Benchmarking Low-Light Image Enhancement and Beyond (Supplementary Material)

Jiaying Liu · Dejia Xu · Wenhan Yang · Minhao Fan · Haofeng Huang

Abstract In this manuscript, we present more visual results of enhancement methods and face detection methods presented in the main body of our submission. Enhancement methods include Multi-Scale Retinex (MSR) (Jobson et al., 1997), Inverse Dehazing (Dehazing) (Dong et al., 2011), Brightness Preserving Dynamic Histogram Equalization (BPDHE) (Ibrahim and Pik Kong, 2007), Naturalness Preserved Enhancement (NPE) (Wang et al., 2013), Low-light IMage Enhancement (LIME) (Guo et al., 2017), Multiple image Fusion (MF) (Fu et al., 2016), Simultaneous Reflectance and Illumination Estimation (SRIE) (Fu et al., 2016), Bio-Inspired Multi-Exposure Fusion (BIMEF) (Ying et al., 2017), Joint Enhancement and Denoising (JED) (Ren et al., 2018), LLNet (Lore et al., 2017), RetinexNet (Wei* et al., 2018), Contextual and Variational Contrast enhancement (CVC) (Celik and Tjahjadi, 2011), DHECI (Nakai et al., 2013), Histogram Equalization (HE), Layered Difference Representation (LDR) (Lee et al., 2013a), Robust Retinex Model (Robust) (Li et al., 2018), Single Image Contrast Enhancer (SICE) (Cai et al., 2018), Weighted Approximated Histogram Equalization (WAHE) (Arici et al., 2009), and Adaptive MultiScale Retinex (AMSR) (Lee et al., 2013b), Kindling the Darkness (KinD) (Zhang et al., 2019), Deep Underexposed Photo Enhancement (DeepUPE) (Wang et al., 2019). Face detection results of Dual Shot Face Detector (DSFD) (Li et al., 2019), PyramidBox (Tang et al., 2018), and Selective Refinement Network (SRN) (Chi et al., 2018) on original and enhanced images are also provided.

Keywords Low-Light Enhancement · Benchmark · Dataset · Face Detection

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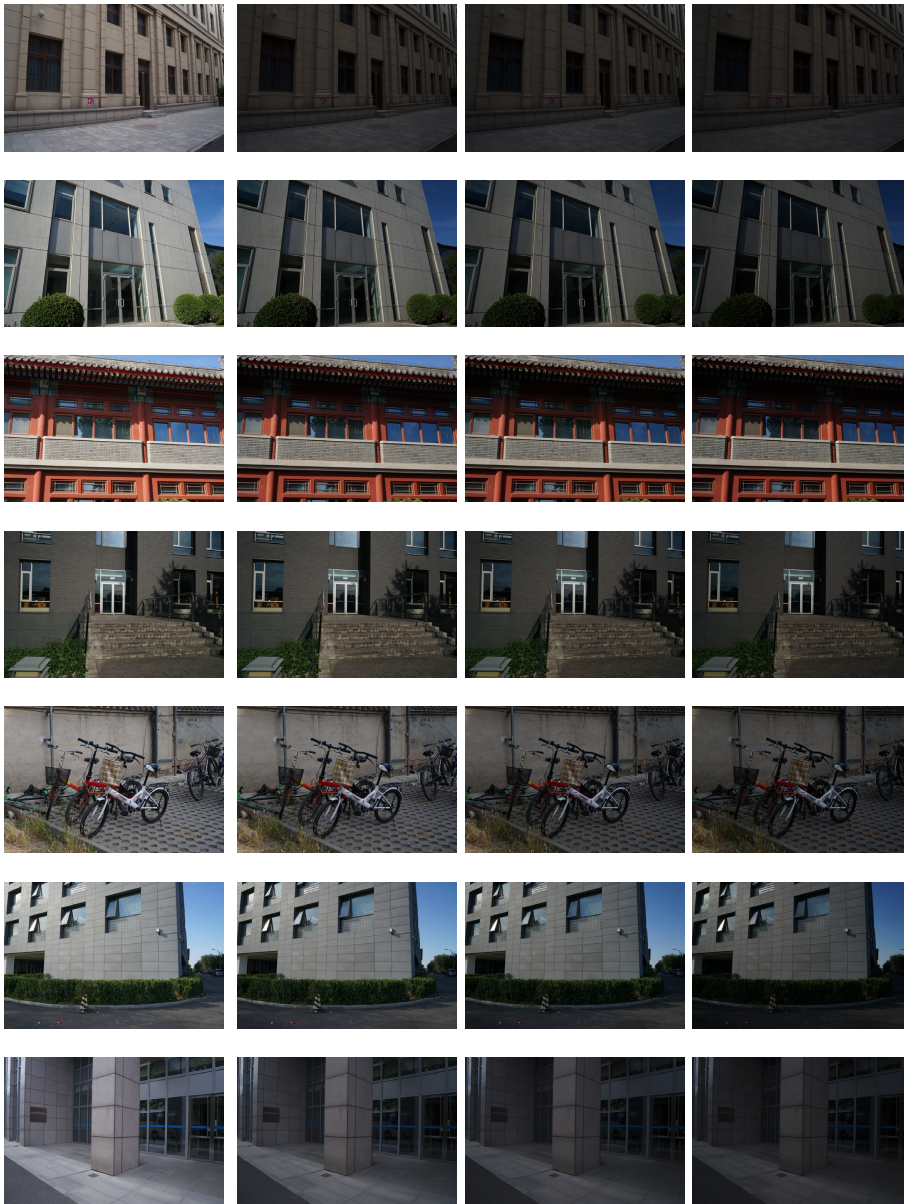
1 Example images of VE-LOL-L

