Fence Removal from Multi-Focus Images

Atsushi Yamashita, Akiyoshi Matsui and Toru Kaneko
Department of Mechanical Engineering
Shizuoka University, Japan
Email: yamashita@ieee.org

***Abstract*—When an image of a scene is captured by a camera through a fence, a blurred fence image interrupts objects in the scene. In this paper, we propose a method for a fence removal from the image using multiple focusing. Most of previous methods interpolate the interrupted regions by using information of surrounding textures. However, these methods fail when information of surrounding textures is not rich. On the other hand, there are methods that acquire multiple images for image restoration and composite them to generate a new clear image. The latter approach is adopted because it is robust and accurate. Multi-focus images are acquired and "defocusing" information is utilized to generate a clear image. Experimental results show the effectiveness of the proposed method.**

***Keywords*-image restoration; defocus; noise reduction**

I. Introduction

In this paper, we propose a method for removing fences from multi-focus images.

When an image of a scene is captured by a camera through a fence, a blurred fence image interrupt objects in the scene, depending on the distance between the camera and the fence. Fig. 1 shows an image taken through a fence. Regions of the image interrupted by the fence are different from the actual values of the objects in lightness and color. This is a significant problem when an image processing is carried out.

A lot of image interpolation or restoration techniques for damaged and occluded images have been also proposed [1]–[5]. However, some of them can only treat with line-shape scratches [1], [2], because they are the techniques for restoring old damaged films. It is also required that human operators indicate the region of noises interactively (not automatically) [3]–[5].

On the other hand, there are automatic methods that can remove occluded noises without helps of human operators [6], [7]. They are effective for moving particles, but not for stationary obstacles like fence. There is a study about string-like occluding objects such as fences [8]. However, this method focuses not on the removal of string-like occluding objects but on the extraction of them.

There are automatic removing methods of stationary noises from images [9]–[11]. However, only noises like waterdrops which adhere to the lens protector of the camera can be removed by [9], [10]. Image artifacts like fences can be removed from multiple input images with different apertures by [11]. This method uses three apertures and estimates the depth of the occluding layer to remove the image artifacts under the assumption that the occluder has a uniform brightness (single color). However, fences sometimes have multiple colors across the ages such as rust and dirt.

Figure 1. Image taken through a fence.

In this paper, we propose an automatic removing method of blurred fences from the captured scene using multi-focus images regardless of its color. The method takes advantage of a property that the regions where the fence exists does not completely lose the information of the object. This can be explained by "reversed projection blurring model" [12].

II. Image Blurring Model

A simple camera model consisting of a thin lens and an image plane is used to derive fundamental characteristics of focusing based on geometrical optics.

When an object is placed at distance a from the lens and a sharply focused image of the object appears at distance b, a and b satisfy the thin lens formula,

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}, \tag{1}$$

where f is the focal length of the lens.

Fig. 2 shows the geometrical relation between the positions of the object, the fence and the image plane. The object is located at distance a_F in front of the lens, and the image plane is located at distance b_F behind the lens. The fence is located at distance a_N, which is shorter than a_F. In Fig. 2, I is a pixel on the object on the image plane and O is the point on the object corresponding to the pixel.

The luminous flux radiated from O is "focused" at I in the image plane by the lens. However, a part of the flux

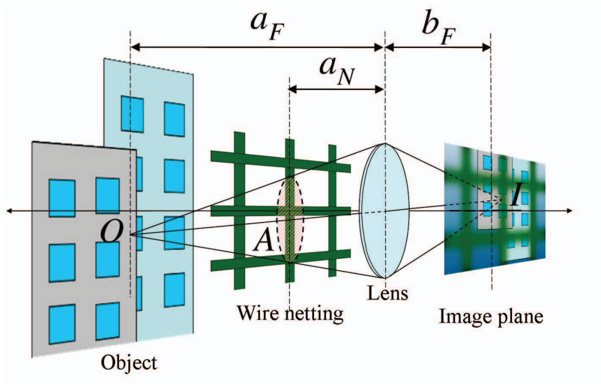


Figure 2. Relation between the object, the fence, and the image plane.

is interrupted by the fence. Let A be the area of the flux passing region, and A_N be the area of the region interrupted by the fence. Also let L_F be the radiance value of O, E_F be the irradiance value of I, and L_N be the radiance value of the region on the fence.

