Supplementary Material on

Zero-Shot Learning for Reflection Removal of Single 360-Degree Image

Byeong-Ju Han[1,2] and Jae-Young Sim[1]

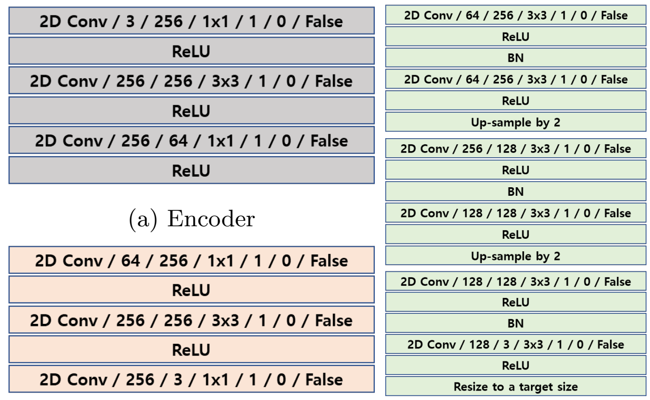
[1] Ulsan National Institute of Science and Technology, Republic of Korea
[2] NAVER Clova, Republic of Korea
{bjhan, jysim}@unist.ac.kr

1 Network Architecture

We construct each sub-network using a small number of CNN layers to train the network parameters in a test time. Figure S-1 shows the network architecture where each block denotes a layer or an individual operation. Figures S-1(a) and (b) visualize the encoder and decoder, respectively, that have similar architectures composed of three CNN layers and ReLU activation functions. Figure S-1(c) also shows the generator for transmission and reflection recovery that consists of six CNN layers followed by ReLU activation functions and batch-normalization. We train the encoder and decoder by using Adam optimizer with a learning rate of 1e-5, and train the generators with different learning rates of 1e-6 and 1e-3, respectively. All networks are updated once for each iteration and trained for 600 iterations.

2 Qualitative Results

In Figures S-2$\sim$ S-31, we provide the complete comparative results of reflection removal on all the 30 test sets of 360-degree images obtained by using the existing methods [1–5] and the proposed method. Note that we used the 360-degree camera that takes the full view around the camera and does not focus on local transmitted scenes in the glass regions. Accordingly, the reflection artifacts in the 360-degree images do not satisfy the smoothness property of the reflected scenes. Therefore, as shown in Figures S-2$\sim$ S-31, the existing reflection removal methods usually fail to separate the transmission images from the reflection images. In contrary, the proposed method successfully reconstructs the transmission and reflection images, respectively, with the help of the reference information within the 360-degree image.



(a) Encoder

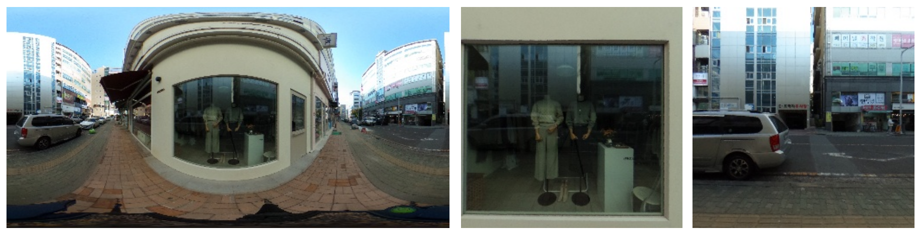
(b) Decoder

(c) Generator

Fig. S-1: The architectures of the proposed network. The layers are serially connected from top to bottom. The convolution layer summarizes the detailed configurations of the numbers of input and output channels, kernel size, stride, padding, and bias existence.

References

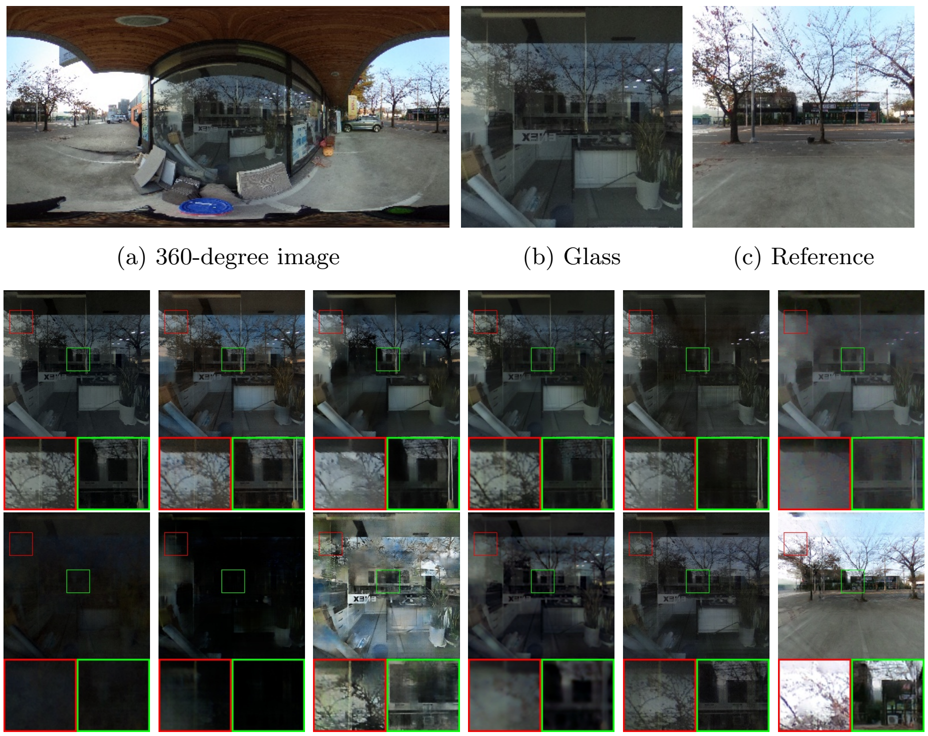
1. Kim, S., Huo, Y., Yoon, S.E.: Single image reflection removal with physically-based training images. In: CVPR (2020)
2. Li, C., Yang, Y., He, K., Lin, S., Hopcroft, J.E.: Single image reflection removal through cascaded refinement. In: CVPR (2020)
3. Li, Y., Brown, M.S.: Single image layer separation using relative smoothness. In: CVPR. pp. 2752–2759 (2014)
4. Yang, J., Gong, D., Liu, L., Shi, Q.: Seeing deeply and bidirectionally: a deep learning approach for single image reflection removal. In: ECCV. pp. 654–669 (2018)
5. Zhang, X., Ng, R., Chen, Q.: Single image reflection separation with perceptual losses. In: CVPR (2018)