Fig. 1 Examples of low-light images with different under-exposed levels in VE-LOL-L-Cap. The left panel: normal-light images. The right three panels: low-light images.
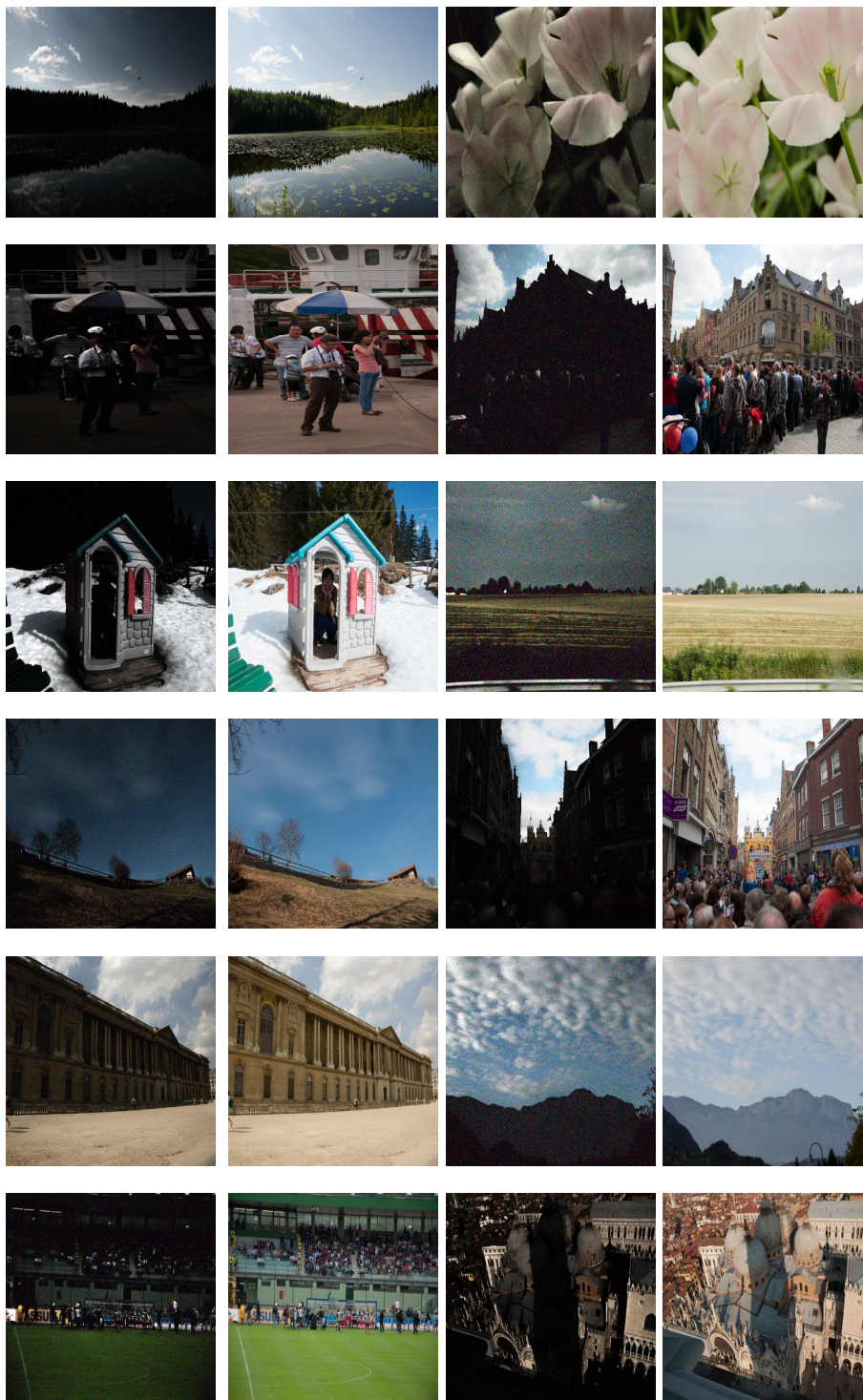