Then, the relation between the incident radiance value to the lens and irradiance value E_F is expressed as follows:

$$E_F = \alpha k \int_{A_N} \frac{L_N}{A_N} \cdot dA_N + (1-\alpha)\, kL_F, \tag{2}$$

where α is a ratio of A_N to A.

If the fence does not exist, Eq. (2) becomes as follows:

$$E_F = kL_F. \tag{3}$$

This means that kL_F in Eq. (2) is equivalent to the irradiance value E_F which is not interrupted by the fence. Then, Eq. (2) can be written as follows:

$$E_e = \frac{1}{1-\alpha} E_F - \frac{\alpha}{1-\alpha} k \int_{A_N} \frac{L_N}{A_N} \cdot dA_N, \tag{4}$$

where $E_e = kL_F$.

The required parameters to estimate irradiance value E_e are irradiance value E_F, radiance value L_N and the area of the reversely projected region. In Eq. (4), it is impossible to acquire the radiance value L_N directly. Therefore, we use the focused image of the fence to make Eq. (4) available (Fig. 3). The relation between irradiance value E_N and radiance value L_N is expressed as follows:

$$E_N = k' L_N. \tag{5}$$

Area A'_N corresponding to A_N in Fig. 3 is given as follows where b_N is the image distance which is obtained from Eq. (1) with $a = a_N$:

$$A'_N = \frac{b_N^2}{a_N^2} A_N. \tag{6}$$

Substituting Eqs. (5) and (6) to Eq. (4), we obtain the following equation:

$$E_e = \frac{1}{1-\alpha} E_F - m \frac{\alpha}{1-\alpha} \overline{E_N}, \tag{7}$$

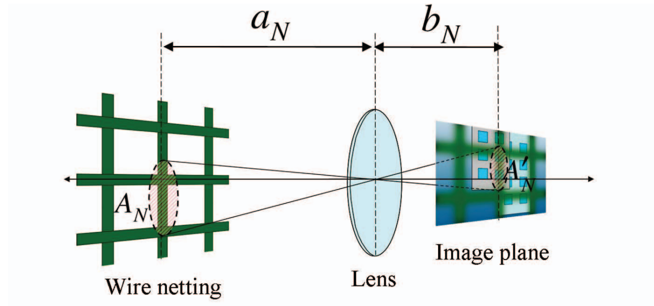
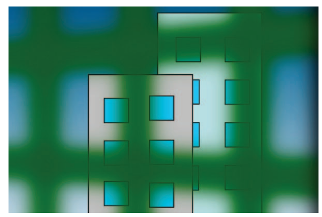
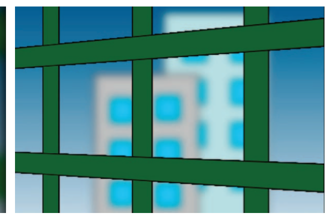


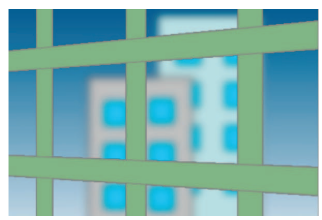
Figure 3. Relation between the fence in focus and the image plane.



(a) Object focusing.



(b) Fence focusing.



(c) Image with flashlight.

(d) Extracted fence.

