IMAGE RESIZING USING IMPROVED SEAM MERGING

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ABSTRACT

In this paper, we propose the improved seam merging method for content-aware image resizing. This method merges a two-pixel-width seam element into one new pixel in image reduction and inserts a new pixel between the two pixels in image enlargement. To preserve important contents and structure, our method uses importance and structure energies. Using the cartoon image of an original image for calculation of structure energy, our method can preserve main structure. In addition, we introduce new energy to suppress distortion generated by excessive reduction or enlargement in the iterative merging or inserting. Experimental results demonstrate that the proposed method can produce satisfactory results in both image reduction and enlargement.

Index Terms— content-aware image resizing, seam carving, seam merging

1. INTRODUCTION

With the diversity of display device sizes and aspect ratios, researches on automatic resizing of images are becoming more important. Cropping and scaling are common approaches to change aspect ratios and resolutions. Cropping, however, can discard important parts on an image, and scaling produces distortion in the case of changing aspect ratios. For effective image resizing, several content-aware image resizing methods have been proposed [1]. Seam carving [2] is one of approaches for content-aware image resizing. It repeatedly removes an 8-connected path of pixels, called seam, from top to bottom or from left to right. An optimal seam to remove has the least total energy. To preserve important contents, the original seam carving and many improved methods [3, 4, 5] use pixel importance as the energy. These methods, however, may distort object shapes because they ignore structure preservation. To solve this problem, we proposed seam merging [6], which merges a two-pixel-width seam that minimizes structural distortion to reduce image size. We provide a brief description of this method in Section 2. See [6] for more details. The seam merging method provides satisfactory results in many images. This method, however, has the following problems to solve. First, it cannot enlarge images because it defines the way to only reduce image size. Second, it may fail to preserve important contents due to the lack of using pixel importance. Last, it may fail to preserve main structure like object outlines for preserving many small structures like texture components.

In this paper, we propose the improved seam merging method to address these problems.

2. PROPOSED METHOD

This section describes our proposed method. We first provide a brief description of the features of our method.

The conventional seam merging method reduces image size by repeatedly merging a two-pixel-width seam into a one-pixel-width seam. While it only defines image reduction, the improved seam merging method can reduce and enlarge image size. This method not only merges a two-pixel-width seam element into one new pixel, but also inserts a new pixel between the two pixels. The former reduces image size, and the latter enlarges.

To calculate pixel values on a resized image and energy to select seams, seam merging uses a merging history, which is a record listing which pixels are merged into a pixel in the resizing process. Seam carving ignores formerly removed parts in each resizing process, and that leads to large distortion generated by the accumulation of small distortion. Seam merging prevents such distortion by referring formerly merged parts using merging histories. In the conventional seam merging method, a merging history is defined as a set. In the improved seam merging method, it is defined as a list which allows duplicate elements for image enlargement.

The conventional seam carving and many improved methods used importance energy to preserve important contents. The conventional seam merging introduced structure energy to preserve structure. To preserve important contents and structure, the improved seam merging combines importance and structure energies. The structure energy is calculated by using the cartoon image of an original image for better structure preservation. In addition, we introduce new energy to suppress distortion generated by excessive reduction or enlargement in the iterative merging or inserting.

In the following subsection, we explain the energy definitions in our proposed method. For simplicity, the discussion is limited to the case of resizing images in a horizontal direction. An upper index in brackets (e.g. $\boldsymbol{s}^{(k)}$) indicates k-th merging/inserting process.

2.1. Improved Seam Merging

A vertical seam is defined as a connected path of seam elements (two-pixel pairs) from top to bottom that contains only one seam element per row. Let $\boldsymbol{s}$ be a seam, which is a set of seam elements $s_{\boldsymbol{r}}$. Here $s_{\boldsymbol{r}}$ is a seam element which creates a new pixel at $\boldsymbol{r}$ after the merging/inserting process. The pixel value of a newly created pixel is defined by using its merging history. Merging history $Q^{(0)}(\boldsymbol{r})$ initially has its coordinate $\boldsymbol{r}$ and is updated in the resizing process. The merging history of newly created pixel $\boldsymbol{r}$ is updated by combining merging histories of pixels constituting seam $s_{\boldsymbol{r}}$. Note that a merging history can contain duplicate elements in the inserting process. The merging histories of pixels located on the left of the newly created pixels remain unchanged. To compensate for the coordinate change due to merging/inserting, the merging histories of pixels located on the right of the newly created pixels are shifted to left in the merging process and to right in the inserting process. A pixel value on a resized image is calculated as the average of pixels listed in a merging history:

$$I^{(k)}(\boldsymbol{r}) = \frac{1}{\mathcal{N}(Q^{(k)}(\boldsymbol{r}))} \sum_{\boldsymbol{q} \in Q^{(k)}(\boldsymbol{r})} I^{(0)}(\boldsymbol{q}) \qquad (1)$$

where $\mathcal{N}(Q^{(k)}(\boldsymbol{r}))$ is the number of elements listed in $Q^{(k)}(\boldsymbol{r})$.

