An Image Retargeting Scheme with Content-based Cropping and Local Significance Aware Seam Carving

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Abstract — **This research presents an image retargeting scheme consisting of two main operations, the content-based cropping and seam carving, to modify the width/height of imagery data. The seam carving is first employed to remove insignificant pixels in the middle part of image. The selection of seams is based on the gradient in one direction and local energy to avoid obvious distortions. When the background tends to be uniform, some seams can be inserted in a similar way to make the aspect ratio closer to the target one. The content-based cropping that considers the visual saliency is then applied to remove boundaries. The final image is formed by scaling directly if necessary. The experimental results will demonstrate the advantages of the proposed method.**

I. Introduction

Visual media retargeting draws a lot of attention in recent years because of its ability to adapting the resolution of images or video frames to the display facilities in a flexible manner. Unlike directly scaling the imagery data to obtain the target aspect ratio, content-based retargeting methods can process the regions of an image in different ways such that the non-uniform scaling can be achieved to make the image fit the required size. The methodologies of retargeting can be classified into four categories: content-based cropping, seam carving, warping, and the use of multi-operator. The content-based cropping can determine the regions of interest in an image by content analysis to remove insignificant boundaries [3][9][10][11]. The methods of warping impose a set of grids on the image and adjust the grids non-uniformly to achieve the global optimization based on certain distortion measurements [4][17]. The gradient, visual saliency, face detection and even motion can be used to evaluate the importance of grids and different kinds of warping can be applied accordingly. Avidan and Shamir [13] proposed the ideas of seam carving for still images. By successively removing the seams with the minimum energy or saliency in the image, important areas can be better preserved. Most of the changes are made in uniform areas so that less severe distortion will be introduced. Rubinstein et al. proposed an improved seam carving method and extended the technique to videos [5]. The “looking-forward energy” helps to reduce the discontinuous seams. Grundmann et al. proposed a discontinuous seam carving method to prevent the moving objects in consecutive frames from being affected by the seam carving process [8]. Domingues et al. proposed the idea of stream carving to remove multiple seams at the same time [2]. The resulting holes will be fixed by image inpainting. The face and line detections are employed to further reduce possible distortions.

Multi-operator methods combine different approaches to pursue more satisfactory results. Hua et al. employed Scale Invariant Feature Transform (SIFT) to evaluate the difference between the quality before and after retargeting so that a more suitable termination of seam carving can be decided [14]. Rubinstein et al. defined “Bi-Directional Warping” to evaluate the quality [6]. The proposed method chooses one operator from cropping, seam carving and scaling based on the evaluation to achieve good retargeting results. The drawback is the speed since the quality evaluation has to be applied in each step. Luo et al. proposed “Accumulated Energy Seam Carving” to improve the single-direction modification so that the resulting image can maintain a closer resolution to the targeted one [15]. Dong et al. combined seam carving and scaling based on the difference measurement and dominating color descriptors [7]. Dong et al. further proposed an energy function to speed up the process but the complexity will still be increased if more operators are used [16].

It should be noted that cropping is always an effective way to remove insignificant boundaries of images since most of the regions of interest are located at the center. The visual saliency in an image has to be evaluated to determine the areas to be cropped off. If the saliency can be calculated efficiently, content-based cropping can be applied without a lot of computation. The risk of cropping is that important objects located near the boundaries may be affected. The techniques of seam carving can help to compensate the deficiency of cropping to remove insignificant pixels in the middle part of an image. If taking them off in an imperceptible way is achievable, the cropping, which follows the operation of seam carving, can have a better chance of preserving the important visual content. However, seam carving is often criticized for its negative impact on image quality. The resulting distortions may appear in several parts of an image when seam carving is the only tool for retargeting.

This research proposes an image retargeting scheme employing both cropping and seam carving to exploit their advantages. The seam carving is applied according to the measurement of pixel energy, which is calculated based on the gradient in one direction and the discontinuity of adjacent pixels. The “global” seam energy will help to select a seam to carve while the “local” energy decides whether a seam is kept or the whole operation has to be terminated. The strategy of checking the local energy is to avoid generating obvious distortions, which may appear at small spots of an image but cause unpleasant visual effects. Some seams can be further added or inserted in the uniform background in a similar way to make the aspect ratio closer to the target one. After the visual saliency is evaluated, the content-based cropping is then applied accordingly to preserve regions of interest in the image. The final step is the normalization step that directly scales the image to the required size. The rest of the paper is organized as follows. Sec. II will detail the proposed algorithm and some experimental results are demonstrated in Sec. III, followed by the conclusion in Sec. IV.

