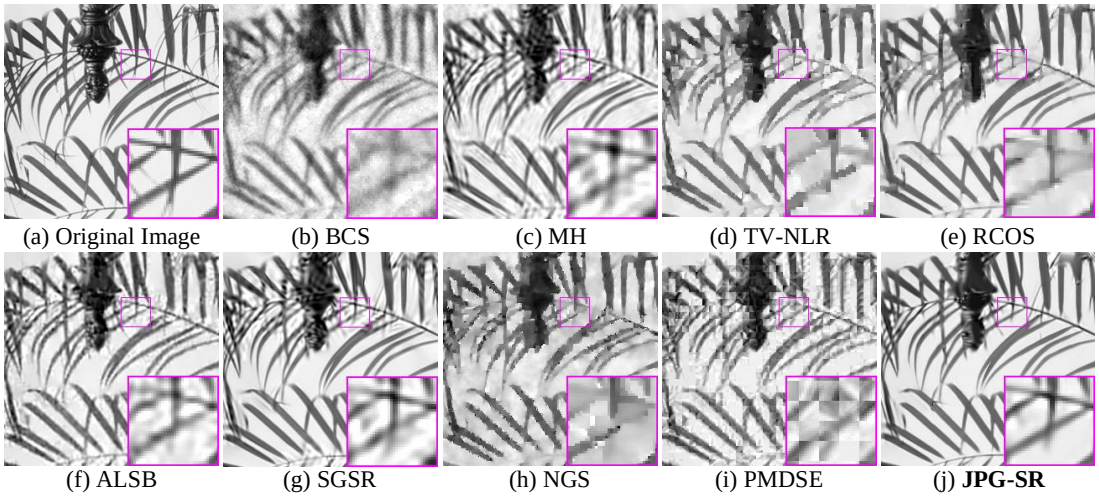
Figure 4: Test images used in the image CS recovery. Top row: from left to right, House, Lake, Fingerprint, Flower, Leaves, Fence, Man; bottom row: from left to right, Lena, Monarch, Parrot, Couple, Airplane, Peppers, Starfish.

Table 1: PSNR (dB) comparison of JPEG, SA-DCT, ANCE, BM3D, WNNM, SSR-QC and JPG-SR for image deblocking.