Figure 4. Image acquisition.

where $m = \frac{k}{k'}$ is a modification coefficient and $\overline{E_N}$ is the average of the irradiance value in A'_N.

$$\overline{E_N} = \int_{A'_N} \frac{E_N}{A'_N} \cdot dA'_N. \tag{8}$$

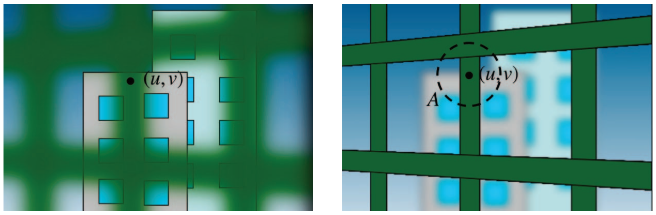
III. Image Acquisition

The proposed method uses three images; one is an image capturing the object in focus through defocused fence (Fig. 4(a)), and the other two are those capturing the fence in focus. One of the latter two images is an image with flashlight (Fig. 4(b)) and the other is without flashlight (Fig. 4(c)).

The purpose of acquiring two images of fence in focus is to extract the fence regions from the image automatically. Automatic extraction can be realized by subtracting the image without flashlight from the image with flashlight (Fig. 4(d)), because distant objects are not influenced by flashlight.

IV. Image Registration

We should perform the registration of the multi-focus images because the scale of objects in images has changed



(a) Object focusing. (b) Fence focusing.

Figure 5. Outline of the removal process.

with variation of the image distance.

First, the geometrical distortion of the images is corrected with Weng's method [13]. After correcting the distortion, it is reasonable to suppose that the variation of images is regarded as a scale transform with a magnification factor [14]. This variation of images is expressed with homogeneous coordinates. Let $\tilde{\mathbf{x}}_F = (u, v, 1)^T$ be the homogeneous coordinates of the object image, and $\tilde{\mathbf{x}}_N = (u', v', 1)^T$ be the homogeneous coordinates of the fence image. Then transform matrix $\mathbf{H}$ gives the magnification and translation from $\tilde{\mathbf{x}}_F$ to $\tilde{\mathbf{x}}_N$.

$$\tilde{\mathbf{x}}_N = \mathbf{H}\tilde{\mathbf{x}}_F, \tag{9}$$

where $\mathbf{H}$ is written as follows:

$$\mathbf{H} = \begin{pmatrix} s & 0 & t_x \\ 0 & s & t_y \\ 0 & 0 & 1 \end{pmatrix}. \tag{10}$$

Component s is the scale, and t_x and t_y are the translations of the image. Two equations are acquired from the pair of coordinates of the fence image and the object image. It requires at least two pairs to solve the components of $\mathbf{H}$ because the number of the unknown parameters of $\mathbf{H}$ is three. To reduce the influence of images noises, the least square method is employed with more pairs of coordinates.

V. Removal Process

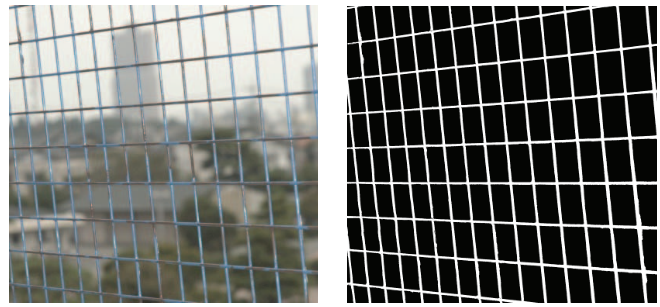
Fig. 5 outlines the fence removal process from multi-focus images.

We perform a camera calibration to determine extrinsic parameters for the fence. The value α of Eq. (7) is acquired by calculating the area of fence included in the region. Also, value $\overline{E_N}$ of Eq. (7) is acquired by averaging the pixel values of the fence included in the region. Then, value E_e is acquired based on Eq. (7) by using the values from the images through the fence.

VI. Experiment

We performed experiments with images of distant buildings acquired through a fence. Fig. 6(a) shows the image taken through the fence. Buildings in the image are interrupted by the blurred fence. Figs. 6(b) and (c) show the images of the fence in focus without and with flashlight, respectively. The camera was fixed by a tripod stand so that the direction of the optical axis would not change while focusing. The focal length of the camera was 70mm and the F-number was 10. The focus of the camera was adjusted by manual operation. It was cloudy when the image was taken.