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

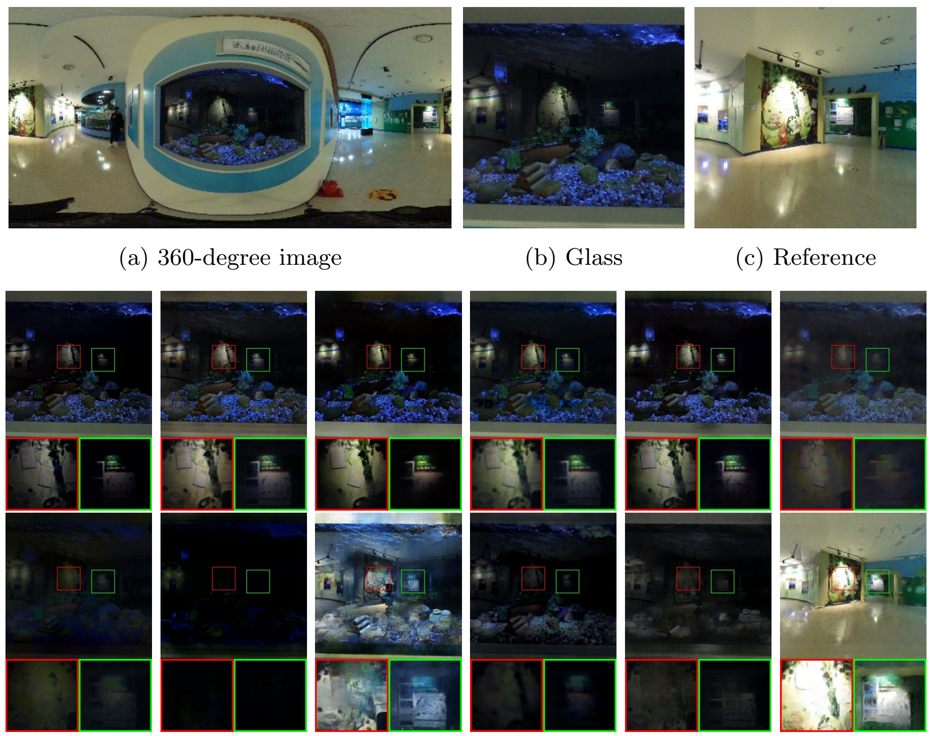
Fig. S-2: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-3: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

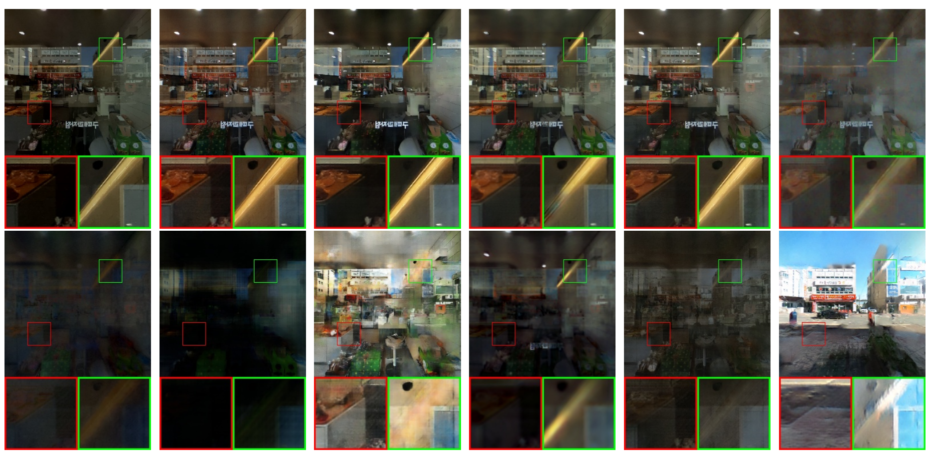
Fig. S-4: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

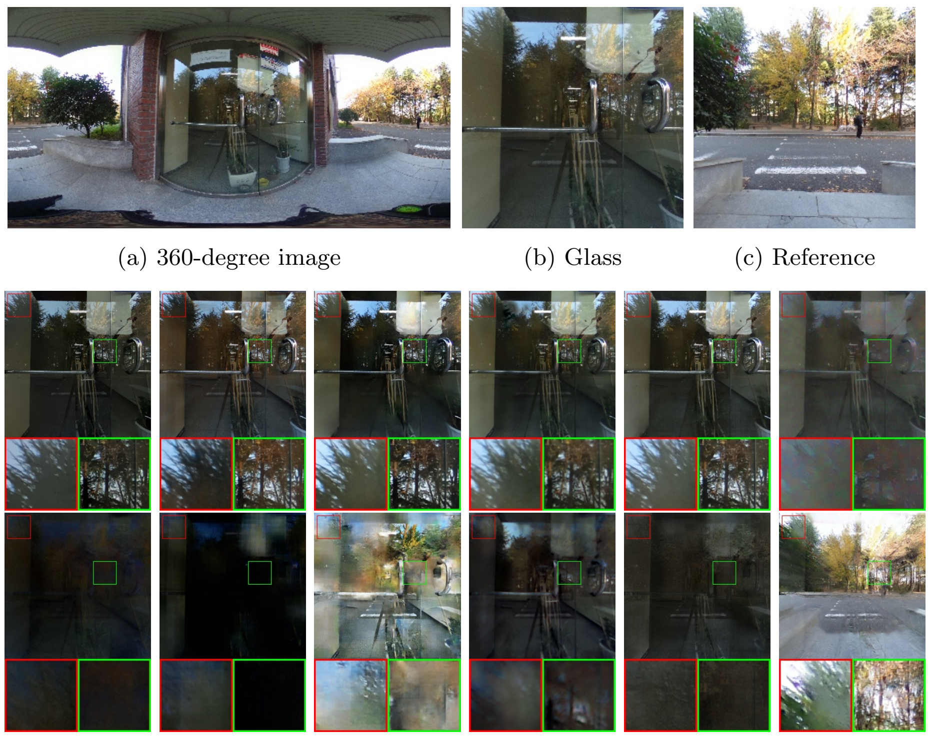
Fig. S-5: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

(a) 360-degree image (b) Glass (c) Reference



(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

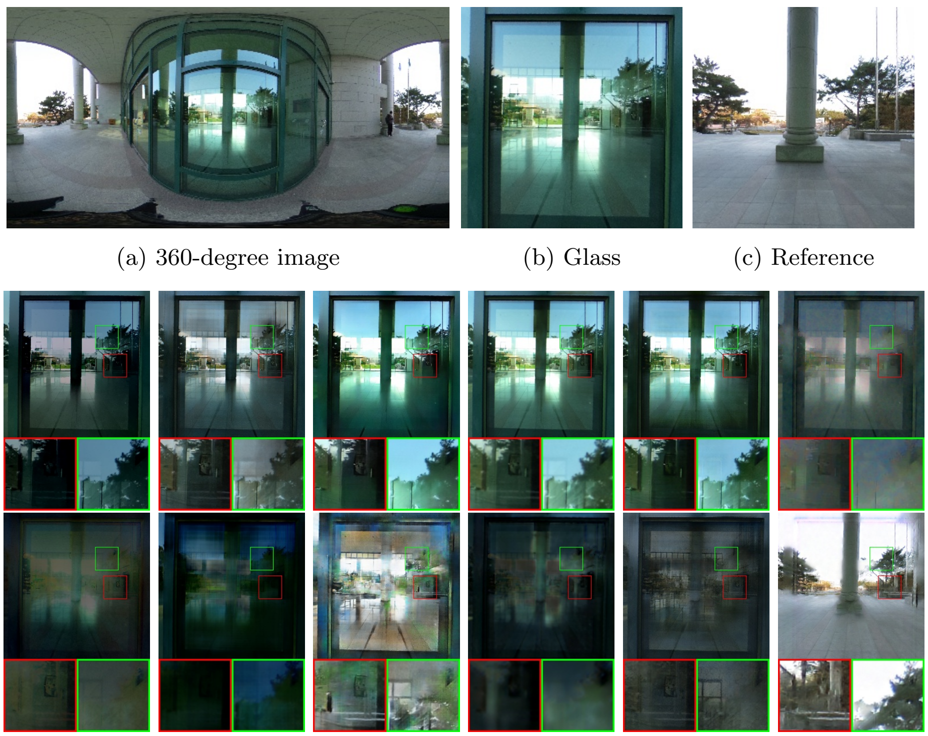
Fig. S-6: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