Fig. 2 Examples of paired low and normal-light images in VE-LOL-L-Syn. The first and third panels: low-light images. The second and forth panels: normal-light images.
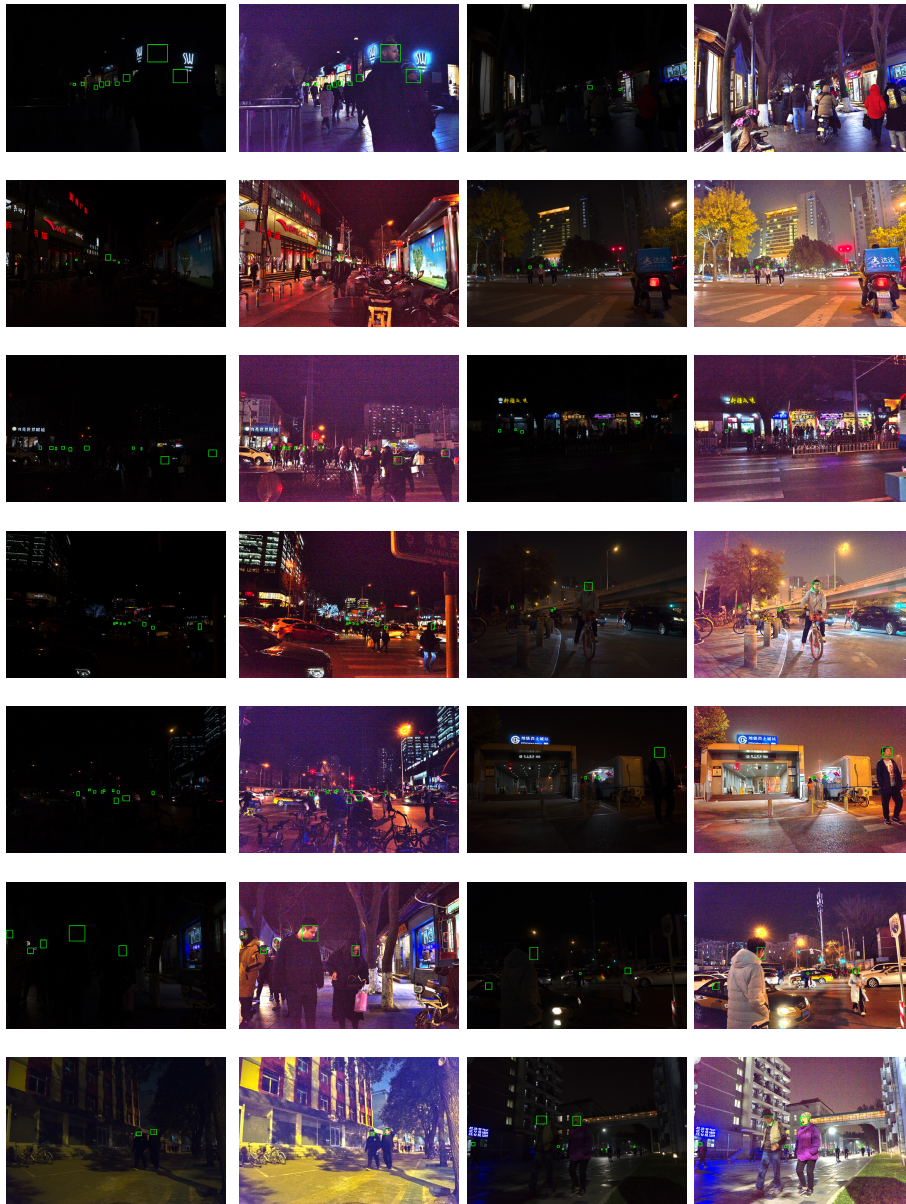
2 Example images of VE-LOL-H

