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Removing Reflection From a Single Image With Ghosting Effect

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***Abstract*—How to remove undesired reflections of images taken through glass is an important problem in digital photography and other vision applications. When taking images through thick or insulating glass windows, the so-called ghosting effect, *i.e.* pattern repetitiveness in reflection, is exploited in existing reflection removal techniques. By formulating reflection removal as a two-layer separation problem, the existing methods take a two-stage approach that first estimates the parameters of ghosting effect and then separates the reflection and latent image layer. This paper aims at addressing one main challenge, *i.e.* how to accurately distinguish repetitive patterns on the two layers. Motivated by the observation on the difference of the number of patterns repeated in two layers, a wavelet transform based regularization with a novel weighting scheme is proposed for separating the two layers. The experiments showed that the proposed method is capable of accurately separating the latent image layer and the reflection layer, and outperforms the existing ones on both synthetic data set and real data set.**

***Index Terms*—Reflection removal, Image separation, Ghosting effects, Image decomposition**

I. Introduction

It often happens that one has to take pictures through glass windows, *e.g.* taking pictures of the paintings in the museum [1], [2], [3], [4], [5], the dresses in the showcase [6], [7], [8], the landscape outside when in a train or plane [9], [10]. Unfortunately, it is known that the resulting picture taken through glass often contains the reflection of the scene behind the camera. The avoidance of the inclusion of such reflection requires either specific hardware (*e.g.* polarizers) or manual control of lighting conditions around cameras. There is certainly the need to develop effective techniques to remove the reflection from an input image taken through a glass window.

In general, it is not possible to separate the reflection caused by glass and the content of the scene of interest, without additional priors or assumptions on the reflection. One popular cue for identifying reflection in the image is the so-called *ghosting effect*. See Fig. 1 for an illustration. The ghosting effects of an image caused by the reflection of glass refer to the two or multiple reflections of the reflected scene off the different glass surfaces. For example, for a two-panel window, both panels will reflect the scene behind and the two reflections differ from each other by their positions and brightness strengths. For a single-panel window with thick glass, both sides of the glass will yield similar effects, but with weakened brightness. See Fig. 2 for an illustration of such two types of reflections. In practice, since the brightness strength of the third reflection is much less than the primary reflection, the double reflection instead of the multiple one is usually considered; see e.g. [11], [12].

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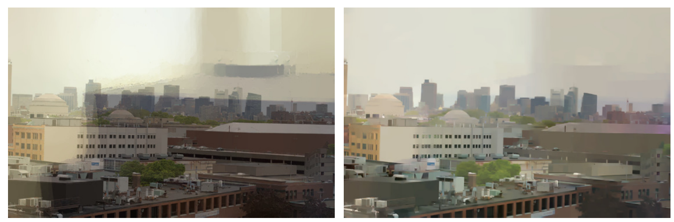
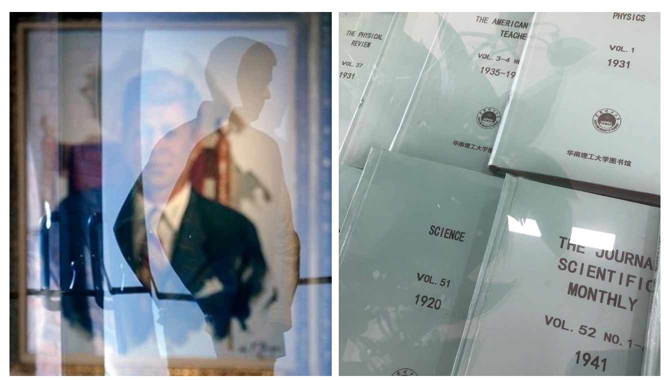


(a) (b)

Fig. 1: Illustration of reflection removal from a single image with ghosting effect. (a) The image with ghosting effect. (b) The result after reflection removal by the proposed method.



(a) (b)

Fig. 2: Illustration of ghosting effect. (a) Ghosting reflection caused by two sides of glass. (b) Ghosting reflection caused by thick glass.

The image with ghost effect is modeled in [11], [12] by the following composite model:

$$\boldsymbol{Y} = \boldsymbol{T} + \boldsymbol{R} \otimes \boldsymbol{k} + \boldsymbol{N}, \tag{1}$$

where $\otimes$ denotes the convolution operation, $\boldsymbol{Y}$ denotes the input image, $\boldsymbol{N}$ denotes the noise, $\boldsymbol{T}$ denotes the transmission layer which is the captured frame of the scene behind the window, and $\boldsymbol{R} \otimes \boldsymbol{k}$ denotes the reflection layer which is the captured frame of the scene in front of the window. The