QF	Methods	Airplane	Bahoon	Barbara	Bridge	Fence	Fingerprint	Girl	Goldhill	House	Lake	Man	Tank	Pentagon	Straw	Average
1	JPEG	22.01	21.05	21.92	20.94	21.63	18.32	25.34	22.92	25.00	20.98	21.45	24.26	20.77	18.72	21.81
	SA-DCT	23.27	21.79	23.30	21.99	22.80	19.55	27.05	24.19	26.61	22.16	22.71	25.88	21.80	19.54	23.05
	ANCE	28.32	25.13	27.98	33.65	25.38	21.49	26.33	25.56	30.64	30.48	26.30	24.50	25.14	22.71	26.68
	BM3D	22.97	21.52	22.97	21.72	22.56	19.69	26.20	23.73	26.23	21.84	22.45	24.96	21.68	19.56	22.72
	WNNM	23.31	21.72	23.45	21.89	23.17	20.27	27.11	24.11	26.97	22.16	22.70	25.74	21.92	19.63	23.15
	SSR-QC	23.22	21.78	23.79	21.83	23.19	20.54	27.09	24.10	27.00	22.04	22.53	25.89	22.00	19.86	23.20
	JPG-SR	**23.67**	**21.81**	**24.00**	**22.02**	**23.61**	**20.65**	**27.55**	**24.22**	**27.45**	**22.35**	**22.82**	**26.70**	**22.20**	**19.97**	**23.50**
5	JPEG	24.70	22.65	23.85	22.99	23.54	20.69	27.92	25.47	27.76	23.64	23.84	27.26	23.03	20.99	24.17
	SA-DCT	23.27	21.79	23.30	21.99	22.80	19.55	27.05	24.19	26.61	22.16	22.71	25.88	21.80	19.54	23.05
	ANCE	28.32	25.13	27.98	33.65	25.38	21.49	26.33	25.56	30.64	30.48	26.30	24.50	25.14	22.71	26.68
	BM3D	22.97	21.52	22.97	21.72	22.56	19.69	26.20	23.73	26.23	21.84	22.45	24.96	21.68	19.56	22.72
	WNNM	23.31	21.72	23.45	21.89	23.17	20.27	27.11	24.11	26.97	22.16	22.70	25.74	21.92	19.63	23.15
	SSR-QC	23.22	21.78	23.79	21.83	23.19	20.54	27.09	24.10	27.00	22.04	22.53	25.89	22.00	19.86	23.20
	JPG-SR	**23.67**	**21.81**	**24.00**	**22.02**	**23.61**	**20.65**	**27.55**	**24.22**	**27.45**	**22.35**	**22.82**	**26.70**	**22.20**	**19.97**	**23.50**
10	JPEG	27.48	24.49	26.28	25.23	25.90	23.75	30.59	28.09	30.55	26.26	26.19	29.51	25.50	23.46	26.66
	SA-DCT	28.71	25.00	27.36	**25.88**	26.78	24.51	31.46	29.00	32.09	27.32	27.08	30.15	26.35	24.31	27.57
	ANCE	28.63	25.02	27.77	25.88	27.19	**25.19**	31.58	29.02	32.11	27.16	27.05	30.31	26.51	24.57	27.71
	BM3D	28.50	25.02	27.52	25.87	26.90	24.77	31.58	29.03	32.08	27.19	27.04	30.30	26.55	24.42	27.63
	WNNM	28.77	24.98	27.81	25.79	27.13	25.14	31.40	28.95	32.43	**27.38**	27.04	30.04	26.63	24.70	27.73
	SSR-QC	28.74	24.84	28.48	25.60	27.48	25.15	31.46	28.88	32.85	27.19	27.01	30.08	26.71	24.80	27.81
	JPG-SR	**28.91**	**25.03**	**28.83**	25.87	**27.60**	25.13	**31.65**	**29.15**	**32.89**	27.37	**27.10**	**30.34**	**26.79**	**24.86**	**27.97**
20	JPEG	30.11	26.30	29.34	27.33	28.47	26.38	32.83	30.50	33.00	28.68	28.41	31.73	27.65	25.74	29.03
	SA-DCT	31.10	26.71	30.36	27.92	29.38	26.89	33.37	31.27	34.12	29.59	29.20	32.13	28.32	26.37	29.77
	ANCE	31.09	26.72	31.27	27.85	29.71	27.47	33.60	31.29	34.30	29.46	29.17	32.37	28.48	26.84	29.97
	BM3D	30.96	26.71	30.70	27.88	29.47	27.11	33.56	31.31	34.29	29.50	29.14	32.35	28.46	26.46	29.85
	WNNM	31.20	26.76	31.09	27.92	29.68	27.48	33.27	31.26	34.41	29.72	29.23	31.96	28.61	26.82	29.96
	SSR-QC	31.20	26.63	31.86	27.73	29.95	27.49	33.37	31.22	**34.76**	29.62	29.18	32.12	**28.69**	26.99	30.06
	JPG-SR	**31.36**	**26.81**	**31.95**	**27.95**	**29.95**	**27.54**	**33.64**	**31.46**	34.66	**29.76**	**29.27**	**32.42**	28.67	**27.11**	**30.18**
30	JPEG	31.52	27.38	31.20	28.51	30.04	27.78	33.98	31.87	34.18	30.08	29.67	32.97	28.84	27.03	30.36
	SA-DCT	32.42	27.75	32.10	29.04	30.87	28.17	34.38	32.58	35.09	30.87	30.38	33.30	29.42	27.53	30.99
	ANCE	32.48	27.82	33.10	29.00	31.16	28.81	34.61	32.61	35.39	30.82	30.37	33.52	29.61	28.16	31.25
	BM3D	32.31	27.75	32.46	29.01	30.94	28.37	34.54	32.64	35.23	30.81	30.32	33.48	29.53	27.62	31.07
	WNNM	32.55	27.85	32.83	29.11	31.16	28.73	34.25	32.65	35.26	31.05	30.47	33.15	29.74	28.01	31.20
	SSR-QC	32.68	27.74	33.49	28.97	31.40	28.84	34.40	32.59	35.73	31.03	30.44	33.26	29.82	28.22	31.33
	JPG-SR	**32.81**	**27.91**	**33.96**	**29.15**	**31.58**	**28.94**	**34.62**	**32.78**	**35.73**	**31.15**	**30.53**	**33.56**	**29.84**	**28.50**	**31.50**
40	JPEG	32.58	28.21	32.51	29.36	31.11	28.76	34.78	32.82	35.04	31.03	30.55	33.78	29.65	27.96	31.30
	SA-DCT	33.37	28.54	33.33	29.84	31.89	29.09	35.14	33.50	35.81	31.77	31.21	34.16	30.18	28.38	31.87
	ANCE	33.52	28.73	34.44	29.86	32.12	29.75	35.38	33.58	36.15	31.76	31.28	34.34	30.42	29.12	32.17
	BM3D	33.30	28.54	33.71	29.82	31.95	29.26	35.29	33.55	35.95	31.73	31.16	34.30	30.28	28.47	31.95
	WNNM	33.51	28.67	34.09	29.96	32.16	29.60	35.05	33.62	35.89	31.97	31.32	34.08	30.51	28.84	32.09
	SSR-QC	33.73	28.62	35.04	29.81	32.48	29.83	35.11	33.51	36.48	32.03	31.32	34.02	30.66	29.20	32.28
	JPG-SR	**33.83**	**28.81**	**35.12**	**30.00**	**32.53**	**29.91**	**35.38**	**33.74**	**36.51**	**32.13**	**31.47**	**34.36**	**30.69**	**29.43**	**32.42**

Table 2: SSIM comparison of JPEG, SA-DCT, ANCE, BM3D, WNNM, SSR-QC and JPG-SR for image deblocking.