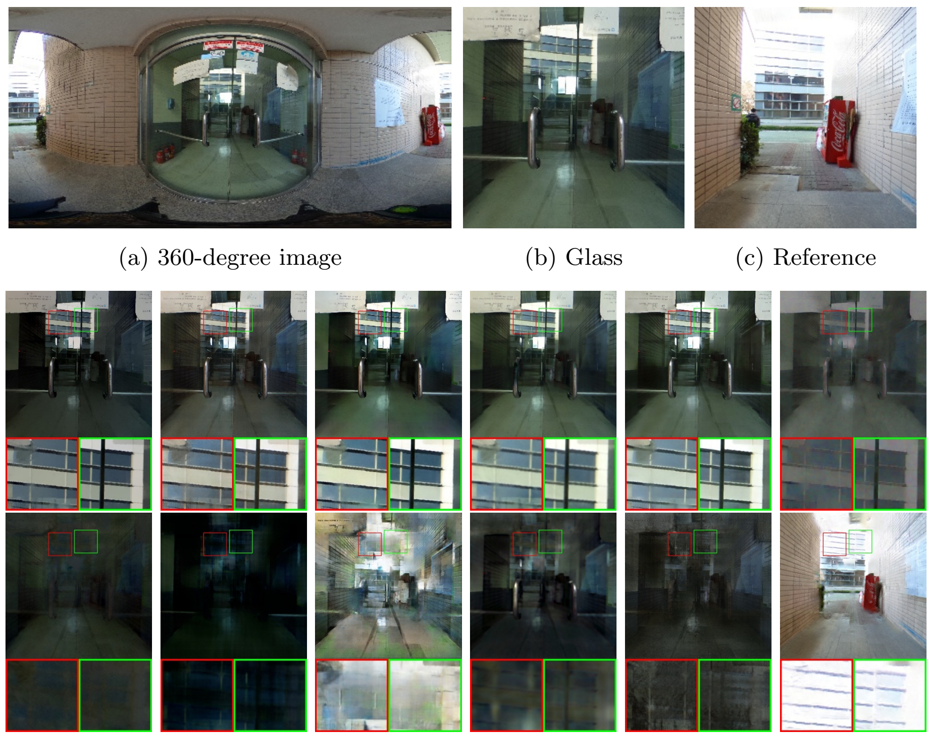
Fig. S-7: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

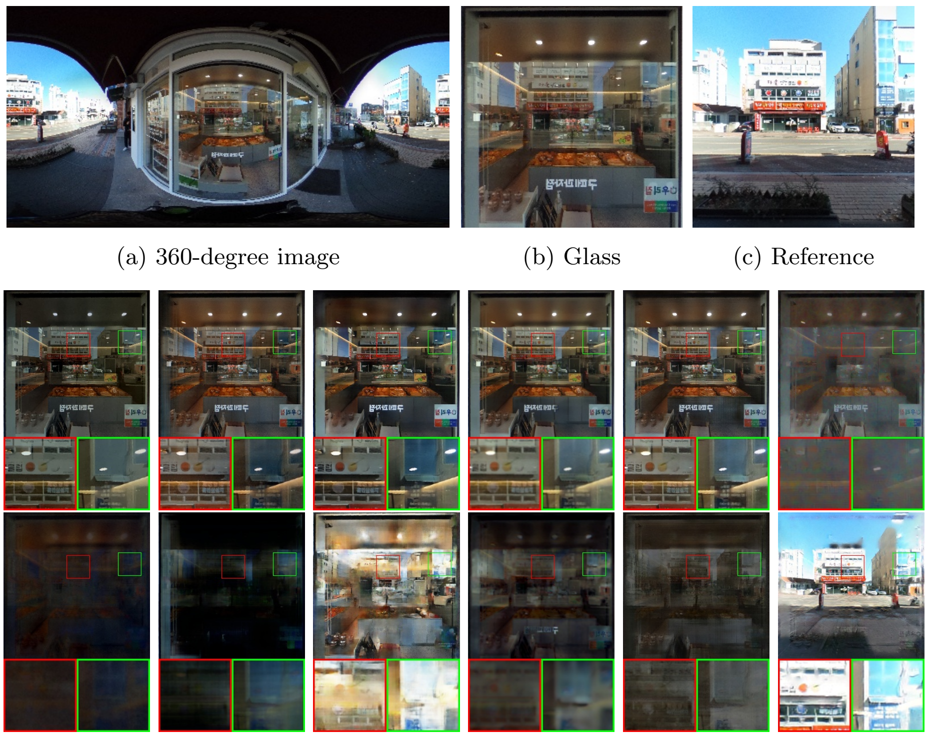
Fig. S-8: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

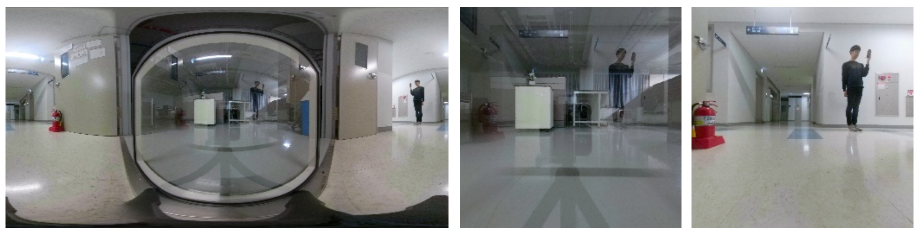
Fig. S-9: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



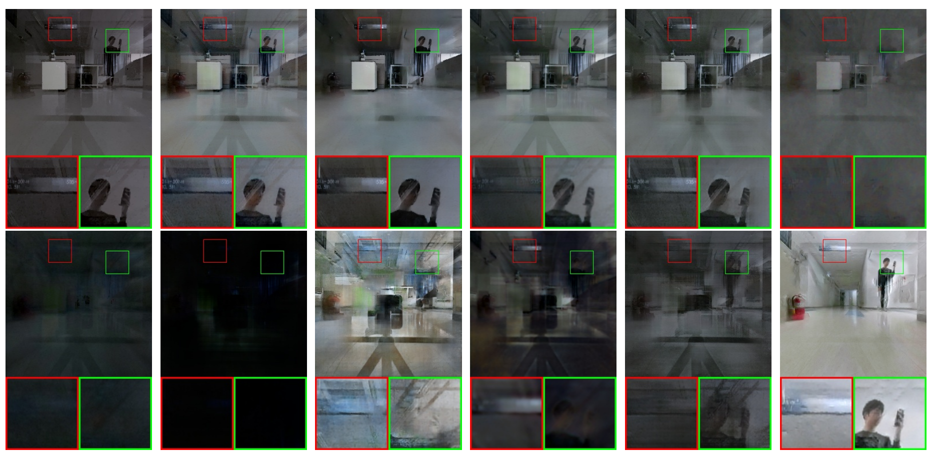
(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-10: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference



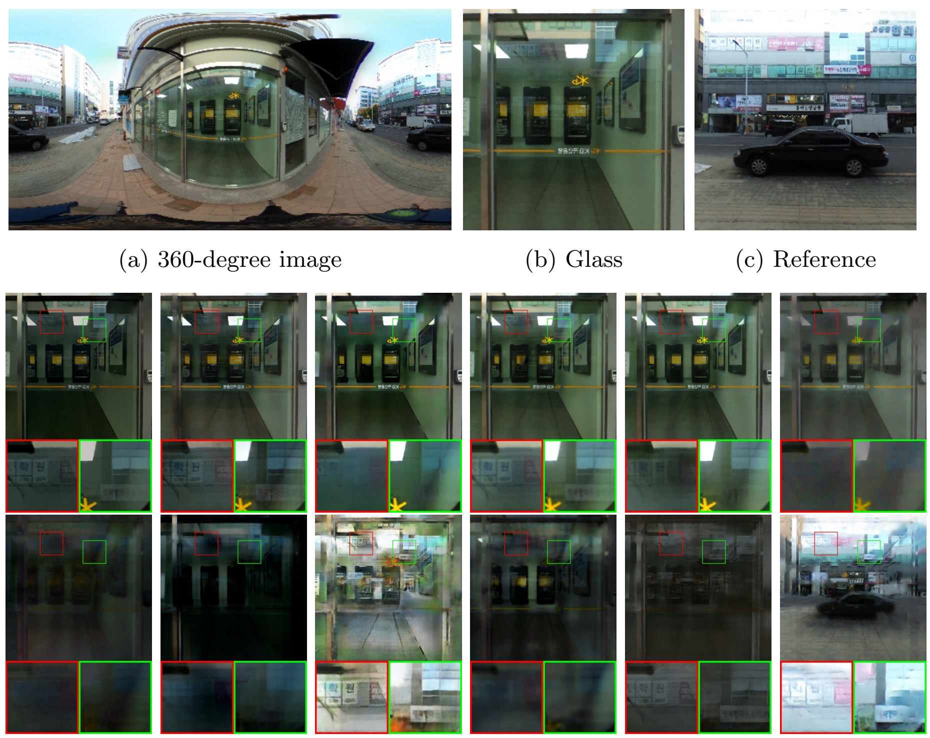
(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-11: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

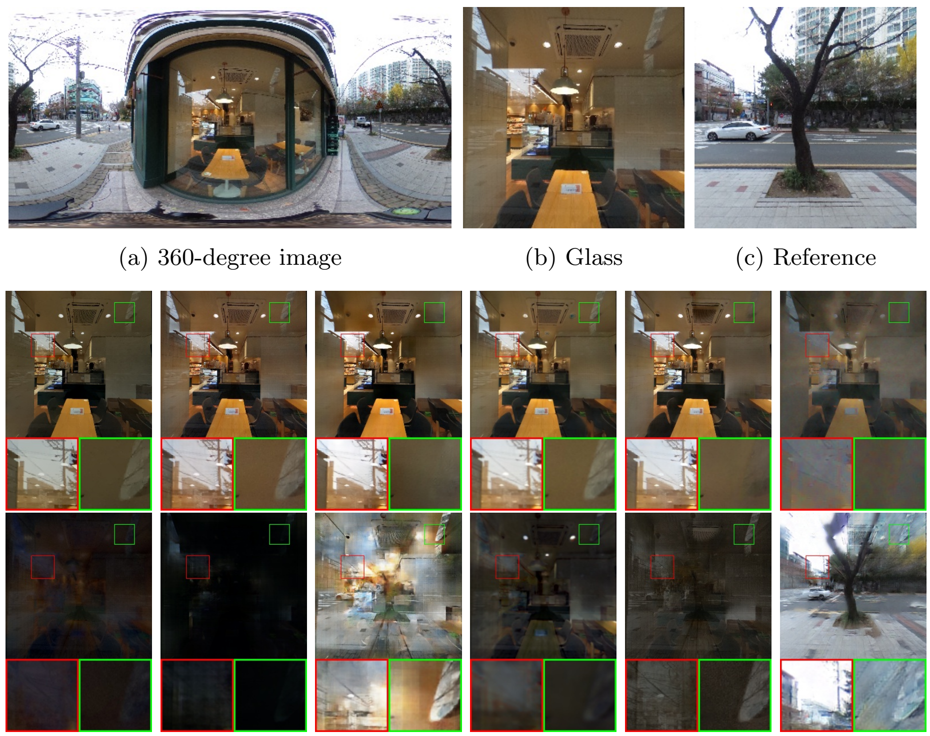
Fig. S-12: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

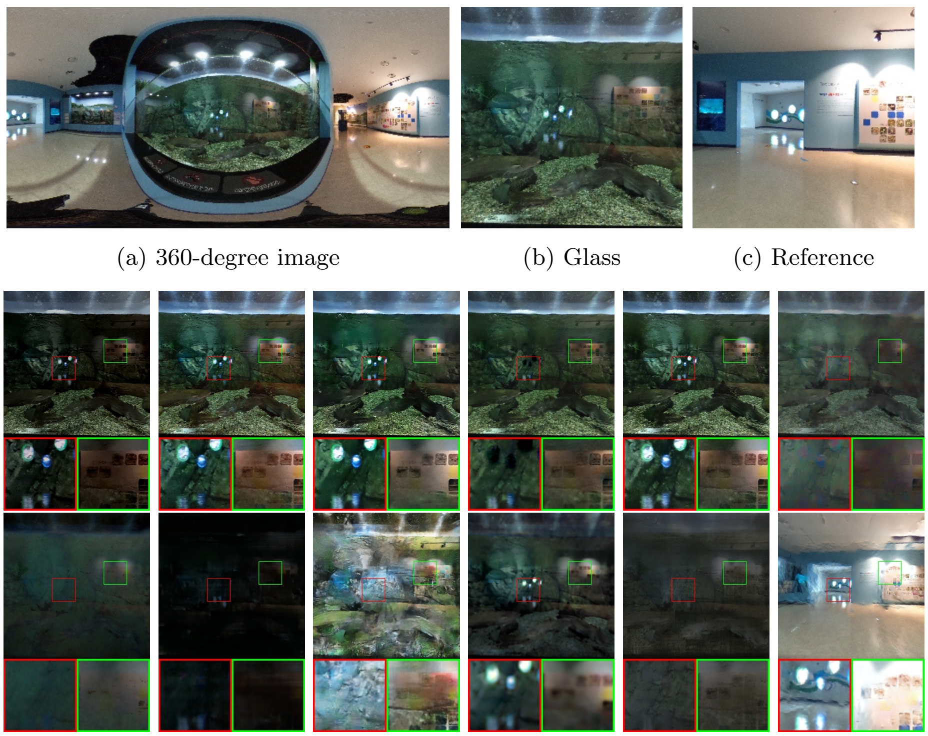
Fig. S-13: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

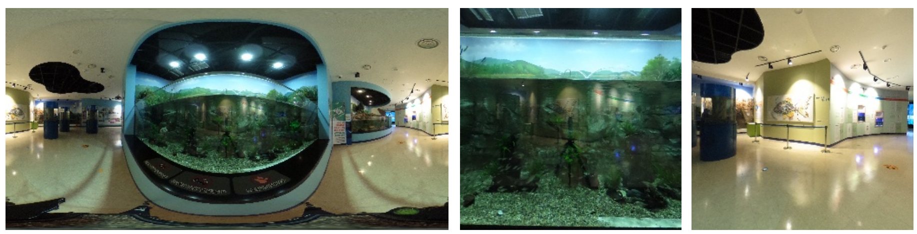
Fig. S-14: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