II. The Proposed Scheme

A. Seam Carving

To apply seam carving, an energy function is defined for identifying the importance of pixels. Given a required image or frame resolution, if the aspect ratio is maintained, scaling with delicate interpolation yields good results. The considered scenario is thus the change of aspect ratio and only one direction, either width or height, will be modified. Without loss of generality, the modification of width is taken into account in this paper. Given an image, *I*, with *N* rows and *M* columns, the vertical seam is defined as

$$S^v = \{x, y_s(x)\}_{x=1}^{N}, |\, y_s(x) - y_s(x-1)\,| \le 1, \quad (1)$$

A vertical seam is thus an eight-neighbor connected path of pixels in the image from top to bottom, containing only one pixel in each row of the image. Removing the pixels of a seam will make the pixels on the right-hand side shift left by one position to compensate for the missing path. The pixels on a seam in an image can be expressed as

$$I_s = \{I(x, y_s(x))\}_{x=1}^{N} \quad (2)$$

When a seam is carved, only a small portion in an image will be affected. The selection of seams to carve is based on the importance of pixels. Given the energy of a seam is $E(I_s)$, we will select the best seam S^* such that the energy from such a seam carving is the minimum, i.e.,

$$S^* = \min_{s}\{E(I_s)\} \quad (3)$$

The calculation is performed via the dynamic programming. From the second row to the last row of an image, all the energy values are accumulated by

$$M(x,y) = e(x,y) + \min\begin{cases} M(x-1, y-1) \\ M(x-1, y) \\ M(x-1, y+1) \end{cases} \quad (4)$$

where $e(x,y)$ is the energy of the pixel (x,y) and M is the cumulative minimum energy. After calculating all the energy values according to (4), we trace back from the last row with the minimal energy and then select the recorded path. The resulting seam is chosen and removed.

There are a few ways of calculating the energy function. Some complicated calculations may include advanced saliency estimation, segmentation or face detection. In [13], a very simple energy function measured by the magnitude of derivatives is adopted, i.e.,

$$e(I) = \left|\frac{\partial}{\partial x} I\right| + \left|\frac{\partial}{\partial y} I\right| = |G_R| + |G_C|. \quad (5)$$

It is worth noting that computing the gradient is efficient and the resulting seams can also perform quite naturally in images. On the other hand, advanced energy functions considering visual saliency certainly help the selected seams to avoid important objects in an image. However, according to our observations, visual saliency in an image usually shows uniform areas or regions. Adjacent seams may traverse along the same direction to escape a certain important object, which can make the adjacent areas around the objects look abnormal. Therefore, the proposed scheme still adopts the magnitude of gradient as the energy function but tries to achieve the balance between the number of carved seams and the image quality. Since only the modification of width is considered and vertical seams are needed, the energy function for seam carving in the proposed scheme is the column gradient, i.e.,

$$e_V(I) = \left|\frac{\partial}{\partial y} I\right| = |G_C|. \quad (6)$$

On the other hand, when the horizontal seams are required, the considered energy function will be e_H, taking account of the row gradient only. The reason of such a choice is to try increasing the number of seams that are allowed to form without seriously affecting the image quality. An obvious example is to accept a vertical seam to pass through a horizontal line, which has a strong e_H but a weak e_V. Serious distortions seldom appear since taking a pixel away still results in a straight line after shifting other pixels horizontally.