An optimal seam has the least total energy required to create new pixels. Let $E^{(k)}(s_{\boldsymbol{r}})$ be energy required to create a new pixel at $\boldsymbol{r}$ in k-th merging/inserting process. An optimal seam is expressed by

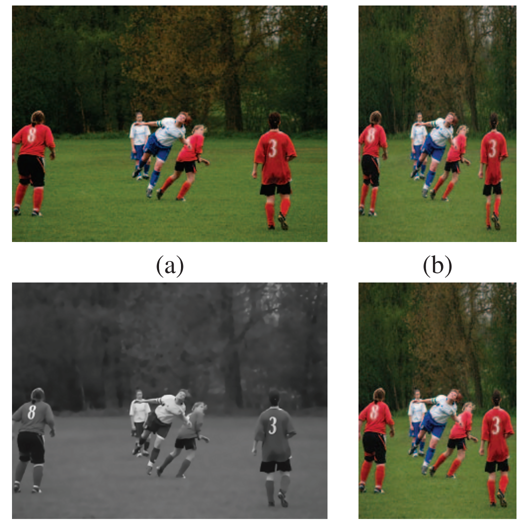
$$\boldsymbol{s}^{(k)} = \arg\min_{\boldsymbol{s}} \sum_{s_{\boldsymbol{r}} \in \boldsymbol{s}} E^{(k)}(s_{\boldsymbol{r}}). \qquad (2)$$

The conventional seam merging method uses structure energy for preserving local structures on an original image. The energy is calculated by using pixel context which expresses a local structure defined as the intensity differences between a pixel and its surrounding pixels. Pixel context is expressed as

$$d^{(k)}(\boldsymbol{r}, \boldsymbol{n}) = I^{(k)}(\boldsymbol{r}) - I^{(k)}(\boldsymbol{r} + \boldsymbol{n}) \qquad (3)$$

where $\boldsymbol{n}$ is a relative coordinates. In this paper, we use 4-connected coordinates as $\boldsymbol{n}$, i.e., $\boldsymbol{n} \in N$ where $N = \{(0,1), (1,0), (0,-1), (-1,0)\}$. A large change of pixel context makes structure distorted. To prevent such distortion, the energy to create a new pixel grows when the change of pixel context is large after merging. Structure energy is expressed using the change of pixel context as

$$E_S^{(k)}(s_r) = \sum_{\boldsymbol{q} \in Q^{(k)}(\boldsymbol{r})} \sum_{\boldsymbol{n} \in N} (\boldsymbol{d}^{(k)}(\boldsymbol{r}, \boldsymbol{n}) - \boldsymbol{d}^{(0)}(\boldsymbol{q}, \boldsymbol{n}))^2. \qquad (4)$$



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

Fig. 1. Resized results using different images for pixel context. (a) Original image. (b) Resized image using pixel context on the original image. (c) Cartoon image of (a). (d) Resized image using pixel context on the cartoon image.

Using this structure energy produces plausible images. In some images, however, it may fail to produce satisfactory results. Fig. 1 (b) is a resized image using the energy expressed by (4). As shown in this figure, body outlines are distorted while unimportant background parts are left. The cause is that the background texture has complicated local structures. Although structure change in areas having many small edges like texture is unnoticeable, structure energy becomes large because of complicated structures. As a result, a seam passes through main structure parts because they have less energy than texture parts have. It leads to significant structure distortion. To obtain better resized images, we need to use structure energy which is little affected by texture components.

Our proposed method calculates structure energy using pixel context on the cartoon image of luminance image Y of original image $I^{(0)}$. Y can be decomposed into two components $Y = u + v$, such that u represents a cartoon or simplification of Y, while v represents noise or texture of Y. To obtain a cartoon image, we use the Rudin, Osher, and Fatemi model [7]:

$$\inf_u \left\{ F(u) = \int |\nabla u| + \lambda \int |v|^2 dx dy, Y = u + v \right\}. \qquad (5)$$

Cartoon image u is an image formed by homogeneous regions and with sharp boundaries. Using u, pixel context is rewritten as

$$d^{(k)}(\boldsymbol{r}, \boldsymbol{n}) = u^{(k)}(\boldsymbol{r}) - u^{(k)}(\boldsymbol{r} + \boldsymbol{n}). \qquad (6)$$

The update rule of u is as follows.

$$u^{(k)}(\boldsymbol{r}) = \frac{1}{\mathcal{N}(Q^{(k)}(\boldsymbol{r}))} \sum_{\boldsymbol{q} \in Q^{(k)}(\boldsymbol{r})} u^{(0)}(\boldsymbol{q}). \qquad (7)$$

Fig. 1 (d) is a resized image using the cartoon image (Fig. 1 (c)) as calculating structure energy. As shown in this figure, using a cartoon image reduces the effect of texture components and keeps main structures on an image.