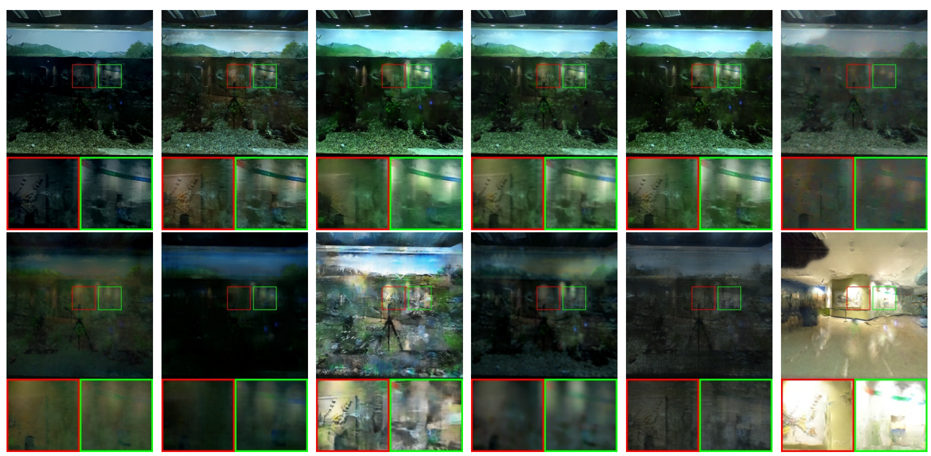
(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-15: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

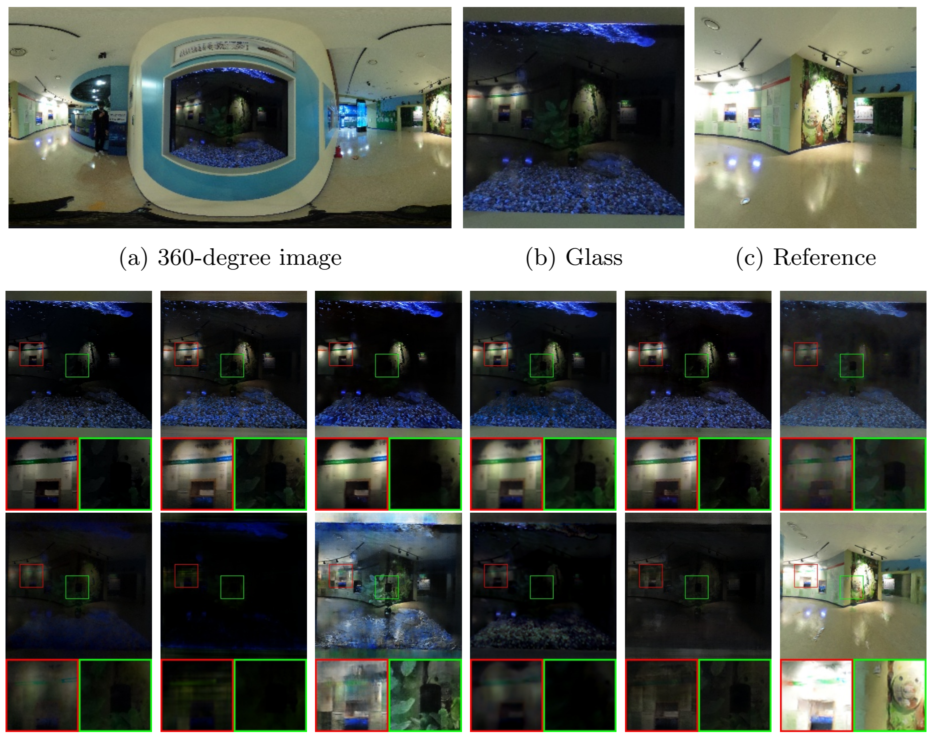


(a) 360-degree image (b) Glass (c) Reference



(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

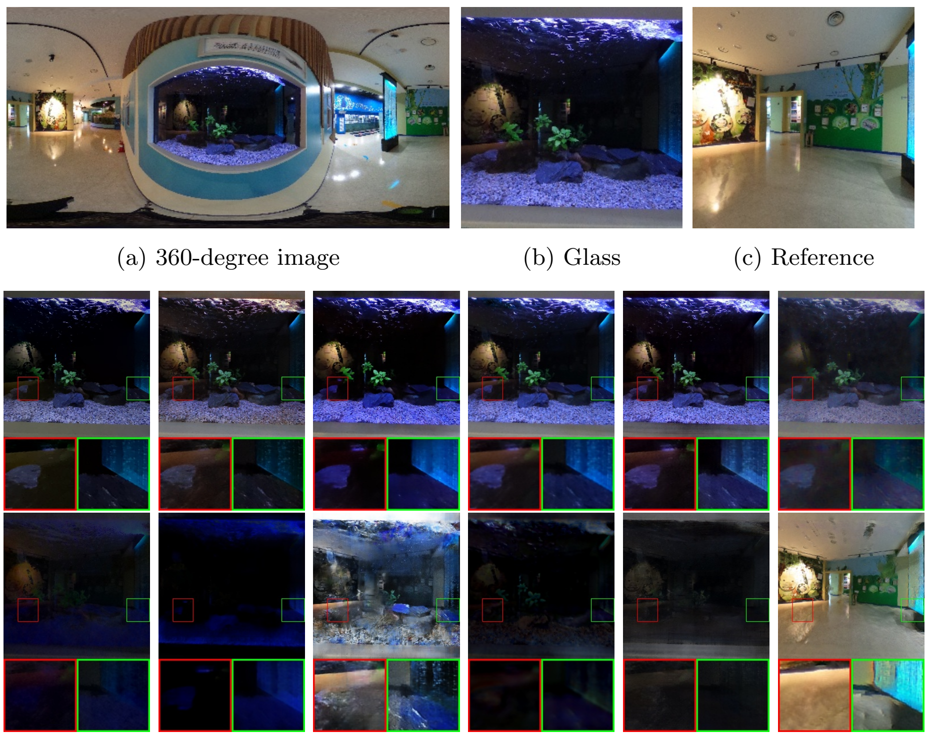
Fig. S-16: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

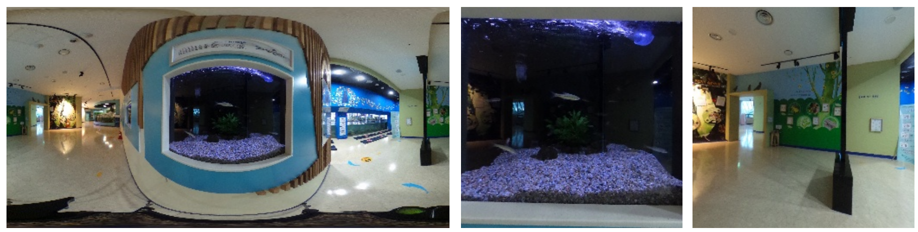
Fig. S-17: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