In addition to the gradient, the continuity between pixel values is also considered in measuring the energy. Assume that $I(x,y)$, $I(x,y+1)$ and $I(x,y+2)$ are the concatenated pixels in the same row and $I(x,y+1)$ is a pixel of a chosen seam. After $I(x,y+1)$ is taken off, $I(x,y)$ and $I(x,y+2)$ are adjacent to each other. The energy of $I(x,y)$ will be increased by S_C, which is considered a penalty for linking the pixels that were not neighbors. S_C can be divided into S_H (horizontal penalty) and S_V (vertical penalty). In the previous example, S_H of $I(x,y)$ or $I(x,y+2)$ is equal to $|I(x,y)-I(x,y+2)|$. For S_V, if $I(x,y)$ remains in the image but its upper or lower neighbor is removed due to the seam carving process, the energy of $I(x,y)$ has to be adjusted. If the upper neighbor becomes $I(x-1,y-1)$ (or $I(x-1,y+1)$), instead of $I(x-1,y)$, the additional penalty will be $|I(x,y)-I(x-1,y-1)|$ (or $|I(x,y)-I(x-1,y+1)|$). Similarly, the lower neighbor will be checked to see if additional penalty has to be imposed. The sum of both penalties will be S_V. The energy function associated with (x,y) is then equal to

$$e(x,y) = e_V(x,y) + ScF(S_V + S_H), \quad (6)$$

where ScF is a weighting factor. A larger ScF will make the position (x,y) have a smaller chance to be chosen in the future so that the selected seams will not be always tangled together.

The results of using seam carving only are usually used as the reference or comparison in existing work since noticeable distortions appear quite often. In our opinions, seam carving has the advantages of removing pixels directly to reduce the size of image but has to be applied with care without being overused. It should be noted that the process of dynamic programming mentioned above ensures that a vertical seam with the length N has the lowest energy. Nevertheless, noticeable distortions can occur in local areas so a global measurement cannot reflect the real situations. This problem becomes more serious in seam carving since the distortions are not additive noises but twists of content. The proposed scheme tries to avoid visible local distortions by defining some salient points and requiring that a selected seam should not contain any such salient point. To be more specific, (x,y) is identified as a salient point if its energy function $e(x,y)$ is larger than a threshold calculated by

$$T_S = \sqrt{\frac{1}{M \times N} \sum_{x=1}^{N} \sum_{y=1}^{M} e_V^{\,2}(x,y)}. \quad (7)$$

e_V can be calculated by Prewitt operator to find vertical edges and T_S is a common threshold to identify edge pixels. One may think that these salient points can be determined first and assigned with a very large energy so that the dynamic programming process will automatically skip these salient points. Nevertheless, it is observed that these points may appear along the edges so the selected seams will also extend along/near the edges and may cause unpleasant results. Our strategy is thus to employ the dynamic programming to select the seam with the smallest energy. During the inverse tracing to find the route, we check whether any salient point is passed. If yes, we give up this seam and turn to find the second best one and so on. This seam carving process will be stopped if we have examined all the seams (M seams at the beginning) and cannot find any seam that doesn't contain any salient point.

The adaptive threshold T_S is quite important but cannot guarantee an excellent result. If T_S is too small, we will have fewer seams, which will be less reasonable since seam carving costs a large amount of computation, compared with cropping or scaling. If T_S is too large, some seams may pass through sharp edges and the quality can be affected. From our observation, the seams passing through sharp edges are the major causes of quality degradation. In the proposed scheme, a smaller threshold is adopted, i.e., T_S/D, so more points will be viewed as edge pixels of foreground. The labelling of connected components is calculated and the points with the number of four-neighbor components smaller than K will be removed from these foreground edges. The energy of the remaining foreground edges will be scaled, e.g., by D, to make these points more significant. Some subtle lines, which may not have stronger energy, can thus be better preserved. However, this method also increases the energy of textural areas where the seams should be allowed to go across. An order filtering with a small support area (n by n) is calculated and the scaled e_V ranked the $Q\%$ smallest value is used as the divisor to decrease e_V . i.e.,

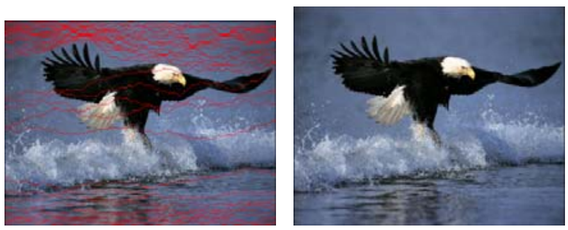
$$e_V^{(A)}(x,y) = \frac{e_V^{(S)}(x,y)}{1 + ord(e_V^{(S)}\{X,Y\}\big|_{\{X,Y\}\in A}, Q\%)}, \quad (8)$$

where $e_V^{(S)}$ is the scaled energy and $ord(.)$ finds the value ranked as the smallest $Q\%$ and A is the set $\{x\text{-}n \le X \le x+n,\ y\text{-}n \le Y \le y+n\}$. $e_V^{(A)}$ is the adjusted energy to replace e_V in (6). If Q is equal to 25, then the denominator is the quantile value plus one. We tend to choose a smaller Q to modify $e_V^{(S)}$ in a more conservative way to reduce the effects on sharp edges.

