String-like occluding region extraction for background restoration

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Abstract

In this paper, we propose a method for extracting string-like objects in a still image for background restoration. We assume that the object regions occluding the background are long and narrow, and contrasted in intensity with background. First the method introduces a circle contrast, the intensity difference between a pixel and those on a circle around, to find the occluding string-like regions. Then the signs of the circle contrast are decided so that the occluding regions and backgrounds are well separated, and further enhanced by an optimization process. Extracted regions are removed with interpolation (inpainting) for background restoration. Experimental results on real images show the validity of the proposed method.

1 Introduction

Removing objects and restoring background image is widely recognized to be important in computer vision, especially after the inpainting [4], and various methods have been proposed such as [3, 7, 1, 9]. These studies assume that a region to be removed is given, so that, when a lot of images are given, an user has to make an effort to specify regions to be interpolated and restored. Some methods[5, 2, 10] use information of several frames in a movie for film or video restoration to remove scratches and blotches, but those cannot be applicable to a still image.

The target of this paper is a scene where background is occluded by some objects such as fences, strings, wires, mesh and tree branches. Such string-like objects are often seen in many photographs when we want to see the background, not the occluding objects. Object-specific methods to remove regions occluding background such as [6] or to detect learned wiry objects [8] have been proposed, however, detecting and removing unknown and general regions of string-like objects are still necessary.

In this paper, we propose a method for extracting string-like objects in a still image. We make relatively general assumptions that the object regions occluding the background are long and narrow, and contrasted in intensity with background. First the method introduces a circle contrast, the intensity difference between a pixel and those on a circle around, to find the occluding string-like regions. Then the signs of the circle contrast are decided so that the occluding regions and backgrounds are well separated, and further enhanced by an optimization process. Extracted regions are removed with interpolation (inpainting) for background restoration. Experimental results on real images show the validity of the proposed method.

2 Circle contrast for string region

In this section, we describe what kind of regions we want to extract. For the case we consider, we make the following four assumptions on the regions to be extracted: a background scene is occluded by an occluding region which

1. has a long and narrow shape like string or wire,
2. is small (but not so tiny) relative to the whole image,
3. has contrast in intensity with the background, and
4. has background regions on both sides whose intensities are similar.

To find string-like occluding regions, here we define a circle contrast $v(\boldsymbol{x})$, the difference between the intensity $I(\boldsymbol{x})$ of the pixel $\boldsymbol{x}$ and the average intensity on a circle $C_1(\boldsymbol{x})$ centered at $\boldsymbol{x}$ with radius r_1;

$$v(\boldsymbol{x}) = I(\boldsymbol{x}) - \frac{1}{2\pi r_1} \int_{C_1(\boldsymbol{x})} I(\boldsymbol{x}')\, d\boldsymbol{x}'. \qquad (1)$$

According to the first assumption, most part of the circle C_1 lays on background (i.e., out of the occluding region, see Fig.1), and the average intensity on C_1 (the second term of eq.(1)) represents the intensity of the background. Therefore, the circle contrast v for a pixel on the occluding region is large because the occluding object is contrasted with the

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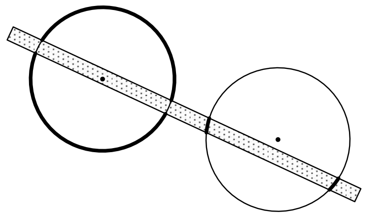

Figure 1. Circle contrasts for pixels on/off the occluding (shaded) region.

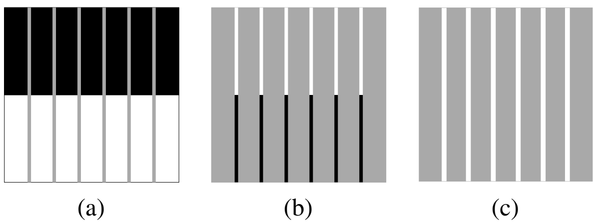

Figure 2. (a) Example. Gray lines occlude black/white backgrounds. (b) positive (white), 0 (gray) and negative (black) v. (c) processed v.

background (see the third assumption), while v is small for a pixel out of the occluding region (on the background) because of small contrast.

However, v alters its sign as the intensity contrast is inverted. For example, in the upper half of Fig.2(a), the occluding region is brighter than the black background and v is positive, while in the lower half v is negative because the background is white.

To identify the proper sign of v for each pixel, we use the sign of a pixel $\boldsymbol{x}''$ with maximum absolute value of v in a local region $R(\boldsymbol{x})$ around each pixel $\boldsymbol{x}$. Because the magnitude of v for the occluding region is still larger than that for backgrounds, the maximum in the local neighbors represents the value of the occluding region, then we take the sign of $v(\boldsymbol{x}'')$ as that of $v(\boldsymbol{x})$. The following process corrects the signs of v for each pixel:

$$\boldsymbol{x}'' = \operatorname*{argmax}_{\boldsymbol{x}' \in R(\boldsymbol{x})} |v(\boldsymbol{x}')|, \tag{2}$$

$$v(\boldsymbol{x}) \Leftarrow \begin{cases} |v(\boldsymbol{x})| & \text{, if } \operatorname{sgn}(v(\boldsymbol{x})) = \operatorname{sgn}(v(\boldsymbol{x}'')) \\ 0 & \text{, otherwise} \end{cases}, \tag{3}$$

where $\operatorname{sgn}(x)$ gives the sign of x.