Fig. 3 Examples of captured images in VE-LOL-H. The first and third panels: low-light images. The second and forth panels: images enhanced by LIME (Guo et al., 2017).

3 Sample face detection results on low-light images

Fig. 4 Examples of face detection results of low-light images in VE-LOL-H. The first and third panels: low-light images with the detected bounding boxes. The second and forth panels: images enhanced by LIME (Guo et al., 2017) with the detected bounding boxes for better visualization.

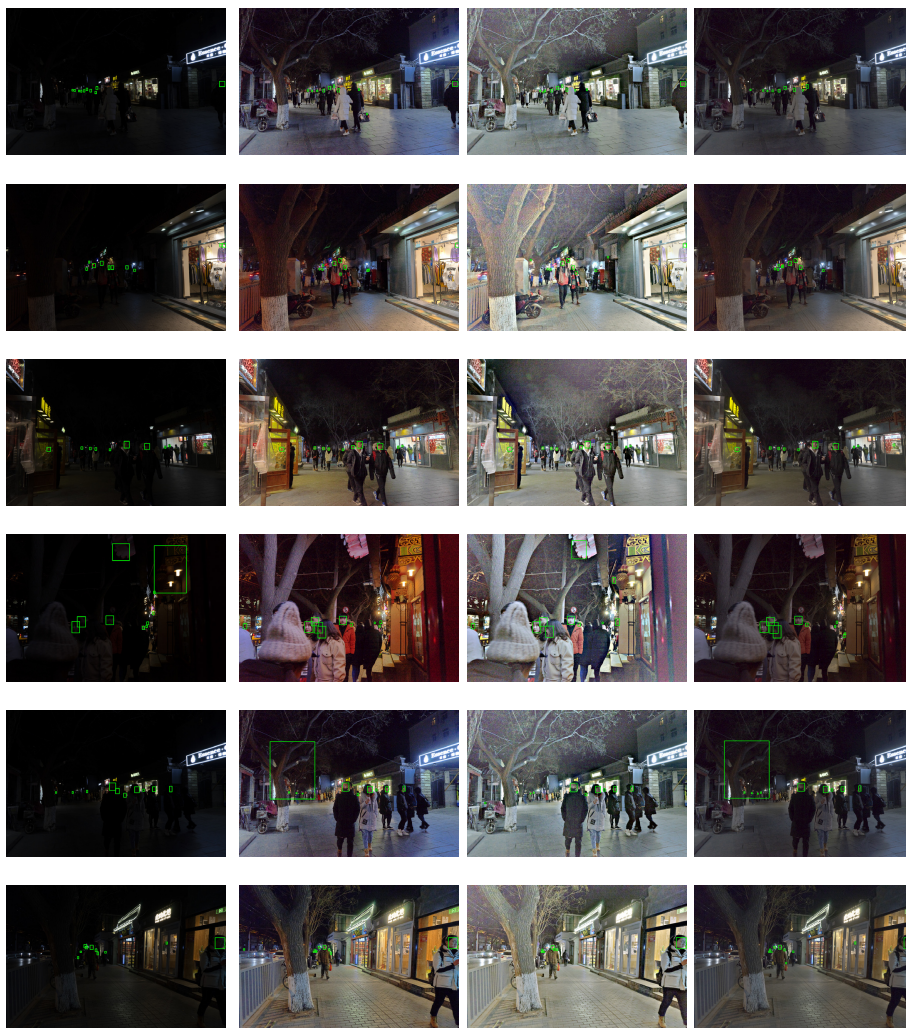## 4 Sample face detection results on enhanced images

Fig. 5 Examples of face detection (DSFD (Li et al., 2019)) results of enhanced images in VE-LOL-H. The first panel: low-light images with the detected bounding boxes. The second panel: Images enhanced by M-F (Fu et al., 2016) with the detected bounding boxes. The third panel: Images enhanced by MSR (Jobson et al., 1997) with the detected bounding boxes. The forth panel: Images enhanced by BIMEF (Ying et al., 2017) with the detected bounding boxes.

Fig. 6 Examples of face detection (PyramidBox (Tang et al., 2018)) results of enhanced images in VE-LOL-H. The first panel: low-light images with the detected bounding boxes. The second panel: Images enhanced by MF (Fu et al., 2016) with the detected bounding boxes. The third panel: Images enhanced by Dehazing (Dong et al., 2011) with the detected bounding boxes. The forth panel: Images enhanced by LIME (Guo et al., 2017) with the detected bounding boxes.