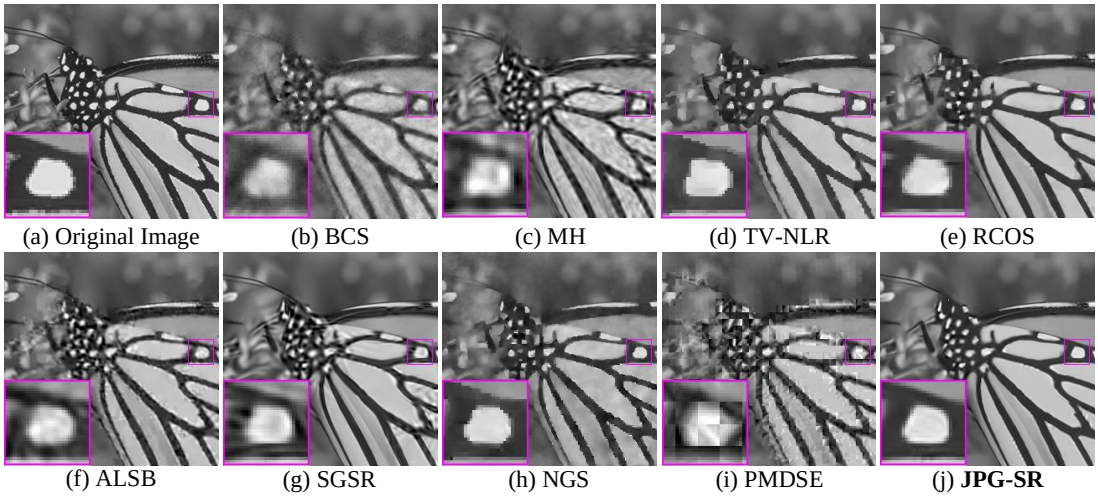
QF	Methods	Airplane	Bahoon	Barbara	Bridge	Fence	Fingerprint	Girl	Goldhill	House	Lake	Man	Tank	Pentagon	Straw	Average
1	JPEG	0.6601	0.3491	0.5284	0.4248	0.6240	0.6007	0.4702	0.4993	0.7202	0.5773	0.4902	0.4928	0.4160	0.3890	0.5173
	SA-DCT	0.7298	0.3747	0.6086	0.4653	0.6604	0.6134	0.5498	0.5691	0.7708	0.6441	0.5514	0.5785	0.4464	0.3620	0.5660
	ANCE	0.7269	0.3726	0.6050	0.4566	0.6576	0.6264	0.5860	0.5618	0.7686	0.6392	0.5522	0.5773	0.4419	0.3728	0.5675
	BM3D	0.7040	0.3649	0.5806	0.4577	0.6532	0.6397	0.5061	0.5397	0.7563	0.6216	0.5379	0.5332	0.4548	0.3931	0.5531
	WNNM	0.7220	0.3683	0.6098	0.4557	0.6670	0.6434	0.5805	0.5579	0.7754	0.6367	0.5562	0.5627	0.4472	0.3577	0.5672
	SSR-QC	0.7235	0.3750	0.6335	0.4552	0.6699	0.6717	0.5249	0.5608	0.7756	0.6354	0.5337	0.5744	0.4597	0.4185	0.5723
	JPG-SR	**0.7495**	**0.3787**	**0.6406**	**0.4686**	**0.6869**	**0.6831**	**0.6413**	**0.5714**	**0.7890**	**0.6612**	**0.5745**	**0.5887**	**0.4729**	**0.4370**	**0.5960**
5	JPEG	0.7518	0.5109	0.6563	0.5797	0.6974	0.7559	0.6462	0.6435	0.7733	0.6999	0.6377	0.6075	0.5870	0.6207	0.6548
	SA-DCT	0.8138	0.5003	0.7124	0.5918	0.7286	0.7651	0.7141	0.6911	0.8144	0.7595	0.6770	0.6361	0.6010	0.6292	0.6882
	ANCE	0.8128	0.5085	0.7132	0.5923	0.7327	0.7781	0.7126	0.6882	0.8143	0.7546	0.6745	0.6392	0.6064	0.6224	0.6893
	BM3D	0.7953	0.5163	0.7071	0.5984	0.7274	0.7813	0.7005	0.6882	0.8084	0.7481	0.6784	0.6375	0.6217	0.6470	0.6897
	WNNM	0.8049	0.4906	0.7107	0.5769	0.7307	0.7779	0.7052	0.6833	0.8180	0.7544	0.6694	0.6347	0.6037	0.6327	0.6852
	SSR-QC	0.8106	0.5082	0.7309	0.5843	0.7481	0.7879	0.7145	0.6854	0.8226	0.7549	0.6723	0.6388	0.6265	0.6537	0.6956
	JPG-SR	**0.8254**	**0.5223**	**0.7448**	**0.6030**	**0.7572**	**0.8022**	**0.7196**	**0.7004**	**0.8284**	**0.7688**	**0.6795**	**0.6463**	**0.6422**	**0.6780**	**0.7084**
10	JPEG	0.8280	0.6695	0.7901	0.7237	0.7878	0.8714	0.7456	0.7628	0.8183	0.7998	0.7493	0.7056	0.7337	0.7724	0.7684
	SA-DCT	0.8748	0.6621	0.8300	0.7280	0.8043	0.8803	0.7698	0.7857	0.8494	0.8464	0.7745	0.7135	0.7493	0.7885	0.7898
	ANCE	0.8758	0.6603	0.8290	0.7274	0.8108	0.8863	0.7753	0.7874	0.8515	0.8417	0.7763	0.7263	0.7526	0.7903	0.7922
	BM3D	0.8660	**0.6714**	0.8341	**0.7334**	0.8100	0.8865	**0.7770**	0.7910	0.8494	0.8422	0.7788	0.7282	0.7618	0.7972	0.7948
	WNNM	0.8720	0.6511	0.8365	0.7120	0.8081	**0.8879**	0.7649	0.7780	0.8534	0.8461	0.7666	0.7065	0.7517	0.8006	0.7882
	SSR-QC	0.8737	0.6552	0.8539	0.7130	0.8199	0.8860	0.7711	0.7825	0.8585	0.8420	0.7723	0.7194	0.7629	0.8059	0.7940
	JPG-SR	**0.8803**	0.6709	**0.8602**	0.7312	**0.8232**	0.8875	0.7749	**0.7916**	**0.8590**	**0.8469**	**0.7791**	**0.7294**	**0.7673**	**0.8111**	**0.8009**