Note that if the circle C_1 is small relative to the width of the occluding region, the second term doesn't represent the background intensity and v can not separate the occluding regions and backgrounds. On the contrary, if C_1 is large, the second term can not represent the local background because of textures in wider range.

We have analyzed the trade-off of the size of C_1 (omit for the limited space of pages), however in any size v is somewhat affected by information beyond the local background. Therefore, in the next section we enhance v so that the occluding regions and backgrounds are well separated.

3 Extraction of string regions based on v

Here we enhance v so that the occluding region have large value and backgrounds have smaller value, then extract regions to be candidates for occluding string-like regions.

3.1 Enhancement of v

v have large gradient around the border between the occluding regions and the background because the magnitude of v is large on the occluding region and small on backgrounds. And the large gradients concentrate around the occluding regions because of the first assumption; i.e., the borders of both sides of the occluding region are very close to each other.

Here we use g, the sum of gradients of v in a disk D_2 with radius r_2 centered at $\boldsymbol{x}$;

$$g(\boldsymbol{x}) = \frac{1}{\pi r_2^2} \iint_{D_2(\boldsymbol{x})} |\nabla v(\boldsymbol{x}')| \, d\boldsymbol{x}'. \tag{4}$$

Then g can be used to weight v to make V, the enhanced version of v, so that $V(\boldsymbol{x})$ takes larger value at $\boldsymbol{x}$ on the occluding region. Giving a smoothness constraint on V, the objective function to be minimized is as follows;

$$\iint_{\Omega} (V - vg)^2 + \lambda(V_x^2 + V_y^2) \, d\boldsymbol{x}, \tag{5}$$

where λ is a lagrange multiplier and Ω is the whole image.

The corresponding Euler equation to be solved is;

$$(vg - V) + \lambda(V_{xx} + V_{yy}) = 0 \tag{6}$$

This partial differential equation is solved by an iterative minimization procedure via Gauss-Seidel method.

3.2 Binarization of V

Binarizing V with a threshold th_{bin}, we obtain candidates of the occluding regions to be removed. Each candidate region l has large value in V than the threshold, and is a connected region, and also has larger area then a threshold th_{area}.

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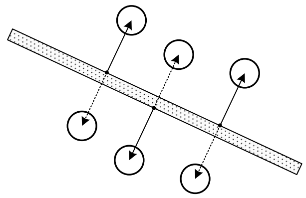

Figure 3. $D(l)$ **for a candidate region** l

3.3 Selecting candidate regions

Finally we choose regions from the candidates according to the fourth assumption. Here we introduce a background intensity difference $D(l)$, the difference between intensities of backgrounds both sides of a candidate region l.

$D(l)$ is defined with the difference of average intensities $\bar{I}$ of disks D_3 with radius r_3 at distance r_1 ($r_3 \ll r_1$) from each pixel on a contour C_l of a candidate region l;

$$D(l) = \frac{1}{N_l} \int_{C_l} \left| \bar{I}(\boldsymbol{x} + r_1 \boldsymbol{n}_{\boldsymbol{x}}) - \bar{I}(\boldsymbol{x} - r_1 \boldsymbol{n}_{\boldsymbol{x}}) \right| \, d\boldsymbol{x}, \quad (7)$$

$$\bar{I}(\boldsymbol{x}) = \frac{1}{\pi r_3^2} \iint_{D_3(\boldsymbol{x})} I(\boldsymbol{x}') \, d\boldsymbol{x}', \quad (8)$$

where $\boldsymbol{n}_{\boldsymbol{x}}$ is the normal at $\boldsymbol{x}$, and N_l is the length of C_l.

The candidate region l is marked as an occluding region if $D(l)$ is larger than a threshold th_{diff}.

4 Experimental Results

We present experimental results to demonstrate the proposed method. In the experiment, all images have occluding regions of which width are $w = 2 \sim 12$ in pixels, and parameters are specified as $r_1 = 3w, w \geq r_2 \geq \frac{w}{2}, r_3 = 2, th_{bin} = 0.005 \times 255, th_{area} = 100$, and $th_{diff} = 100$.

Fig.4 shows results of the proposed method. In each row, an original image, circle contrast image, extracted string-like regions, and background restoration result are shown. In this experiment, a simple inpaint algorithm is employed to restore background; just an interpolation using neighboring pixels. Only few samples are shown in Fig.4, but we have conducted experiments for many images and the results still demonstrate that various shapes of string-like objects, such as fences, branches and strings are detected by our algorithm.