Fig. 7 Examples of face detection (SRN (Chi et al., 2018)) results of enhanced images in VE-LOL-H. The first panel: low-light images with the detected bounding boxes. The second panel: Images enhanced by M-F (Fu et al., 2016) with the detected bounding boxes. The third panel: Images enhanced by MSR (Jobson et al., 1997) with the detected bounding boxes. The forth panel: Images enhanced by BIMEF (Ying et al., 2017) with the detected bounding boxes.
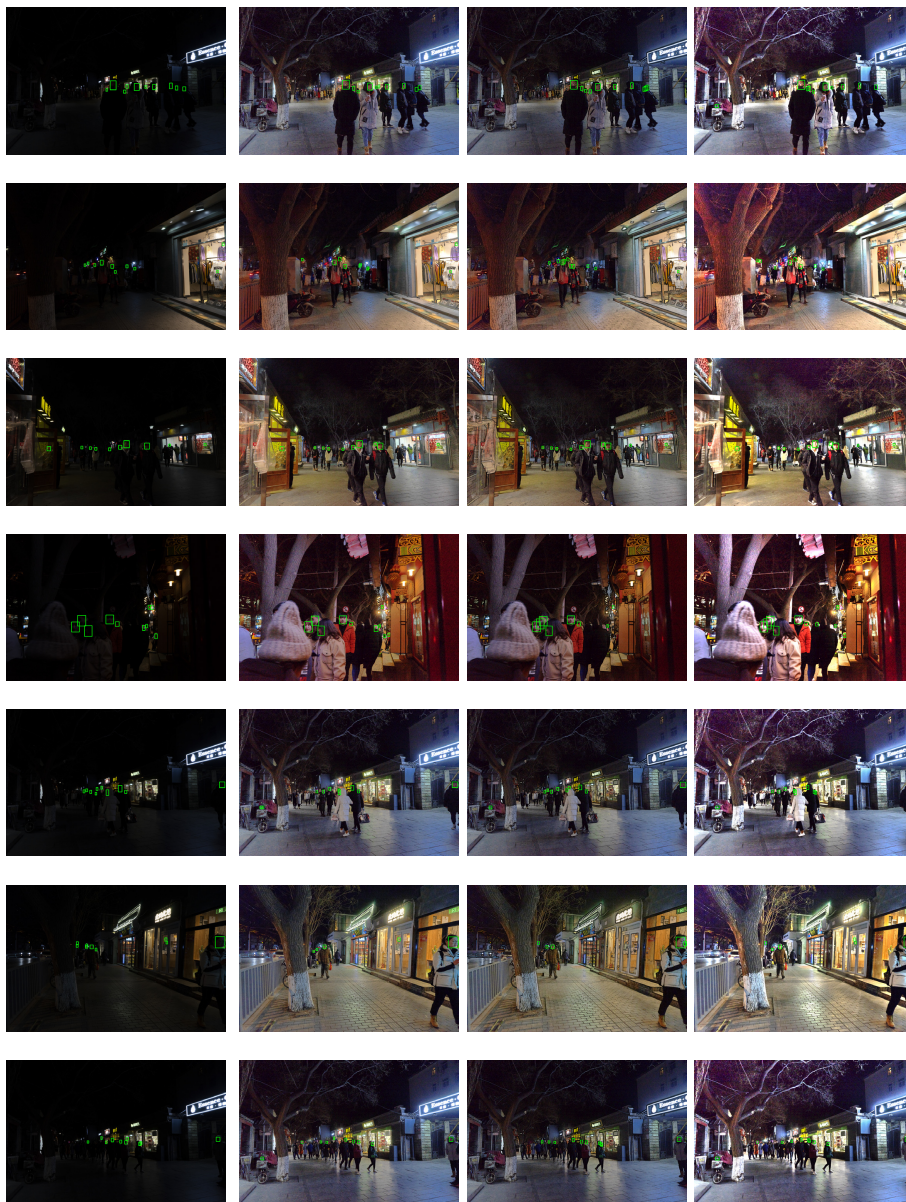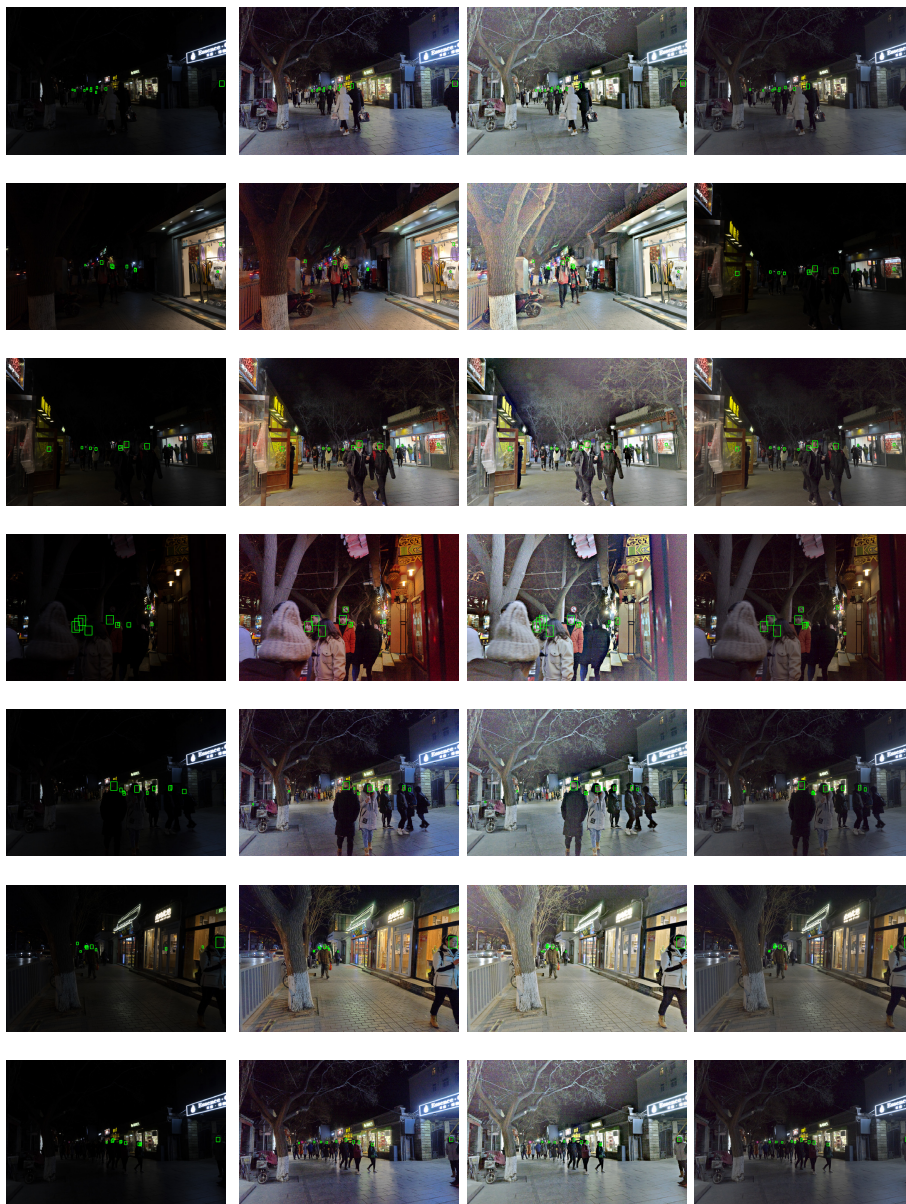
5 Example of Enhanced Results of VE-LOL-L