20	JPEG	0.8897	0.7772	0.8831	0.8245	0.8621	0.9270	0.8180	0.8483	0.8613	0.8722	0.8395	0.8026	0.8264	0.8597	0.8494
	SA-DCT	0.9155	0.7788	0.9089	0.8311	0.8754	0.9326	0.8235	0.8605	0.8722	0.9010	0.8585	0.7970	0.8380	0.8715	0.8617
	ANCE	0.9182	0.7728	0.9119	0.8264	0.8775	0.9356	0.8346	0.8634	0.8784	0.8990	0.8579	0.8115	0.8390	0.8778	0.8646
	BM3D	0.9133	0.7833	0.9130	0.8327	0.8789	0.9351	0.8306	0.8646	0.8770	0.8998	0.8600	0.8098	0.8439	0.8751	0.8655
	WNNM	0.9143	0.7757	0.9152	0.8256	0.8771	0.9380	0.8184	0.8549	0.8740	0.9012	0.8544	0.7839	0.8422	0.8817	0.8612
	SSR-QC	0.9160	0.7722	0.9229	0.8204	0.8831	0.9362	0.8291	0.8583	0.8804	0.9007	0.8557	0.8028	0.8458	0.8857	0.8650
	JPG-SR	**0.9197**	**0.7878**	**0.9239**	**0.8356**	**0.8856**	**0.9388**	**0.8390**	**0.8687**	**0.8810**	**0.9021**	**0.8616**	**0.8179**	**0.8496**	**0.8911**	**0.8716**
30	JPEG	0.9166	0.8268	0.9173	0.8647	0.8938	0.9471	0.8567	0.8859	0.8824	0.9021	0.8760	0.8462	0.8646	0.8968	0.8841
	SA-DCT	0.9361	0.8314	0.9345	0.8728	0.9031	0.9506	0.8551	0.8949	0.8871	0.9225	0.8917	0.8412	0.8746	0.9053	0.8929
	ANCE	0.9377	0.8261	0.9387	0.8680	0.9043	0.9534	0.8645	0.8968	0.8943	0.9227	0.8906	0.8523	0.8755	0.9128	0.8956
	BM3D	0.9357	0.8335	0.9377	0.8732	0.9055	0.9523	0.8612	0.8977	0.8904	0.9220	0.8923	0.8496	0.8784	0.9076	0.8955
	WNNM	0.9352	0.8315	0.9393	0.8717	0.9052	0.9548	0.8483	0.8927	0.8852	0.9232	0.8906	0.8293	0.8800	0.9142	0.8930
	SSR-QC	**0.9379**	0.8279	0.9447	0.8665	0.9082	0.9543	0.8601	0.8938	0.8959	0.9239	0.8902	0.8439	0.8819	0.9179	0.8962
	JPG-SR	0.9375	**0.8355**	**0.9466**	**0.8741**	**0.9110**	**0.9557**	**0.8663**	**0.8998**	**0.8976**	**0.9241**	**0.8926**	**0.8556**	**0.8835**	**0.9230**	**0.9002**
40	JPEG	0.9306	0.8570	0.9353	0.8883	0.9124	0.9573	0.8788	0.9058	0.8981	0.9180	0.8970	0.8702	0.8857	0.9163	0.9036
	SA-DCT	0.9446	0.8625	0.9481	0.8963	0.9204	0.9599	0.8764	0.9139	0.8988	0.9352	0.9101	0.8686	0.8950	0.9225	0.9109
	ANCE	0.9483	0.8593	0.9524	0.8925	0.9208	0.9623	0.8849	0.9153	0.9056	0.9360	0.9096	0.8767	0.8962	0.9308	0.9136
	BM3D	0.9445	0.8637	0.9507	0.8962	0.9220	0.9609	0.8814	0.9157	0.9015	0.9346	0.9104	0.8743	0.8974	0.9244	0.9127
	WNNM	0.9433	0.8635	0.9522	0.8966	0.9218	0.9631	0.8717	0.9125	0.8943	0.9357	0.9095	0.8613	0.8999	0.9298	0.9111
	SSR-QC	0.9470	0.8599	**0.9572**	0.8903	0.9236	0.9632	0.8791	0.9111	0.9072	0.9366	0.9078	0.8673	0.9015	0.9351	0.9134
	JPG-SR	**0.9484**	**0.8661**	0.9570	**0.8969**	**0.9260**	**0.9642**	**0.8862**	**0.9171**	**0.9093**	**0.9370**	**0.9115**	**0.8784**	**0.9026**	**0.9382**	**0.9171**



