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Detection of Seam Carved Image Based on Additional Seam Carving Behavior

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Abstract

Seam carving is a kind of content aware image retargeting algorithm and can be applied to resize and deliberately remove objects from digital images. Based on the observation that after applying an additional seam carving operation, the similarity, the energy relative error, and the difference of seam distance of original image are quite different from those of the seam-carved image, we propose and develop a new method for detecting seam carving or seam insertion of natural images without knowledge of the original image. First, we apply an additional seam carving operation to the testing image, then calculate similarity, energy relative error, and difference of seam distance between the testing image and its seam carved version. Last, we extract 11 dimensional features to detect seam carving operation to train a support vector machine classifier for recognizing whether an image is an original or it has been modified using seam-carving. Our experimental results demonstrate that our proposed forensic method achieves not only better detection rate but also lower dimensional features compared with other existing seam carved detection methods.

Keywords: *Image forensic, Seam carving; Content-Aware Image Retargeting; Similarity; Seam Distance*

1. Introduction

Seam carving[1], as a content aware image retargeting algorithm, has achieved the most widespread use and has been successfully applied to resize and deliberately remove objects from digital images, in which perceptually important content was preserved. The proliferation of seam carving makes a serious challenge in image forensics. How to detect seam carving operations has become one of image forensic scientific challenges in the first image forensics challenge organized by the IEEE information forensics and security technical committee (IFS-TC)[2] in June 2013.

Some works for seam carving forensic have been done since 2009[3-7]. Firstly, Sarkar *et. al.,* [3] employed 324-dimensional Markov features for seam carving detection in 2009. Those features consisting of 2D difference histograms in the 8×8 block-based Discrete Cosine Transform (DCT) domain, which was originally developed to detect JPEG-based steganograms by Shi *et. al.,* [8], were extended for seam carving detection. This algorithm yielded a detection accuracy of 80% and 85% for seam carving and seam insertion, respectively. Fillion and Sharma [4] proposed several intuitive features for seam carving detection in 2010. Those statistical features included the bias of energy distribution, the dispersal of seam behavior, and the affection of wavelet absolute

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moments. Their work achieved higher detection accuracies of 84.0% and 91.3% for 20% and 30% seam-carved images respectively. SeungJin Ryu *et. al.*, [5] extracted 14 dimensional features consisting of average column energy, average row energy, average energy, max seam, and so on, and trained the method by SVM. The accuracies of their method were between 71.52% and 93.5%. But there was a limitation of incapability of objects removal. Qingzhong Liu[6][9] merged shift-recompression-based characteristic features in spatial domain and shift-recompression-based neighboring joint density in DCT domain together to detect the content aware-based forgery in JPEG images. Recently, Jyh-Da Wei *et. al.*, [7] proposed an excellent patch-based detection method. First, they divided image into 2 * 2 mini-squares. For each mini-square, there were nine types of 2*3 patches as the candidate patches for possible seam carving effects. Then they searched for one of nine types of patches that were likely to recover a mini-square from seam carving and analyzed the patch transition probability among three-connected mini-squares. Last, 252 dimensional features were sent to a SVM classifier system that detected whether the test image has been seam carved. Their method achieved the best detection accuracies among the existing methods, namely, 92.2% and 95.8% for 20% and 50% seam-carved images, respectively.

In this paper, we propose a new seam carving detector by revealing the additional seam carving behavior. Our method is based on the fact that some artifacts and warping will be introduced to the seam carved image although perceptually important content is preserved. If the amount of carved seam exceeds some bound, then one will feel that the original image is damaged and the resulting image is not similar to the original one any longer. We found that the similarity, the energy relative error, and the difference of seam distance of original image were quite different from those of the seam-carved image after applying an additional seam carving operation. First, we apply a seam carving operation to the testing image, and then calculate similarity, energy relative error and difference of seam distance between the testing image and its seam carved version. Last, 11 dimensional features are extracted to train a support vector machine classifier. Compared with other existing seam carved detection methods, our method generates better detection accuracies than the existing methods, namely, 93.81%, 97.83% and 98.85% for 30%, 40% and 50% seam-carved images respectively.

2. The Proposed Algorithm

2.1. Overview of Seam Carving Process

Seam Carving [1] is an efficient method for resizing images in a content-aware mode, and has gained a measure of popularity due to its ability to overcome the limitations of traditional scaling and cropping. Seam carving was originally proposed to automatically remove the paths of least importance, known as seams, to reduce image size or insert seams to extend it. A seam is defined as an 8-connected path of low energy pixels crossing the image from top to bottom, or from left to right. A dynamic programming technique is used to select the optimal seams in each direction, which are defined as the seams with the lowest accumulated energy indicative of the combined importance of the pixels on the seam.