(a) Input (b) MSR (1997) (c) BPDHE (2007) (d) WAHE (2009)

(e) GT (f) CVC (2011) (g) LDR (2013a) (h) NPE (2013)

(i) DHECI (2013) (j) MF (2016) (k) SRIE (2016) (l) LIME (2017)

(m) LLNet (2017) (n) BIMEF (2017) (o) SICE (2018) (p) RetinexNet (2018)

(q) JED (2018) (r) Robust (2018) (s) KinD (2019) (t) DeepUPE (2019)

Fig. 8 Examples of enhanced results on a real low-light image from VE-LOL-L-Cap.

(a) Input   (b) MSR (1997)   (c) BPDHE (2007)   (d) WAHE (2009)

(e) GT   (f) CVC (2011)   (g) LDR (2013a)   (h) NPE (2013)

(i) DHECI (2013)   (j) MF (2016)   (k) SRIE (2016)   (l) LIME (2017)

(m) LLNet (2017)   (n) BIMEF (2017)   (o) SICE (2018)   (p) RetinexNet (2018)

(q) JED (2018)   (r) Robust (2018)   (s) KinD (2019)   (t) DeepUPE (2019)

Fig. 9 Examples of enhanced results on a real low-light image from VE-LOL-L-Cap.

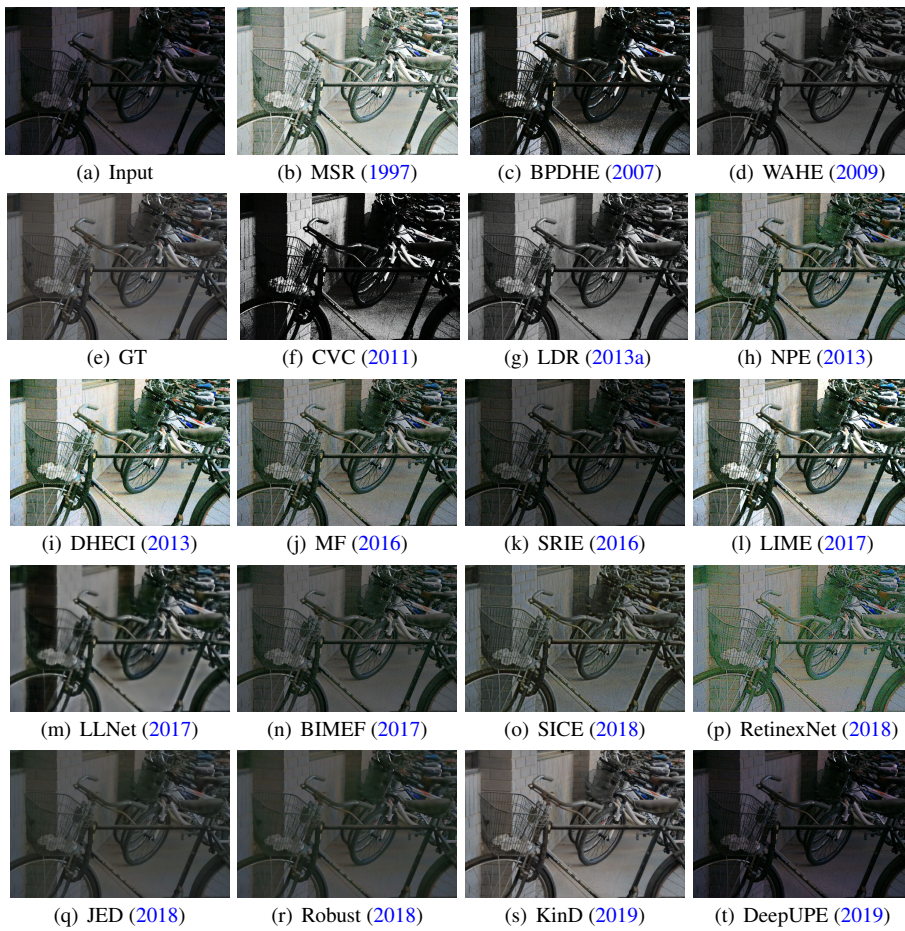**Fig. 10** Examples of enhanced results on a real low-light image from VE-LOL-L-Cap.