The first row in Fig.4 is a scene with an even-spaced fence, while the second row the spaces of the wires change (contrast is also decreases) as the top-right corner, then the method fails to detect the wires around there. Another mis-detections can be found in all rows where long and narrow edges or textures are detected as occluding regions. However, these regions satisfies the assumptions and are not remarkable so that only unnoticeable artifacts arise in the restored images even the removed region are not an actual occluding object.

Note that the computational time is about a second for an image with an PC with 1.3Hz CPU.

5 Conclusions and Future works

In this paper, we propose a method for extracting string-like objects, such as wires, strings, and tree branches, in a still image for background restoration. We have introduced the circle contrast to find the occluding string-like regions, then demonstrated the proposed method with experimental results using real images.

The proposed method only uses intensity for the circle contrast and can not be applicable to a low-contrasted image. Considering color information or textures are future works as well as investigation of the effect on the extraction as the parameters change.

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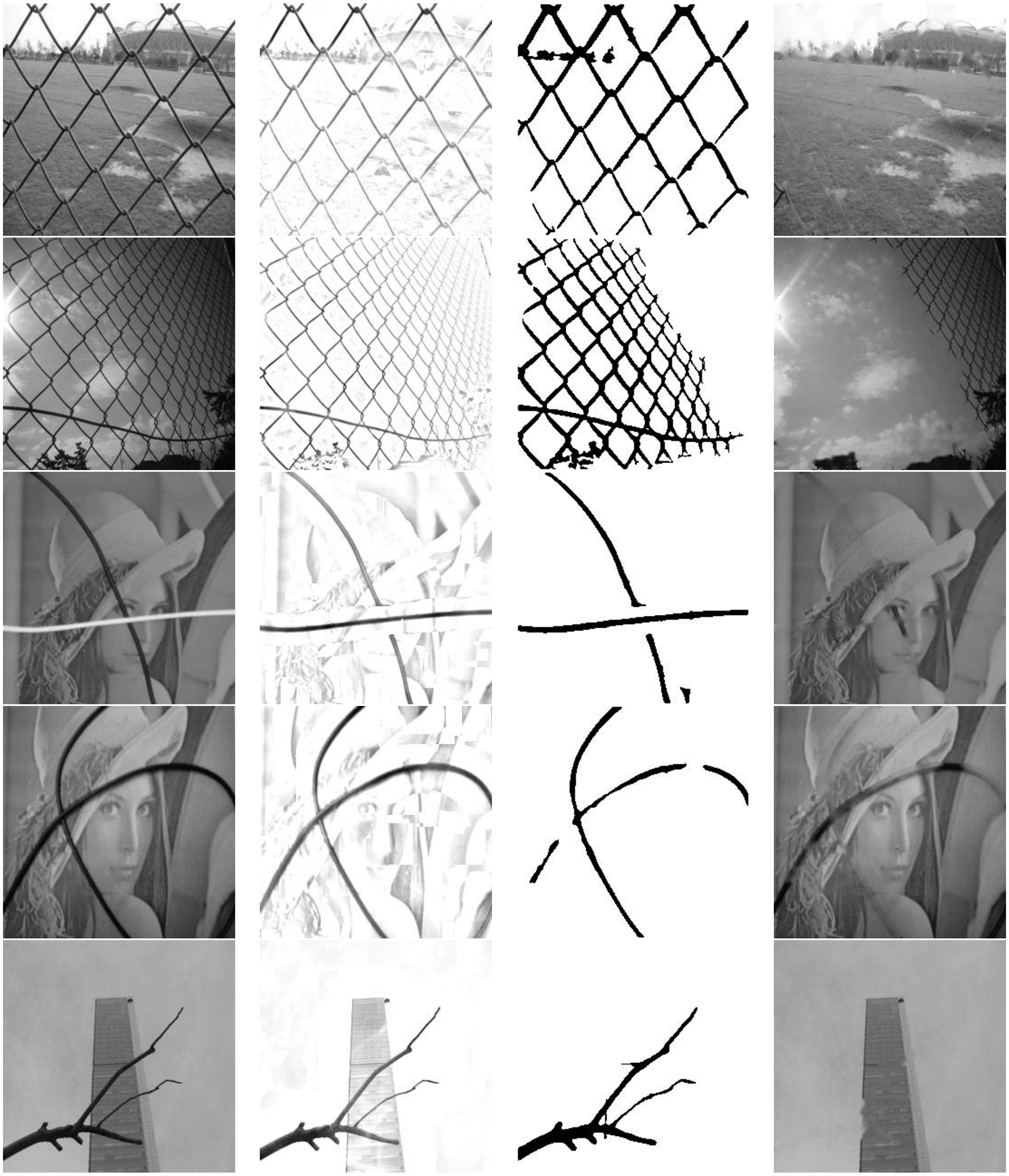

(a) (b) (c) (d)

Figure 4. Experimental results. In each row, (a) an original image, (b) sign-corrected circle contrast, (c) extracted occluding regions, and (d) restored background (inpainted) are shown.