(a) Fence out of focus. (b) Fence in focus.



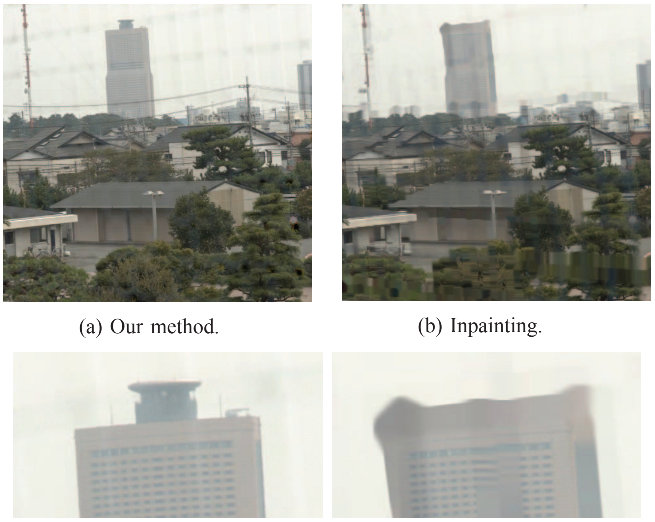
(c) Image with flashlight. (d) Fence extraction.

Figure 6. Acquired images.

Figs. 6(d) shows the extraction result of the fence. Fig. 7(a) shows a fence removal result by our proposed method. Fig. 7(b) shows a fence removal result by image inpainting method [3] for comparison. The reconstruction of the objects is failed in the regions interrupted by the fence in Fig. 7(b). For example, a part of a roof of a building in the image center is lost (Fig. 7(d)). On the other hand, our proposed method succeeds in the reconstruction of the building (Fig. 7(c)).

Both resultant images are converted into grayscale images to compare with an image in which the fence is removed physically. The image is shown in Fig. 8(a). Fig. 8(b) is the difference image of Fig. 8(a) and the original image (Fig. 6(a)). Fig. 8(b) shows that the difference occurs by the fence in the regions interrupted by the fence. Fig. 8(d) shows the difference image of Fig. 8(b) and the reconstruction image by image inpainting method(Fig. 7(a)). Fig. 8(c) shows the difference image of Fig. 8(a) and the reconstruction image by our proposed method (Fig. 7(b)). The results by two methods are different in the region with complex texture. The difference result of image inpainting method has regions with large different values. Contrary to image inpainting method, our proposed method can remove only the influence of the fence.

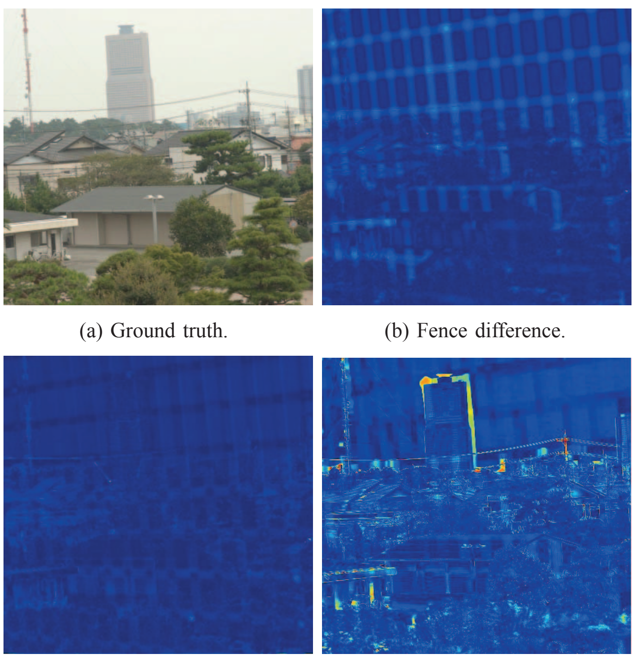
From these results, it is verified that our method can



(a) Our method. (b) Inpainting.

