Robust Reflection Removal against Accumulated Error by Using Stereo Camera System

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***Abstract*—In this paper, an error model of stereo camera system and a robust methodology are presented for reflection removal from pictures taken through a glass with long-shot background. The proposed method, when compared with the previous methods, results to be robust to the projection of the reflection error. Experimental test with real images-scenario were conducted to prove the validity of the developed method.**

***Index Terms*—Reflection Removal, Visibility Enhancement, Image Decomposition, Stereo Camera**

I. Introduction

Sometimes taking pictures through glass is unavoidable. For example, when taking pictures through car or airplane's window, the reflection of objects inside window can obstruct the scene we want. Reflecton removal is also benefit to remote control of robot. For this reason, reflection removal has gained a lot of attention by the research community. To remove reflection from images, [1] and [2] used polarizers because reflected light is polarized. [3] used the smoothness difference between background and reflection to remove reflection. [4] used depth difference between background and reflection caused different movement when camera moves. Tsurumi et al. tried to remove the reflection using stereo camera system [5]. However, every step's error will accumulate during processing and the result will become worse. Therefore, it is necessary to build an error model of stereo camera reflection removal method and restrain the accumulate error to stop result getting worse.

II. Reflection Removal Using Stereo Camera System

Stereo camera system consists of two horizontal parallel fixed cameras. Figure 1 shows the input images taken by stereo cameras. Background is night scene of buildings. Reflection is constisted of two posters. [5]'s first assumption that background is far enough from camera and reflection is near to camera, input images have same background and reflection moves a distance d horizontally. [5] divided the input images into several parts horizontally with distance *d*. The relationship of left and right input images can be represented as:

$$L_k^B = R_k^B \tag{1}$$

$$L_k^F = R_{k-1}^F \tag{2}$$

where L_k^B is ground truth of background in left input image's k^{th} part. R_k^F is reflection in right input image's k^{th} part. Because input images can be considered as linear combination of background and reflection, we have

$$L_k = L_k^B + L_k^F \tag{3}$$

$$R_k = R_k^B + R_k^F \tag{4}$$

where L_k is left input image's k^{th} part. Another assumption of [5] that input images contain no-reflection areas. The first part of left input image and the final part of right input image contain no reflection. Every part's background can be calculated with the result of former part and the other input image. Using no-reflection area as initial value, the reflection of every part can be removed. Same method can be used for processing left input image and right input image. In this paper, we take left input image's process as an example. [5]'s process of left input image can be shown as

$$B_k = L_k + B_{k-1} - R_{k-1} \tag{5}$$

where B_k is reflection removal result of left input image's k^{th} part. According to the assumption that B_1 equal to L_1, the equation can be rewritten as:

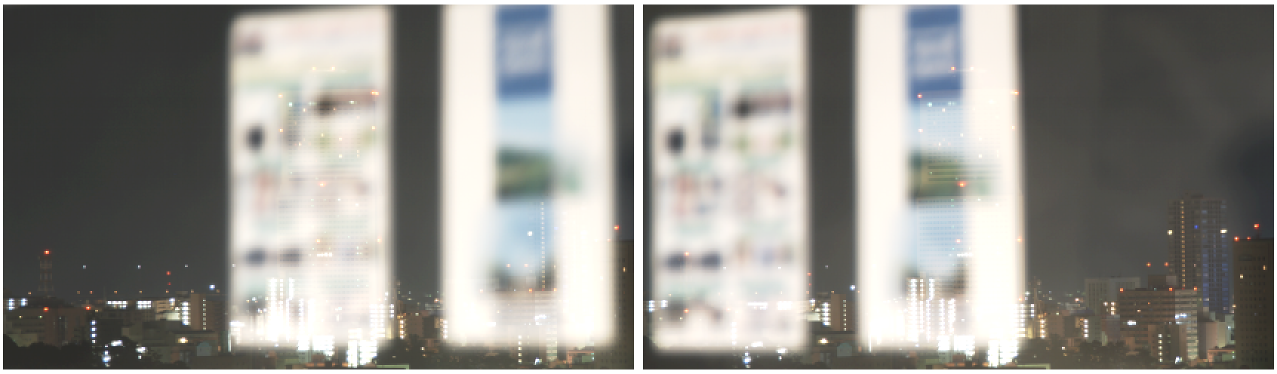
$$B_k = L_k + \sum_{i=1}^{k-1} (L_i - R_i) \tag{6}$$

According equation (3) and (4), the equation (6) can be rewritten as:

$$B_k = L_k^B + \sum_{i=1}^{k-1} (L_i^B - R_i^B) + \sum_{i=2}^{k} (L_i^F - R_{i-1}^F) \tag{7}$$

According to equation (1) and (2), the second and third term of equation (7) should be zero. Therefore, the reflection removal result should be same as the ground truth.

However, in real input images, the second and third term are usually not zero. Because the background and reflection are not very same in two input images. When the baseline of stereo cameras is not parallel to the glass, the . Because the result is used for next part's process. The error of former part will remain in next part's result. The error of every part will accumulate to final result. In order to restrain the accumulate error, we propose a new method that considers restrictions during calculation. Noticing that the final part's background should be similar to right input image's no-reflection part,



(a) Left input image of [5]

(b) Right input image of [5]

Fig. 1: Input images of stereo camera system.

(a) Left result of [5]

(b) Left result of proposed method

Fig. 2: Comparison of [5] and proposed method.

the difference between the result and right input images' no-reflection parts is used during calculation. According to equation (5), when input images are divided into n parts, the background of left input image can be calculated as:

$$B = \underset{\{Bi\}_2^n}{\operatorname{argmin}} \Big(\sum_{i=2}^{n} (B_i - L_i + R_{i-1} - B_{i-1})^2 + (B_n - R_n)^2 \Big) \tag{8}$$

where B is reflection removal result of left input image.

III. Experimental Results

Experiments with real pictures were performed to comfirm the validity of proposed method. Input images shown in Figure 1 are divided into three parts to process. Figure 2 shows the reflection removal result comparision between [5] and proposed method. In [5]'s result we can notice that the error of left poster's removal result repeats in right poster's removal result. In proposed method's result, not only the error of left poster's removal result is restrained in right poster's removal result, but also the left poster's removal result got better. The experiment result shows that proposed method is more robust than previous method and accumulate error is successfully restrained.

IV. Conclusion

In this paper, a novel model of accumulate error is set up for reflection removal using stereo camera system. In order to restrain the accumulate error, the proposed method uses an optimization method to minimize the difference of background part between input images and result. The effectiveness of the proposed method has been verified by the experimental results. Improvement of the performance and the computation time will be explored in future work.

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