(a) Input   (b) MSR (1997)   (c) BPDHE (2007)   (d) WAHE (2009)

(e) GT   (f) CVC (2011)   (g) LDR (2013a)   (h) NPE (2013)

(i) DHECI (2013)   (j) MF (2016)   (k) SRIE (2016)   (l) LIME (2017)

(m) LLNet (2017)   (n) BIMEF (2017)   (o) SICE (2018)   (p) RetinexNet (2018)

(q) JED (2018)   (r) Robust (2018)   (s) KinD (2019)   (t) DeepUPE (2019)

Fig. 11 Examples of enhanced results on a synthetic low-light image from VE-LOL-L-Syn.
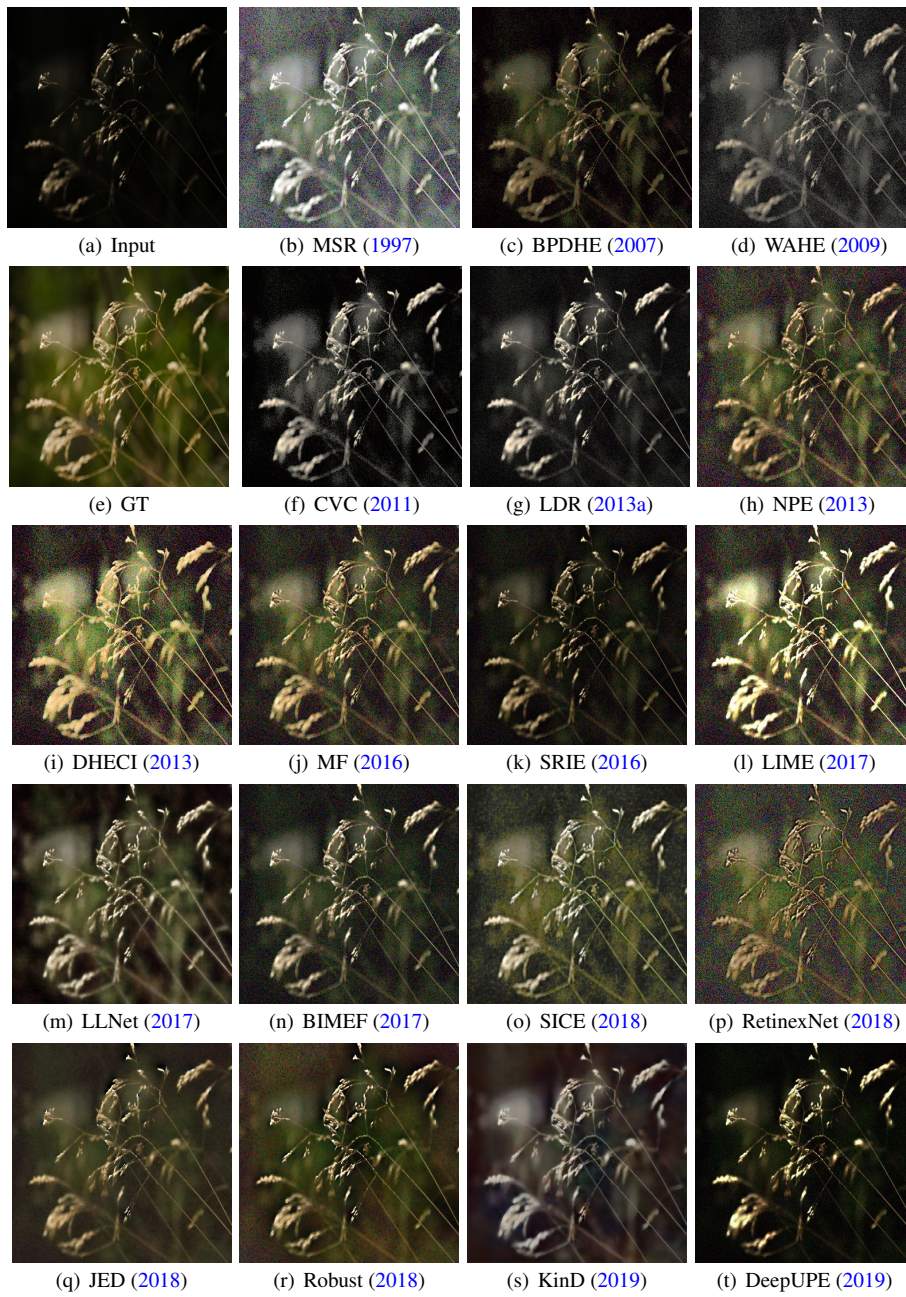
Fig. 12 Examples of enhanced results on a synthetic low-light image from VE-LOL-L-Syn.