(c) Closeup of (a). (d) Closeup of (b).

Figure 7. Removal results.



(a) Ground truth. (b) Fence difference.

(c) Our method. (d) Inpainting.

Figure 8. Comparison with ground truth.

remove a blurred fence from the image taken through the fence.

VII. Conclusion

In this paper, we propose a method for a fence removal from an image using multiple focusing.

It is shown that the pixel value depends on the radiance value of the object and the fence on the basis of "reversed projection blurring model". We perform the lightness and color adjustment based on the relation between pixels and the radiance value of the object and the fence. As a result, a defocused fence is eliminated from the image taken through the fence. Experimental results show the effectiveness of the proposed method.

As a future work, the quality of the final result will be improved by more accurate ray tracing.

References

[1] A. C. Kokaram, R. D. Morris, W. J. Fitzgerald and P. J. W. Rayner: "Interpolation of Missing Data in Image Sequences," *IEEE Transactions on Image Processing*, Vol.4, No.11, pp.1509–1519, 1995.

[2] L. Joyeux, O. Buisson, B. Besserer and S. Boukir: "Detection and Removal of Line Scratches in Motion Picture Films," *Proceedings of CVPR1999*, pp.548–553, 1999.

[3] M. Bertalmio, G. Sapiro, V. Caselles and C. Ballester: "Image Inpainting," *Proceedings of SIGGRAPH2000*, pp.417–424, 2000.

[4] Y. Matsushita, E. Ofek, X. Tang and H.-Y. Shum: "Full-frame Video Stabilization," *Proceedings of CVPR2005*, Vol.1, pp.50–57, 2005.

[5] Y. Wexler, E. Shechtman and M. Irani: "Space-Time Completion of Video," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol.29, No.3, pp.463–476, 2007.

[6] H. Hase, K. Miyake and M. Yoneda: "Real-time Snowfall Noise Elimination," *Proceedings of ICIP1999*, Vol.2, pp.406–409, 1999.

[7] K. Garg and S. K. Nayar: "Detection and Removal of Rain from Videos," *Proceedings of CVPR2004*, Vol.1, pp.528–535, 2004.

[8] T. Tamaki, H. Suzuki and M. Yamamoto: "String-like Occluding Region Extraction for Background Restoration," *Proceedings of ICPR2006*, Vol.3, pp.615–618, 2006.

[9] A. Yamashita, T. Harada, T. Kaneko and K. T. Miura: "Virtual Wiper -Removal of Adherent Noises from Images of Dynamic Scenes by Using a Pan-Tilt Camera-," *Advanced Robotics*, Vol.19, No.3, pp.295–310, 2005.

[10] Y. Tanaka, A. Yamashita, T. Kaneko and K. T. Miura: "Removal of Adherent Waterdrops from Images Acquired with a Stereo Camera System," *IEICE Transactions on Information and Systems*, Vol.89-D, No.7, pp.2021–2027, 2006.

[11] J. Gu, R. Ramamoorthi, P. Belhumeur and S. K. Nayar: "Removing Image Artifacts Due to Dirty Camera Lenses and Thin Occluders," *Proceedings of SIGGRAPH ASIA 2009*, 2009.

[12] N. Asada, H. Fujiwara and T. Matsuyama: "Seeing Behind the Scene - Analysis of Photometric Properties of Occluding Edges by the Reversed Projection Blurring Model-," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol.20, No.2, pp.155–167, 1998.

[13] J. Weng, P. Cohen and M. Herniou: "Camera Calibration with Distortion Models and Accuracy Evaluation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol.14, No.10, pp.965–980, 1992.

[14] R. G. Willson and S. A. Shafer: "What is the Center of the Image?," *Journal of the Optical Society of America*, Vol.11, No.11, pp.2946–2955, 1994.