(a) Original Image (b) BCS (c) MH (d) TV-NLR (e) RCOS

(f) ALSB (g) SGSR (h) NGS (i) PMDSE (j) **JPG-SR**

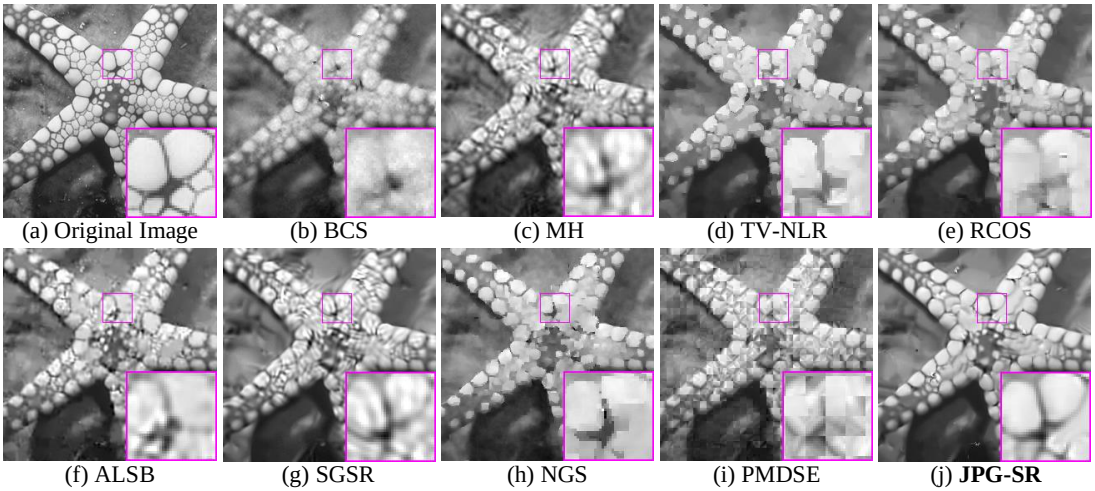
Figure 5: Visual comparison of *Leave* for image CS recovery with $0.1N$ measurements. (a) Original image; (b) BCS (PSNR = 18.55dB, SSIM = 0.5797); (c) MH (PSNR = 20.89dB, SSIM = 0.7365); (d) TV-NLR (PSNR = 19.36dB, SSIM = 0.7067); (e) RCOS (PSNR = 21.97dB, SSIM = 0.8264); (f) ALSB (PSNR = 21.61dB, SSIM = 0.7961); (g) SGSR (PSNR = 22.39dB, SSIM = 0.8451); (h) NGS (PSNR= 17.87dB, SSIM = 0.6501); (i) PMDSE (PSNR= 18.13dB, SSIM = 0.6184); (j) JPG-SR (PSNR= **25.37dB**, SSIM = **0.9087**).



(a) Original Image (b) BCS (c) MH (d) TV-NLR (e) RCOS

(f) ALSB (g) SGSR (h) NGS (i) PMDSE (j) **JPG-SR**

Figure 6: Visual comparison of *Monarch* for image CS recovery with $0.1N$ measurements. (a) Original image; (b) BCS (PSNR = 21.96dB, SSIM = 0.7015); (c) MH (PSNR = 23.19dB, SSIM = 0.7575); (d) TV-NLR (PSNR = 23.37dB, SSIM = 0.7845); (e) RCOS (PSNR = 25.41dB, SSIM = 0.8428); (f) ALSB (PSNR = 24.23dB, SSIM = 0.8142); (g) SGSR (PSNR = 24.44dB, SSIM = 0.8373); (h) NGS (PSNR= 22.72dB, SSIM = 0.7776); (i) PMDSE (PSNR= 21.02dB, SSIM = 0.6926); (j) JPG-SR (PSNR= **27.15dB**, SSIM = **0.8833**).