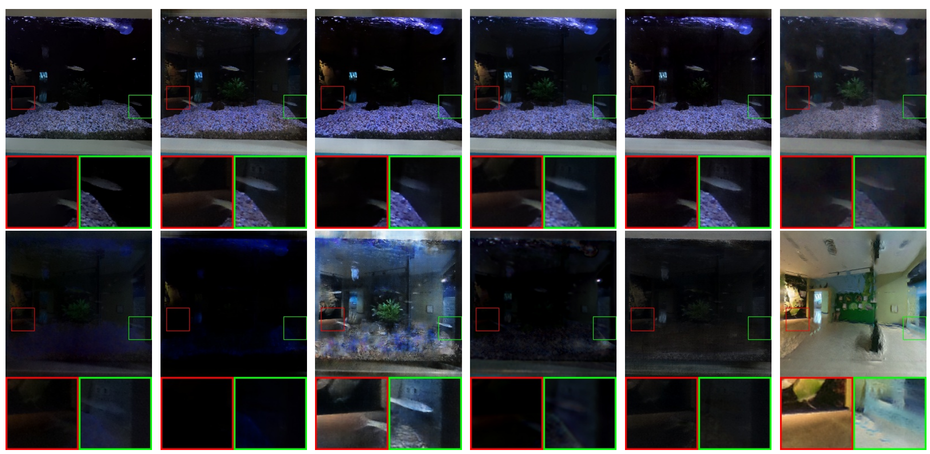
(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-18: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

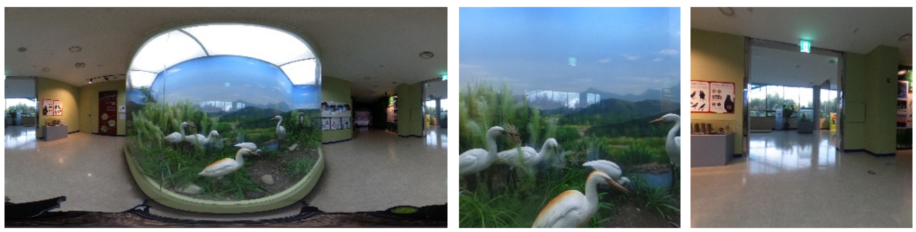


(a) 360-degree image (b) Glass (c) Reference



(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

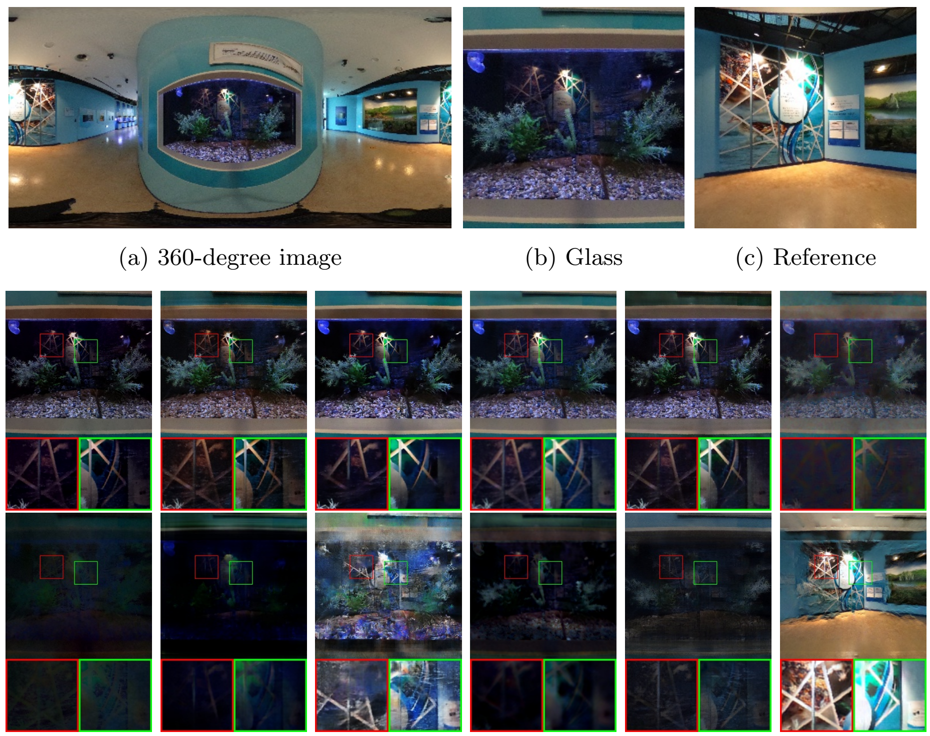
Fig. S-19: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

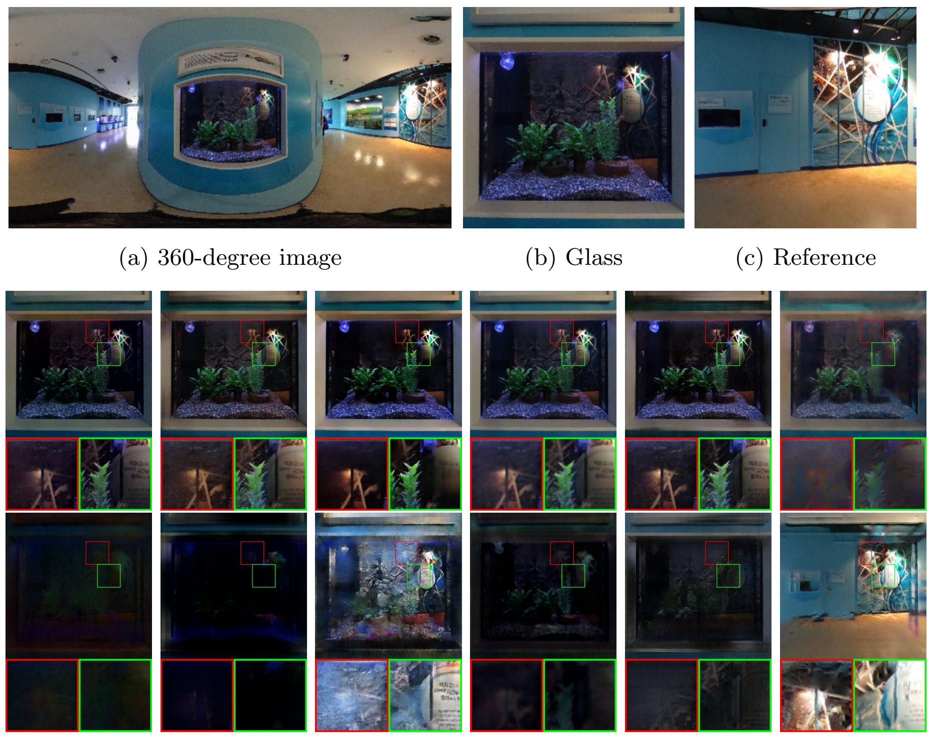
Fig. S-20: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