References

Arici, T., Dikbas, S., Altunbasak, Y., 2009. A histogram modification framework and its application for image contrast enhancement. IEEE Trans. on Image Processing 18, 1921–1935.

Cai, J., Gu, S., Zhang, L., 2018. Learning a deep single image contrast enhancer from multi-exposure images. IEEE Trans. on Image Processing 27, 2049–2062.

Celik, T., Tjahjadi, T., 2011. Contextual and variational contrast enhancement. IEEE Trans. on Image Processing 20, 3431–3441.

Chi, C., Zhang, S., Xing, J., Lei, Z., Li, S.Z., Zou, X., 2018. Selective refinement network for high performance face detection. arXiv preprint arXiv:1809.02693 .

Dong, X., Wang, G., Pang, Y., Li, W., Wen, J., Meng, W., Lu, Y., 2011. Fast efficient algorithm for enhancement of low lighting video, in: Proc. IEEE Int'l Conf. Multimedia and Expo, pp. 1–6.

Fu, X., Zeng, D., Huang, Y., Liao, Y., Ding, X., Paisley, J., 2016. A fusion-based enhancing method for weakly illuminated images. Signal Processing 129, 82 – 96.

Fu, X., Zeng, D., Huang, Y., Zhang, X., Ding, X., 2016. A weighted variational model for simultaneous reflectance and illumination estimation, in: Proc. IEEE Int'l Conf. Computer Vision and Pattern Recognition, pp. 2782–2790.

Guo, X., Li, Y., Ling, H., 2017. Lime: Low-light image enhancement via illumination map estimation. IEEE Trans. on Image Processing 26, 982–993.

Ibrahim, H., Pik Kong, N.S., 2007. Brightness preserving dynamic histogram equalization for image contrast enhancement. IEEE Transactions on Consumer Electronics 53, 1752–1758.

Jobson, D.J., Rahman, Z., Woodell, G.A., 1997. A multiscale retinex for bridging the gap between color images and the human observation of scenes. IEEE Trans. on Image Processing 6, 965–976.

Lee, C., Lee, C., Kim, C.S., 2013a. Contrast enhancement based on layered difference representation of 2d histograms. IEEE Trans. on Image Processing 22, 5372–5384.

Lee, C.H., Shih, J.L., Lien, C.C., Han, C.C., 2013b. Adaptive multiscale retinex for image contrast enhancement, in: Signal-Image Technology & Internet-Based Systems (SITIS), 2013 International Conference on, IEEE. pp. 43–50.

Li, J., Wang, Y., Wang, C., Tai, Y., Qian, J., Yang, J., Wang, C., Li, J., Huang, F., 2019. Dsfd: Dual shot face detector, in: Proc. IEEE Int'l Conf. Computer Vision and Pattern Recognition.

Li, M., Liu, J., Yang, W., Sun, X., Guo, Z., 2018. Structure-revealing low-light image enhancement via robust retinex model. IEEE Trans. on Image Processing 27, 2828–2841.

Lore, K.G., Akintayo, A., Sarkar, S., 2017. Llnet: A deep autoencoder approach to natural low-light image enhancement. Pattern Recognition 61, 650 – 662.

Nakai, K., Hoshi, Y., Taguchi, A., 2013. Color image contrast enhacement method based on differential intensity/saturation gray-levels histograms, in: International Symposium on Intelligent Signal Processing and Communications Systems, pp. 445–449.

Ren, X., Li, M., Cheng, W.H., Liu, J., 2018. Joint enhancement and denoising method via sequential decomposition, in: IEEE Int'l Symposium on Circuits and Systems.

Tang, X., Du, D.K., He, Z., Liu, J., 2018. Pyramidbox: A context-assisted single shot face detector, in: Proc. IEEE European Conf. Computer Vision.

Wang, R., Zhang, Q., Fu, C.W., Shen, X., Zheng, W.S., Jia, J., 2019. Underexposed photo enhancement using deep illumination estimation, in: Proc. IEEE Int'l Conf. Computer Vision and Pattern Recognition.

Wang, S., Zheng, J., Hu, H.M., Li, B., 2013. Naturalness preserved enhancement algorithm for non-uniform illumination images. IEEE Trans. on Image Processing 22, 3538–3548.

Wei*, C., Wang*, W., Yang, W., Liu, J., 2018. Deep retinex decomposition for low-light enhancement, in: British Machine Vision Conference.

Ying, Z., Li, G., Gao, W., 2017. A Bio-Inspired Multi-Exposure Fusion Framework for Low-light Image Enhancement. ArXiv e-prints .

Zhang, Y., Zhang, J., Guo, X., 2019. Kindling the darkness: a practical low-light image enhancer. ACM Int'l Conf. on Multimedia .