(a) Original Image (b) BCS (c) MH (d) TV-NLR (e) RCOS

(f) ALSB (g) SGSR (h) NGS (i) PMDSE (j) **JPG-SR**

Figure 7: Visual comparison of *Starfish* for image CS recovery with $0.1N$ measurements. (a) Original image; (b) BCS (PSNR = 22.97dB, SSIM = 0.6687); (c) MH (PSNR = 22.54dB, SSIM = 0.6843); (d) TV-NLR (PSNR = 22.90dB, SSIM = 0.6783); (e) RCOS (PSNR = 23.74dB, SSIM = 0.7146); (f) ALSB (PSNR = 23.61dB, SSIM = 0.7274); (g) SGSR (PSNR = 22.91dB, SSIM = 0.7065); (h) NGS (PSNR= 23.24dB, SSIM = 0.6846); (i) PMDSE (PSNR= 22.07dB, SSIM = 0.6509); (j) JPG-SR (PSNR= **25.10dB**, SSIM = **0.7698**).

Table 3: PSNR (dB) comparison of BCS, MH, TV-NLR, RCOS, ALSB, SGSR, NGS, P-MDSE and JPG-SR for image CS recovery.

Ratio	Methods	Airplane	Couple	Fence	Fingerprint	Flower	House	Lake	Leaves	Lena	Man	Monarch	Parrot	Peppers	Starfish	Average
0.1	BCS	22.92	23.59	19.52	17.10	23.69	26.99	21.83	18.55	25.42	22.60	21.96	23.15	24.47	22.97	22.48
	MH	23.67	23.56	24.02	20.26	24.15	30.28	22.17	20.89	26.13	22.92	23.19	25.34	25.33	22.54	23.89
	TV-NLR	23.59	24.12	20.03	16.48	24.71	29.75	22.84	19.36	26.37	23.43	23.37	24.90	25.62	22.90	23.39
	RCOS	24.69	25.07	23.17	16.31	25.36	31.46	23.64	21.97	27.47	24.02	25.41	25.71	27.54	23.74	24.68
	ALSB	24.81	24.75	25.11	20.68	24.92	32.17	23.60	21.61	27.29	23.73	24.23	26.41	26.76	23.61	24.98
	SGSR	24.23	24.44	25.64	20.47	25.09	33.06	22.62	22.39	27.11	23.62	24.44	26.06	27.08	22.91	24.94
	NGS	24.46	24.44	19.92	15.78	24.99	31.25	23.05	17.87	26.58	23.87	22.72	23.65	26.52	23.24	23.45
	PMDSE	22.46	22.70	18.63	16.65	22.96	26.22	21.03	18.13	23.91	21.68	21.02	24.00	22.93	22.07	21.74
	JPG-SR	**25.50**	**25.20**	**27.02**	**21.28**	**26.31**	**34.05**	**23.90**	**25.37**	**28.05**	**24.33**	**27.15**	**27.53**	**28.00**	**25.10**	**26.34**
0.2	BCS	25.86	25.57	21.57	18.50	25.93	30.54	24.05	21.12	28.15	24.67	25.21	26.52	27.15	25.29	25.01
	MH	27.19	26.96	27.56	23.06	27.47	33.84	25.42	25.14	29.81	25.86	27.10	29.23	28.61	25.93	27.37
	TV-NLR	26.54	26.37	22.21	18.04	27.39	32.99	25.29	23.47	28.94	26.04	27.27	27.27	29.39	25.59	26.20
	RCOS	28.28	27.95	27.31	19.59	28.46	35.21	26.56	26.93	30.33	26.77	29.69	28.63	30.78	27.33	28.13
	ALSB	28.62	28.13	28.41	23.69	28.62	36.07	27.07	27.15	30.68	26.77	28.08	29.70	29.96	27.30	28.59
	SGSR	28.07	28.25	29.42	23.60	29.21	35.81	26.59	28.79	30.89	27.00	28.76	30.60	30.51	27.19	28.91
	NGS	28.18	27.27	23.65	17.90	28.17	34.79	26.36	25.40	29.60	26.65	28.90	26.60	30.56	26.78	27.20
	PMDSE	24.82	24.81	22.62	19.92	25.48	29.41	23.02	21.99	27.24	24.07	23.98	25.95	25.42	24.38	24.51
	JPG-SR	**29.45**	**28.65**	**29.87**	**23.91**	**29.89**	**36.47**	**27.33**	**30.65**	**31.35**	**27.67**	**30.99**	**31.50**	**31.17**	**29.13**	**29.86**
0.3	BCS	28.02	27.12	23.24	19.96	27.84	32.85	25.92	23.16	30.16	26.38	27.55	28.80	29.05	27.20	26.94
	MH	29.67	28.61	29.42	24.80	29.47	35.69	27.19	27.63	31.99	27.62	29.20	31.01	30.20	27.90	29.31
	TV-NLR	28.51	28.35	24.72	19.74	29.18	35.63	26.47	26.43	30.09	28.06	29.80	29.12	30.81	27.94	28.20
	RCOS	30.72	30.39	29.91	23.03	30.84	37.10	29.14	30.59	32.38	28.82	32.75	30.88	32.69	30.11	30.67
	ALSB	31.14	30.91	30.83	25.84	31.53	38.34	29.72	31.08	33.36	28.98	31.60	32.31	32.37	30.35	31.31
	SGSR	31.04	30.72	31.56	25.84	32.16	37.37	29.31	33.00	33.26	29.22	31.99	32.52	32.71	30.79	31.53
	NGS	31.07	30.14	27.61	20.25	30.60	36.43	28.68	29.10	32.45	28.67	32.53	29.47	32.90	29.87	29.98
	PMDSE	26.87	26.97	25.31	22.39	27.24	32.05	25.22	24.43	29.09	26.00	26.39	28.33	27.57	26.68	26.75
	JPG-SR	**31.98**	**31.24**	**31.85**	**26.27**	**32.45**	**38.45**	**30.12**	**33.37**	**33.95**	**29.81**	**33.24**	**33.32**	**33.02**	**31.90**	**32.21**
0.4	BCS	29.96	28.51	24.81	21.67	29.51	34.65	27.52	25.07	32.06	27.91	29.59	30.89	30.77	28.94	28.70
	MH	31.57	30.47	30.94	26.11	30.98	36.65	28.87	29.66	33.60	29.11	31.13	33.49	31.81	29.62	31.00
	TV-NLR	30.11	30.87	28.18	21.25	31.91	37.33	28.91	29.87	32.17	29.74	31.90	30.77	32.18	30.44	30.40
	RCOS	32.94	32.31	32.19	25.11	32.89	38.60	31.05	33.67	34.31	30.42	35.14	32.79	34.26	32.46	32.72
	ALSB	33.82	33.44	32.83	27.70	34.19	**40.25**	31.99	34.57	35.47	30.99	34.42	34.85	34.44	32.98	33.71
	SGSR	33.36	33.18	33.34	27.85	34.40	38.99	31.62	35.83	35.68	31.24	34.66	**35.81**	34.47	33.67	33.86
	NGS	33.50	32.45	30.59	22.98	33.37	37.82	31.11	32.99	35.10	30.66	35.13	32.04	34.57	32.78	32.51
	PMDSE	28.18	28.73	27.66	24.22	29.06	33.94	26.20	26.81	30.97	27.72	27.48	30.41	28.94	28.24	28.47
	JPG-SR	**34.18**	**33.76**	**33.71**	**28.27**	**34.69**	40.19	**32.31**	**36.06**	**35.95**	**31.64**	**35.63**	35.76	**34.67**	**34.46**	**34.38**