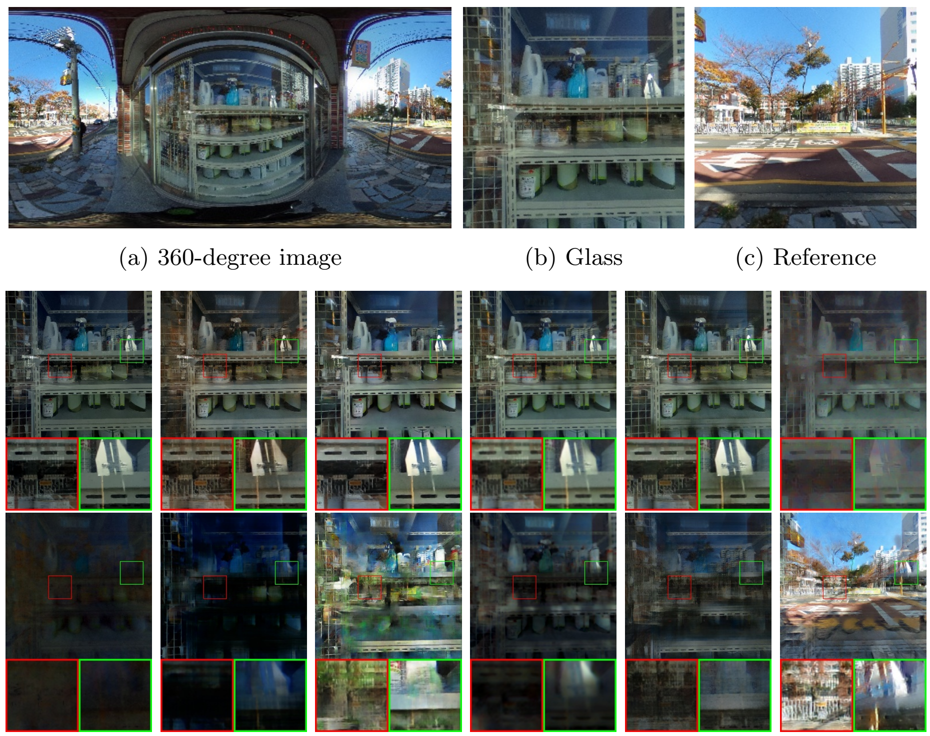
Fig. S-21: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

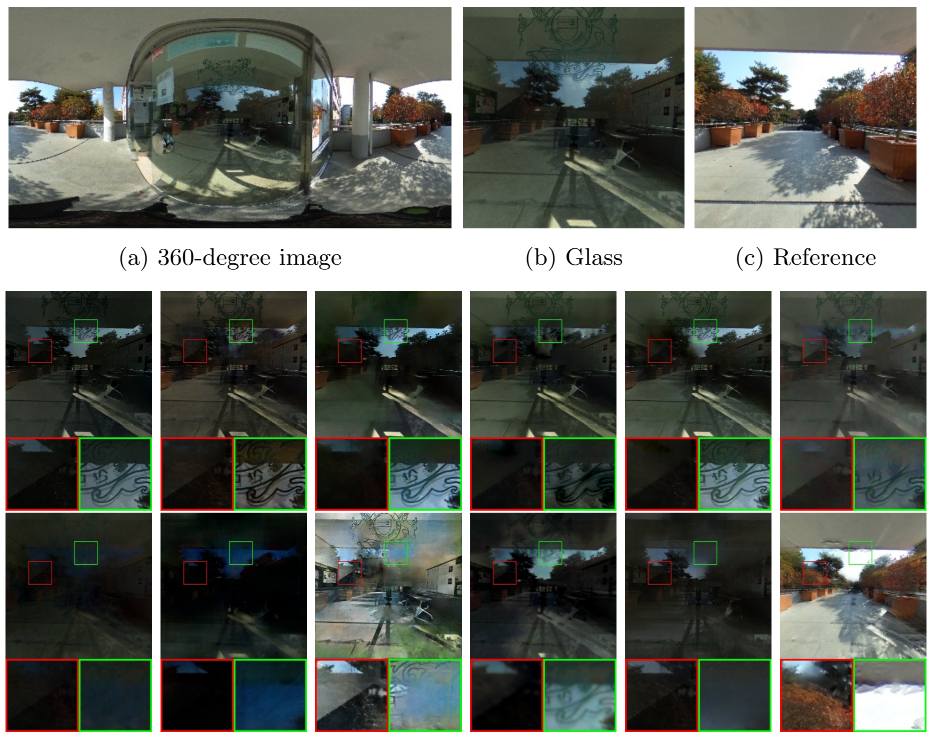
Fig. S-22: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

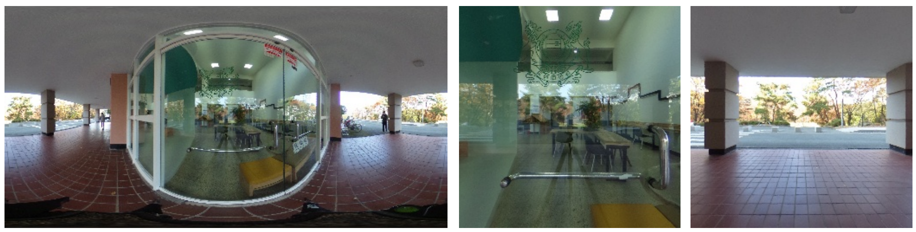
Fig. S-23: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

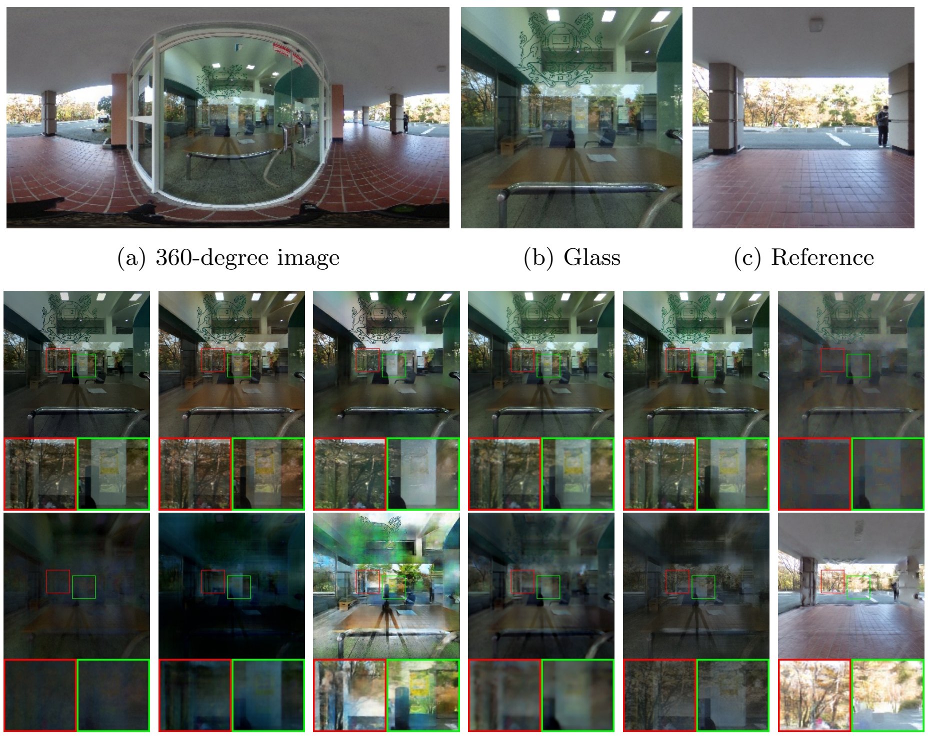
Fig. S-24: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-25: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-26: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