When a seam is selected to carve, partial updating is applied to adjust the energy function of affected pixels only. Since the pixels of a seam are eight-neighbor connected, when $I(x,y)$ is chosen, at least two out of $I(x+1,y-1)$, $I(x+1,y)$ and $I(x+1,y+1)$ are examined. Besides, if the energy function of a pixel is changed, the three pixels in the next row will be checked too. The proposed scheme computes the energy function only once and applies the updating on pixels if necessary. The pixel that is chosen in a seam will be assigned with a large energy value so that it will not be selected again. In fact, we can draw the seams on the image directly and then carve these seams to reduce the width of the image. Fig. 1 shows an example with Fig. 1(a) demonstrating an Eagle image with the superimposed seams and Fig. 1(b) illustrating the image processed by the proposed seam carving.

(a) (b)

Fig. 1 An example of seam carving (a) the Eagle image with the carved seams and (b) the resulting seam-carved image.



(a) (b)

Fig. 2 An example of adding seams (a) the seam carved image superimposed with inserted seams and (b) the resulting image.

When the background is not complex and further change of width is still necessary, we can choose to insert horizontal seams. The procedure is similar to the seam carving algorithm. Basically, we determine the seam based on $|G_R|$ and the penalty mentioned before. The seams are copied, instead of being carved. As long as the threshold is set lower, say T_S/F, the copying is similar to the interpolation since the considered areas are usually uniform. Fig. 2 shows an example of seam adding, with the inserted seams in flat areas.

B. Visual Saliency for Content-based Cropping

After the seam carving, if the width has to be reduced further, content-based cropping will be applied. The visual saliency, instead of the energy function mentioned before, will be needed to determine the boundaries of regions of interest. The method proposed by Montabone et al. [12] is used to calculate the visual saliency. This method makes use of the property that the human perceive the visual information by the on-center and off-center ganglion cells in eyes; on-center ganglion cells respond to bright areas surrounded by a dark background while off-center ganglion cells respond to dark areas surrounded by bright areas. The saliency map is then calculated as follows. After converting the image into grayscale values, the 3 by 3 Gaussian filter is employed to smooth the grayscale image twice and then the integral image is calculated. The integral image *G(x,y)* represents the sum of the values above and to the left of (*x, y*), i.e.,

$$G(x,y) = \sum_{y' \le y, x' \le x} g(x',y'), \tag{9}$$

where *g* is the filtered pixel. The sum of any rectangular area defined by two points, (*x1,y1*) and (*x2,y2*), can be calculated by *G(x,y)* in constant time, i.e.,

$$\begin{aligned} &Sum(x1,y1,x2,y2) \\ &= G(x2,y2) - G(x1,y2) - G(x2,y1) + G(x1,y1) \end{aligned} \tag{10}$$

The on-center and off-center differences with two surrounding values, 3 and 7, and three scales, 2, 3 and 4, can be computed efficiently to acquire six intensity submaps: $3\cdot2^2$, $3\cdot2^3$,$3\cdot2^4$, $7\cdot2^2$, $7\cdot2^3$ and $7\cdot2^4$, so the set of scale *q* is {12, 24, 48, 28, 56, 112}. The surrounding pixels are defined as

$$surround(x,y,q) = \frac{Sum(x-q, y-q, x+q, y+q) - g(x,y)}{(2q+1)^2 - 1} \tag{11}$$