Table 4: SSIM comparison of BCS, MH, TV-NLR, RCOS, ALSB, SGSR, NGS, PMDSE and JPG-SR for image CS recovery.

Ratio	Methods	Airplane	Couple	Fence	Fingerprint	Flower	House	Lake	Leaves	Lena	Man	Monarch	Parrot	Pepper	Starfish	Average
0.1	BCS	0.7200	0.5944	0.4956	0.3434	0.6210	0.7681	0.6040	0.5797	0.7420	0.5607	0.7015	0.7941	0.6956	0.6687	0.6349
	MH	0.7638	0.6482	0.7317	0.7220	0.6782	0.8357	0.6435	0.7365	0.7976	0.5837	0.7575	0.8219	0.7258	0.6843	0.7236
	TV-NLR	0.7680	0.6454	0.5577	0.3373	0.7128	0.8347	0.7013	0.7067	0.7941	0.6330	0.7845	0.8302	0.7600	0.6783	0.6960
	RCOS	0.7971	0.7005	0.6882	0.3539	0.7444	0.8525	0.7368	0.8264	0.8227	0.6554	0.8428	0.8453	0.8010	0.7146	0.7415
	ALSB	0.8146	0.7015	0.7692	0.7391	0.7403	0.8617	0.7419	0.7961	0.8301	0.6526	0.8142	0.8566	0.7820	0.7274	0.7734
	SGSR	0.7982	0.7119	0.7929	0.7412	0.7517	0.8673	0.6961	0.8451	0.8360	0.6540	0.8373	0.8583	0.7973	0.7065	0.7781
	NGS	0.7782	0.6503	0.5467	0.3124	0.7077	0.8439	0.6941	0.6501	0.7888	0.6403	0.7776	0.8303	0.7711	0.6846	0.6911
	PMDSE	0.7317	0.6041	0.5024	0.4589	0.6492	0.7574	0.6410	0.6184	0.7179	0.5818	0.6926	0.7837	0.6747	0.6509	0.6475
	JPG-SR	**0.8262**	**0.7232**	**0.7981**	**0.7476**	**0.7849**	**0.8742**	**0.7488**	**0.9087**	**0.8469**	**0.6847**	**0.8833**	**0.8749**	**0.8123**	**0.7698**	**0.8060**
0.2	BCS	0.8089	0.6979	0.6232	0.5461	0.7246	0.8395	0.6988	0.7047	0.8277	0.6730	0.7998	0.8659	0.7750	0.7678	0.7395
	MH	0.8525	0.7934	0.8355	0.8412	0.8019	0.8934	0.7713	0.8608	0.8806	0.7359	0.8660	0.8975	0.8156	0.7972	0.8316
	TV-NLR	0.8568	0.7700	0.6949	0.5313	0.8216	0.8802	0.7980	0.8619	0.8656	0.7560	0.8808	0.8843	0.8457	0.7963	0.8031
	RCOS	0.8842	0.8216	0.8279	0.6416	0.8484	0.8937	0.8332	0.9310	0.8894	0.7730	0.9213	0.8998	0.8639	0.8392	0.8477
	ALSB	0.8977	0.8419	0.8557	**0.8650**	0.8617	**0.9165**	0.8477	0.9299	0.9041	0.7886	0.9025	0.9128	0.8537	0.8471	0.8732
	SGSR	0.8827	0.8466	**0.8754**	0.8641	0.8716	0.9017	0.8345	0.9487	0.9049	0.7998	0.9162	0.9125	0.8639	0.8391	0.8758
	NGS	0.8789	0.7914	0.7342	0.5298	0.8301	0.8904	0.8170	0.8955	0.8718	0.7721	0.9002	0.8879	0.8571	0.8190	0.8197
	PMDSE	0.8146	0.7349	0.7082	0.7145	0.7633	0.8296	0.7390	0.8009	0.8341	0.7177	0.8122	0.8503	0.7661	0.7684	0.7753