The energy function is given as follows:

$$e\ (I)=\left|\frac{\partial}{\partial x}I\right|+\left|\frac{\partial}{\partial y}I\right| \tag{1}$$

where I is an n × m image. A vertical seam is defined as:

$$s^x=\{s_i^x\}_{i=1}^n=\{(x(i),i)\}_{i=1}^n,\ s.t.\ \ \forall j,\left|x(i)-x(i-1)\right|\le 1 \tag{2}$$

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Where x is a mapping $x:[1,...,n] \rightarrow [1,...,m]$. The optimal seam s* is the seam with the lowest energy cost and can be found using dynamic programming with the cumulative minimum energy M for all possible connected seams for each entry (i,j).

$$M(i,j) = e(i,j) + \min(M(i-1,j-1), M(i\text{-}1,j), M(i-1,j+1)) \quad (3)$$

For image reduction, seam selection ensures that, while preserving the image structure, more low energy pixels are removed and more high energy pixels are maintained.

2.2. The Characteristics of Seam Carved Images

Although seam carving can keep important image content by successively removing low energy seams, previous work [10] and our experiments showed that with the increase in the number of the removed seams, seam carving caused the distortion of image contents. If the amount of carved seam exceeds some bound, then one can feel that the original image is damaged and the resulting image is not similar to the original one any longer.

In Figure 1, (a) is original image, (b) is 20% seam carved image(20% of the columns and the rows in the original image are removed), (c) is 30% seam carved image, and (d),(e) and (f) are the result images after removing 3% seams of (a),(b) and (c), respectively. We adopt PatchMatch [11] method to compute the dissimilarity value between the testing image and the additional seam carved image. The dissimilarity value between (a) and (d) is 7.7625. It is quite different from that between (b) and (e), 21.1560, and also different from that between (c) and (f), 25.3526. Based on a large number of experiments, we observed that when k seams (k is less than the threshold) were removed from an original image, unimportant seams with the lowest accumulated energy were carved. So the original image was similar to its seam carved version. However, unimportant seams with the lowest accumulated energy have been carved in a seam carved image, and then important seams with the high accumulated energy will be carved when an additional seam carving operation was applied in the seam carved image. So the seam carved image is dissimilar to the additional seam carved version. Therefore, image similarity can be taken into account for detecting image seam carving operation.

(a) Original image (b) 20% seam carved image (c) 30% seam carved image

(d) image after removing 3% seams of (a), (e) image after removing 3% seams of (b), (f) image after removing 3% seams of (c)

Figure 1. Original Image and its Seam Carved Versions

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In terms of energy, only low energy seams of original image are removed, but high energy seams are removed for the seam carved image after applying an additional seam carving operation. Therefore, the energy relative error of removed seams energy to entire image energy can become another feature for detecting image seam carving operation.

Based on the ideas in the literature [4], we also observe that the optimal seam path across an image tends to be more dispersed after seam-carving. The optimal seam path of images which have not been seam-carved will be able to maintain its original path, or will find a minimal path nearby. When the image is seam-carved, the optimal seam path will be more likely to change as more part of the image is traversed. Corresponding minimal paths will tend to be further apart. Figures 2 demonstrates the seam path behavior. The difference of seam distance between the testing image and its seam carved version becomes the third feature in our paper.

(a) Seams of original image (b) seams of 20% seam carved image (c) seams of 30% seam carved image

(d) image after removing 3% seams of (a), (e) image after removing 3% seams of (b), (f) image after removing 3% seams of (c)

Figure 2. Optimal Seam Path through 10% (Magenta), 25% (Cyan), 50% (Green), 75% (Red), and 100% (Blue) of an Image

2.3. The Proposed Algorithm

Based on the characteristics of seam carved image mentioned above, we propose an efficient blind detection algorithm of seam carved image.

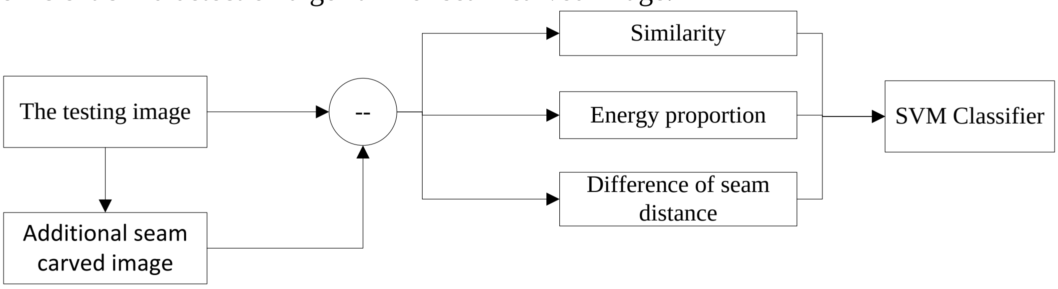

Figure 3. The Proposed Detection Method of Seam Carved Image

The proposed algorithm as illustrated in figure 3 performs under the following rules:

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Step one: Obtain additional seam carved image. For all images with size of M × N, seam carved images with size of (M-k) × (N-k) are generated by removing k seams of image using seam carving algorithm[1].