The intensity submaps are then calculated by

$$Int_{(On,q)}(x,y) = \max\{g(x,y) - surround(x,y,q), 0\}, \tag{12}$$

$$Int_{(Off,q)}(x,y) = \max\{surround(x,y,q) - g(x,y), 0\}, \tag{13}$$

The saliency image *P(x,y)* is formed by

$$P(x,y) = \max\{\sum_q Int_{(On,q)}(x,y), \sum_q Int_{(Off,q)}(x,y)\} \tag{14}$$

Fig. 3 shows an example, in which the eagle is apparently the main object of the image and higher saliency values are assigned correctly to the area where the eagle is located. Although this method does not include complex algorithms such as image segmentation or object detection, the detected saliency can reasonably reflect the regions of interest and also preserve the advantages of image gradients. In contrast, some advanced visual saliency methods do successfully identify a large object in an image and view all other areas as the background. However, if these background pixels are all removed, the image will look quite strange. We found that this simple visual saliency tends to preserve more areas and can be quite suitable to the cropping operations.

(a) (b)

Fig. 3. A saliency example: (a) the original image and (b) the saliency map.

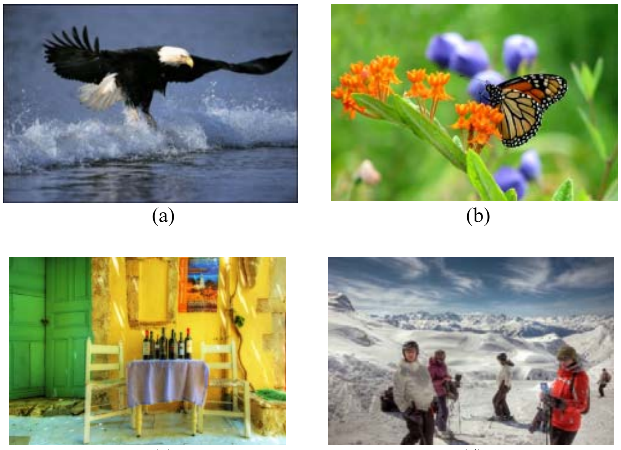
C. Content-based Cropping

The cropping is applied on both sides of an image until a meaningful foreground is touched according to the saliency map. We calculate the average values of the saliency pixels in *m* by *m* blocks. If the average value is larger than the threshold ε, the block is considered a foreground block. The block size *m* can be related to the image size. The threshold ε is decided using Otsu's algorithm. All the pixels in the block will be set either 255 (foreground) or 0 (background). The foreground image will be processed by the eight-connected-component labeling and we will determine whether a component is important based on the number of connected foreground blocks. Next, we employ the property of "Rule of Third" in digital photography [1], which states that the central 1/3 of the image is usually the region of interest. Two constraints are imposed: 1) The foreground objects located around the two sides of the image are seldom important so they should be viewed as the background and can be cropped off. We thus trace the significant components starting from the two sides toward the center. When a foreground pixel is found following a background one during the trace, an object is said to be encountered and should be kept. 2) Since the top/bottom 1/3 of an image may not be important according to the property of "Rule of Third", we conservatively ignore top/bottom 1/9 of the image, which will not be traced to find the foreground area.

Fig. 4 shows an example. The white pixels in Fig. 4(a) are identified as the foreground. The small red blocks generated during the tracing help to determine the locations of edges so the cropping can be applied efficiently as shown in Fig. 4(b). Comparing Figs. 2 and 4, one may think that we should analyze the cropping boundaries after the seam carving. Nevertheless, the seam carving operations may change the content at the boundaries and the first constraint mentioned above may be affected. The proposed scheme thus determines the boundaries from the original image first. The boundary pixels are recorded for the subsequent content-based cropping, after the seam carving process. By doing so, it seems that we should apply cropping before the seam carving since the necessary number of lines can be removed by cropping. The remaining image with a smaller size can be processed more efficiently in the seam carving. However, it should be noted that cropping will more or less lose image content near the boundaries, where many people may have different opinions on whether certain parts should be preserved or not. Therefore, we still prefer to employ the seam carving first to remove some imagery data and help preserve more content near the sides of an image.

(a) (b)

Fig. 4. A cropping example: (a) the determination of the foreground and suitable cropping positions and (b) the result of cropping.