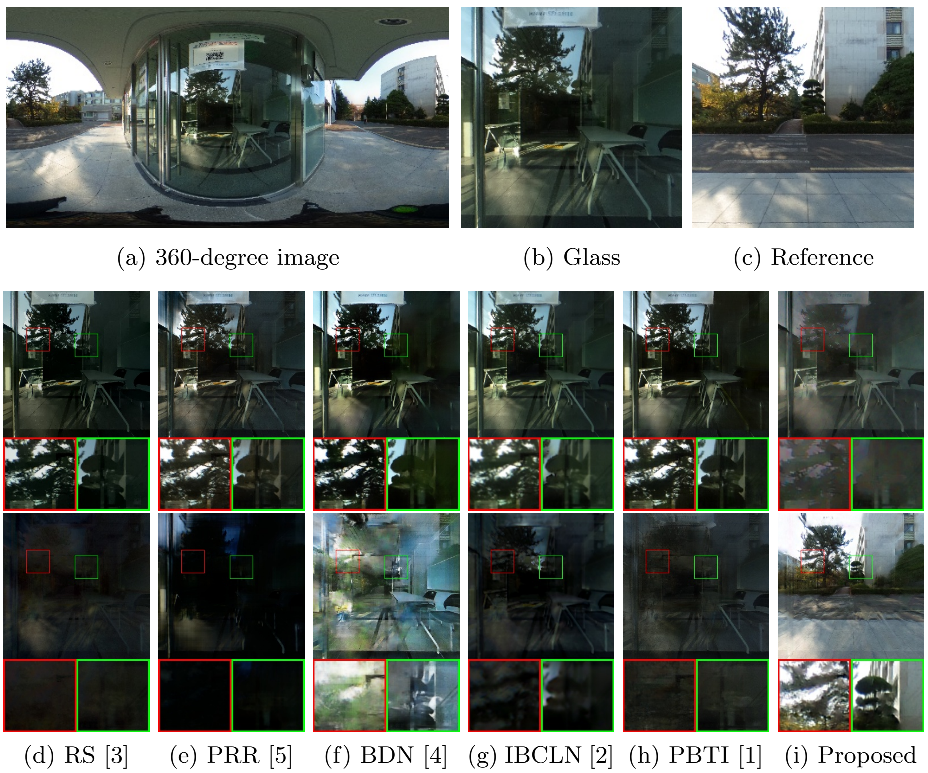
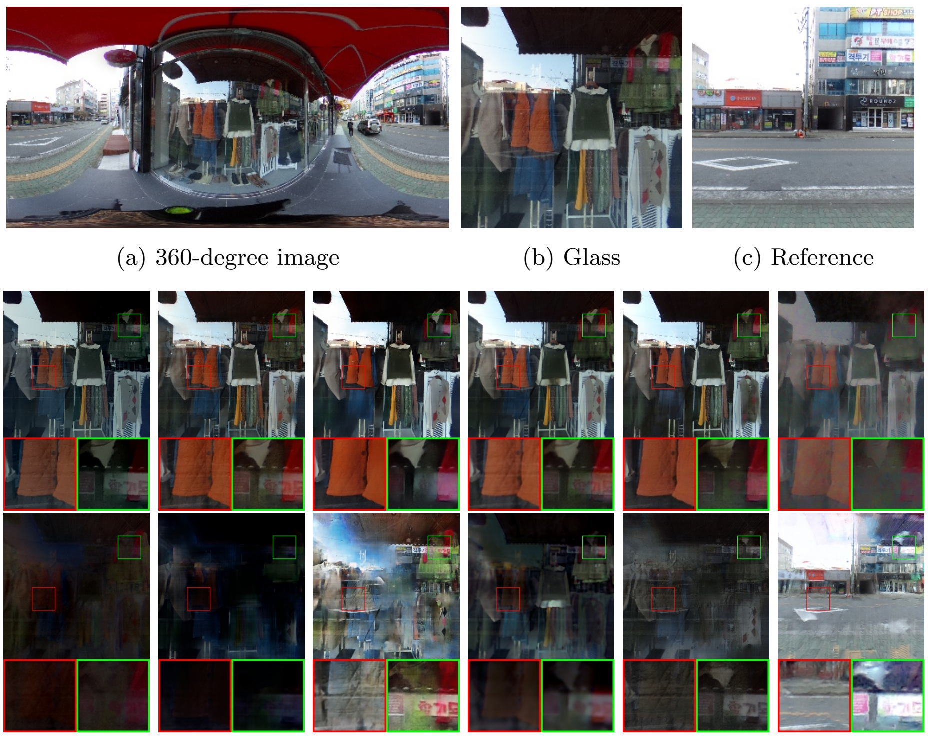


Fig. S-27: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-28: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

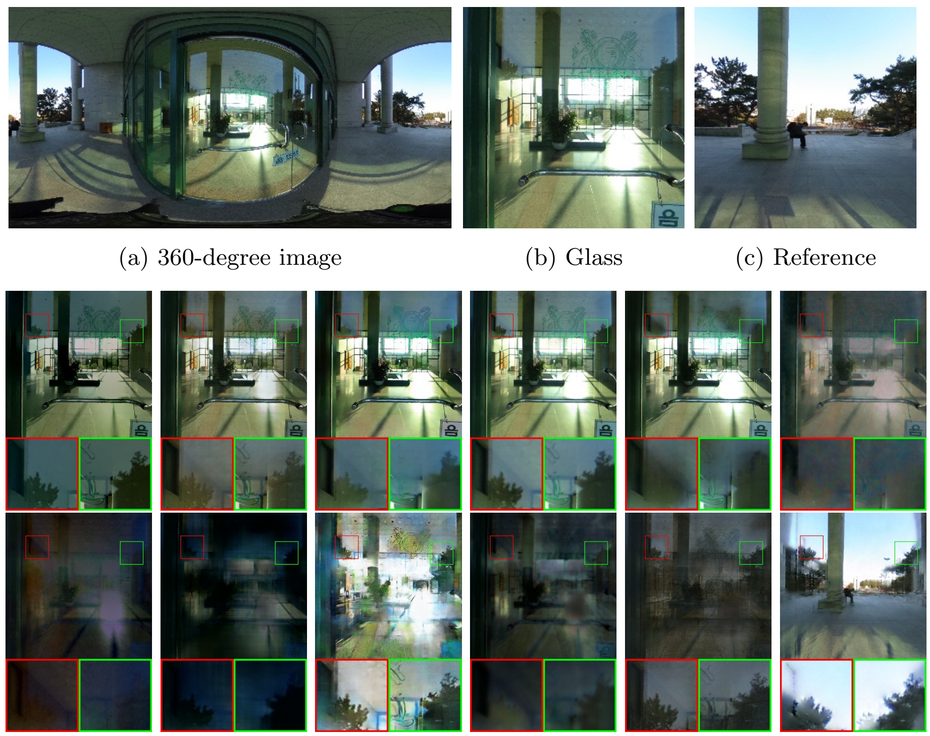
(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-29: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.

(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-30: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.



(a) 360-degree image (b) Glass (c) Reference

(d) RS [3] (e) PRR [5] (f) BDN [4] (g) IBCLN [2] (h) PBTI [1] (i) Proposed

Fig. S-31: Qualitative comparison of the reflection removal performance. A triplet of (a) the 360-degree image, (b) the glass image, and (c) the reference image. The results of the recovered transmission and reflection images obtained by (d) RS [3], (e) PRR [5], (f) BDN [4], (g) IBCLN [2], (h) PBTI [1], and (i) the proposed method.