Keeping important parts is as needed as keeping structure to obtain satisfactory resized results. The conventional seam carving and many improved methods use an importance map to prevent important parts from distortion. These methods, however, may produce distorted results because they repeatedly remove the least important seams ignoring which parts were removed before. It leads to excessive removal of unimportant parts and introduces distortion. To prevent such distortion, Cho et al. [5] proposed the use of importance diffusion, which propagates importance of removed pixels to their neighbors. The improved seam carving method uses an importance map and calculates importance energy using merging histories to prevent such distortion. Using importance map T, importance energy to create new pixel $\boldsymbol{r}$ is expressed as

$$E_T^{(k)}(s_r) = \sum_{\boldsymbol{q} \in Q^{(k)}(\boldsymbol{r})} T(\boldsymbol{q}). \tag{8}$$

As shown in this equation, image importance is accumulated in the resizing process. Pixel importance can be measured by intensity gradient, saliency measure, and many other measures. In this paper, we use the L_1-norm of the intensity gradient of a luminance image as

$$T = |\frac{\partial}{\partial x} Y| + |\frac{\partial}{\partial y} Y|. \tag{9}$$

To obtain more satisfactory results, we introduce an additional energy. In many cases, using the foregoing structure and importance energies can prevent excessive merging/inserting in an area because of energy accumulation. However they fail to prevent it in smooth areas for little accumulation. To solve this problem, we introduce the following energy which grows when merging/inserting is repeated.

$$E_U^{(k)}(s_r) = \mathcal{N}(Q^{(k)}(\boldsymbol{r})). \tag{10}$$

Finally, to define the energy in Eq. (2) for selecting an optimal seam with the three energies $E_S^{(k)}$, $E_T^{(k)}$ and $E_U^{(k)}$, we need to normalize these energies, which are defined in different measures. Before starting the resizing process, we calculate the following maximum energy on each of the three energies individually, and then divide each energy by the corresponding maximum energy in the resizing process.

$$E_* = \max_{\boldsymbol{s}} \sum_{s_{\boldsymbol{r}} \in \boldsymbol{s}} E_*^{(1)}(s_{\boldsymbol{r}}). \tag{11}$$

Using normalized energies, the total energy to create a new pixel at $\boldsymbol{r}$ is expressed as

$$E^{(k)}(s_r) = E_S^{(k)}(s_r) + E_T^{(k)}(s_r) + E_U^{(k)}(s_r). \tag{12}$$

An optimal seam expressed Eq. (2) can be found using dynamic programming.

3. EXPERIMENTAL RESULTS

To validate our method, we implemented our proposed method and tested it on a variety of images. Because the conventional seam merging method [6] and our proposed method tend to create similar satisfactory results, we show the results which are clearly different between them.

Fig. 2 shows the results of image reduction with improved seam carving methods [3] [5], the conventional seam merging method, and the improved seam merging method. The widths of the resized images are reduced by half. Method [3] [5] distort object outlines. The conventional seam merging method fails to preserve main structures due to the effect of back ground textures. Since our method uses a cartoon image for structure preservation, our method achieves better outline preservation than the conventional seam merging method.

We next show the results of image enlargement with [3] and our method. As shown in Fig. 3, our method keeps main objects and structures, while seam carving based approach [3] distorts some objects. In image enlargement, seam carving once removes seams, and then duplicates corresponding seams on an original image. The reason is straightforward pixel inserting creates a stretching artifact [2]. Additionally, seam carving needs to break the process into several steps in the case of excessive image enlarging (for instance, greater than 50%) like the bottom case in Fig. 3. As shown in this process, seam carving selects seams optimized for image reduction, not for image enlargement. In contrast, our method enlarges images straightforwardly without excessive stretching artifact due to the accumulation of energies.

4. CONCLUSION

In this paper, we have proposed the improved seam merging method for content-aware image resizing. This method merges a two-pixel-width seam element into one new pixel in image reduction and inserts a new pixel between the two pixels in image enlargement. To preserve important contents and structure, our method uses importance and structure energies. Using the cartoon image of an original image for calculation of structure energy, our method can preserve main structure. In addition, we introduce new energy to suppress distortion generated by excessive reduction or enlargement in the iterative merging or inserting. Experimental results demonstrate that the proposed method can produce satisfactory results in both image reduction and enlargement.

Our future work is to extend our proposed method for video resizing.

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(a) Original (b) Rubinstein [3] (c) Cho [5] (d) Seam merging (e) Our method

Fig. 2. Comparison of our method with other methods in image reduction.

(a) Original (b) Rubinstein [3] (c) Our method

Fig. 3. Results of image enlargement with Rubinstein's method and our method.

6. REFERENCES

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