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

Fig. 5. Test images. (a) Eagle, (b) Butterfly, (c) Wine and (d) Ski

III. Experimental Results

The setting of the proposed scheme is described as follows. *ScF* in (6) is set as 4. The factor *D* for finding weak lines or curves is 2. The number of connected components *K* for determining the meaningful lines is 128. In the order filtering, the size *n* used in the supporting area is 13 and the parameter *Q* is 12.5. The factor *F* for determining the threshold in adding seams is 4. The block size *m* for cropping is empirically set as the image height divided by 24. We compare the results with Seam Carving (SC) [5] and Multi-Op (MO) [6]. The test images and target resolutions are set according to [7] with the width being reduced by half. The original images are shown in Fig. 5, including Eagle (402x600), Butterfly (700x1024), Wine (697x1024) and Ski (661x1003). Figs. 6 to 9 show the comparisons. The scores of quality assessment using [18] are also listed in the captions of Figs. 6 to 9 as the reference. In the proposed scheme, the numbers of carved seams are 71, 71, 135 and 113 for Eagle, Butterfly, Wine and Ski respectively. A reasonably large number of seams are carved and this is reasonable and even required since the process of seam carving does take some time. The numbers of added seams are 30, 45, 29 and 19 for these four images and we can see that the seams are inserted in a more conservative way to prevent possible distortions. The numbers of cropped lines are 94, 409, 53 and 106 for Eagle, Butterfly, Wine and Ski respectively. In Fig. 6, the eagle's wing on the right-hand side has been distorted in SC and MO. In Fig. 7, the butterfly is perfectly preserved in the proposed method as the cropping achieves most of the width reduction. In contrast, the shape of butterfly is modified in SC and MO. In Figs. 8 and 9, the detailed comparisons are also illustrated in Fig. 8(d) and Fig. 9(d). The feet of chairs are trimmed too much in SC and MO. For the person on the left-hand side in Ski, his legs are distorted seriously in SC and his body becomes too slim in MO.

(a) (b) (c)

Fig. 6. Comparison of Eagle: (a) SC (0.68) (b) MO (0.7) (c) Ours (0.76).

(a) (b) (c)

Fig. 7. Comparison of Butterfly: (a) SC (0.79) (b) MO (0.78) (c) Ours (0.8).

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

Fig. 8. Comparison of Wine: (a)SC (0.6) (b) MO (0.61) (c) ours (0.76) (d) close-up comparison of the chair (SC,MO, Ours).

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

Fig. 9. Comparison of Ski: (a) SC (0.61) (b) MO (0.75) (c) ours (0.75) (d) close-up comparison of the man (SC,MO, Ours).

It should be noted that the numerical settings may have different effects on images. The design principle is to ensure that a larger number of seams can be carved and the seams should not pass through clear or sharp edges. Therefore, images with varying characteristic are collected, especially those containing sharp lines or curves, to help determine suitable parameters. The objective of cropping is to preserve the visually significant objects. Nevertheless, different users may have varying opinions about the same content. Fig. 10 shows two examples. In Fig. 10(a), “DKNYgirl”, cropping more helps to maintain the shape of girl well but the taxi in the background may not be included. In Fig. 10(b), “Umdan”, if the two persons on the left-hand side are cropped off, we can prevent the other five persons from being “squeezed” horizontally, but some users may prefer to keep all the seven persons instead. In the proposed scheme, we try to crop more background in Fig. 10(a) but keep all the persons in Fig. 10(b). Fig. 10(c) and Fig. 10(d) demonstrate the resulting images by reducing the width by half using the proposed method.

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

Fig. 10. The examples for determining the parameters in cropping: (a) DKNYgirl, (b) Umdan, (c) retargeted DKNYgirl and (d) retargeted Umdan.

IV. Conclusion and Future Work

This research presents an image retargeting scheme that combines the seam carving and content-based cropping. The seam carving is designed to avoid possible distortions in local areas. Carving and adding seams can be applied in a similar way. The content-based cropping can remove insignificant boundaries efficiently according the visual saliency. The experiments show that, the proposed method outperforms [6] in several images. The proposed method can be further improved by considering more advanced saliency detection, such as the inclusion of face detection, to avoid generating perceptible distortions when the human face occupies larger areas. The algorithm can certainly be extended to video processing, e.g., on the key frame of a video segment or static scenes without obvious camera motions.

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