	JPG-SR	**0.9028**	**0.8489**	0.8689	0.8579	**0.8806**	0.9126	**0.8499**	**0.9635**	**0.9087**	**0.8070**	**0.9381**	**0.9187**	**0.8721**	**0.8771**	**0.8862**
0.3	BCS	0.8631	0.7685	0.7148	0.6880	0.7943	0.8781	0.7654	0.7768	0.8764	0.7504	0.8533	0.9017	0.8217	0.8287	0.8058
	MH	0.8944	0.8388	0.8786	0.8932	0.8555	0.9186	0.8227	0.9040	0.9154	0.8003	0.9005	0.9254	0.8513	0.8506	0.8749
	TV-NLR	0.8989	0.8456	0.7981	0.6892	0.8765	0.9109	0.8446	0.9233	0.8969	0.8349	0.9228	0.9140	0.8774	0.8667	0.8643
	RCOS	0.9248	0.8897	0.8862	0.8279	0.9031	0.9200	0.8926	0.9642	0.9248	0.8406	0.9534	0.9271	0.8967	0.9021	0.9038
	ALSB	0.9336	0.9087	0.9088	0.9167	0.9201	**0.9465**	0.9040	0.9664	0.9407	0.8645	0.9464	0.9401	0.8951	0.9113	0.9216
	SGSR	0.9241	0.9016	**0.9153**	0.9168	0.9216	0.9257	0.8951	0.9740	0.9359	0.8646	0.9488	0.9344	0.8978	0.9091	0.9189
	NGS	0.9245	0.8776	0.8509	0.7189	0.8926	0.9138	0.8792	0.9485	0.9209	0.8393	0.9460	0.9223	0.8946	0.8915	0.8872
	PMDSE	0.8707	0.8181	0.8039	0.8197	0.8309	0.8872	0.8143	0.8667	0.8837	0.7966	0.8705	0.8931	0.8242	0.8396	0.8442
	JPG-SR	**0.9379**	**0.9089**	0.9153	**0.9183**	**0.9271**	0.9439	**0.9080**	**0.9782**	**0.9425**	**0.8756**	**0.9579**	**0.9407**	**0.9025**	**0.9279**	**0.9275**
0.4	BCS	0.8995	0.8208	0.7834	0.7954	0.8432	0.9050	0.8156	0.8289	0.9103	0.8088	0.8898	0.9281	0.8591	0.8732	0.8544
	MH	0.9287	0.8904	0.9072	0.9210	0.8900	0.9212	0.8620	0.9289	0.9351	0.8485	0.9237	0.9379	0.8831	0.8859	0.9045
	TV-NLR	0.9266	0.9045	0.8779	0.7867	0.9228	0.9322	0.8943	0.9591	0.9295	0.8735	0.9475	0.9347	0.9011	0.9171	0.9077
	RCOS	0.9487	0.9248	0.9222	0.8916	0.9346	0.9405	0.9251	0.9802	0.9477	0.8822	0.9678	0.9456	0.9180	0.9366	0.9333
	ALSB	**0.9586**	0.9448	0.9374	0.9461	0.9516	**0.9633**	0.9352	0.9826	0.9589	0.9087	0.9659	0.9567	0.9225	0.9458	0.9484
	SGSR	0.9474	0.9370	0.9388	0.9468	0.9472	0.9475	0.9277	0.9836	0.9568	0.9073	0.9651	0.9531	0.9204	0.9414	0.9443
	NGS	0.9503	0.9218	0.9035	0.8415	0.9360	0.9332	0.9216	0.9743	0.9493	0.8890	0.9644	0.9440	0.9173	0.9331	0.9271
	PMDSE	0.8977	0.8760	0.8609	0.8825	0.8763	0.9172	0.8446	0.9108	0.9163	0.8531	0.8959	0.9212	0.8591	0.8812	0.8852
	JPG-SR	0.9583	**0.9449**	**0.9420**	**0.9491**	**0.9530**	0.9609	**0.9377**	**0.9868**	**0.9607**	**0.9143**	**0.9712**	**0.9575**	**0.9241**	**0.9545**	**0.9511**

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