Step two: Convert both of the testing image and its additional seam carved image to the grayscale images.

Step three: Construct the first feature based on the dissimilarity between the testing image and its additional seam carved version.

In this paper, we choose the bidirectional Similarity measure to calculate similarity value between the testing image and its additional seam carved version. The bidirectional similarity measure method is proposed by Simakov for summarizing image or video [11]. Its essential idea is that a good visual summary should satisfy the following two properties. It should contain as much information as possible from the original image. It should introduce as few artifacts not in the original as possible.

For the testing image S and its additional seam carved image T, the distance measure is defined simply as the sum of the average distance of all patches in source image S to their most similar patches in target image T and vice versa:

$$d_{BDS}(S,T) = \overbrace{\frac{1}{N_S}\sum_{s\subset S}\min_{t\subset T} D(s,t)}^{d_{complete}(S,T)} + \overbrace{\frac{1}{N_T}\sum_{t\subset T}\min_{s\subset S} D(t,s)}^{d_{cohere}(S,T)} \tag{4}$$

where s and t denote patches in S and T, respectively, and NS and NT are the numbers of patches in S and T, respectively. For each patch s, we search for the nearest similar patch t, and measure their distance D (,). The term $d_{complete}(S,T)$ measures the deviation of T from "completeness" with regard to S, the term $d_{cohere}(S,T)$ measures the deviation of T from "coherence" with regard to S.

Step four: Construct the second feature based on the energy relative error between the testing image and its additional seam carved version.

For one image, energy mean and energy difference are defined as:

$$\text{Energy}_{\text{mean}} = \frac{1}{m*n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\frac{\partial}{\partial x}I(i,j)\right| + \left|\frac{\partial}{\partial y}I(i,j)\right|\right) \tag{5}$$

$$\text{Energy}_{\text{difference}} = \frac{1}{m*n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left\|\frac{\partial}{\partial x}I(i,j)\right| - \left|\frac{\partial}{\partial y}I(i,j)\right\|\right) \tag{6}$$

where I is an n×m image. In this paper, we define energy relative error as:

$$\text{Relative Error}_{energy} = \frac{E_{testing} - E_{carved}}{E_{testing}} \tag{7}$$

where $E_{testing}$ is the energy mean or energy difference of the test images, and E_{carved} is the energy mean or energy difference of its additional seam carved images.

Step five: Construct the third feature based on the difference of seam distance between the testing image and its additional seam carved version.

First, seam distance used in [4] is also introduced in our paper. For the horizontal seam, we define the seam distance as:

$$D_p = \sum_{j=1}^{N_p} \frac{\left| y_p(j) - y_{tot}(j) \right|}{N_p} \tag{8}$$

where D_p is the distance between the optimal seam through p percent of the image and p percent of the optimal seam through the entire image, N_p is the number of pixels through p percent of the image, and y_p is the vertical coordinate of the optimal seam through p percent of the image, and y_{tot} is the vertical coordinate of p percent of the optimal seam through the entire image. Vertical seam distance is calculated in a similar fashion.

Second, we calculate the difference of seam distance between the testing image and its additional seam carved version as:

$$\mathrm{Diff}_{\mathrm{seamdistance}} = Dp_{testing} - Dp_{carved} \tag{9}$$

where $Dp_{testing}$ is the seam distance of the test images and Dp_{carved} is the seam distance of additional seam carved images.

Step six: Three feature sets are fed into a support vector machine (SVM) for classification. Those features consist of 2 dimensional energy relative error of energy mean and energy difference, 1 dimensional similarity, and 8 dimensional difference of seam distance between the optimal seam through p percent of the image and p percent of the optimal seam through the entire image at vertical and horizontal direction, in which p is 10%, 25%, 50%, and 75%. We employ a LSSVM with RBF kernel as the classifier. We use the "grid-search" method to find the optimal parameters σ and γ of RBF kernel.

3. Results and Discussion

To evaluate the effectiveness of our proposed seam carving detector and to compare its performance with existing seam carving detection techniques, the popular image dataset UCID [12] is introduced for test. This formed a benchmark because it was also used in previous works [3-5, 7]. The UCID dataset consists of 1338 uncompressed TIFF images on a variety of topics including natural scenes and man-made objects, both indoors and outdoors. All images are color images with 384×512 pixels in size. The images were reduced by seam carving from 10% to 50% in steps of 10% using seam carving algorithm[1]. Also, the images were enlarged by seam insertion from 10% to 50% in steps of 10%. Eight hundred images were randomly selected in every dataset in our experiments. We partitioned our image sets randomly into two halves, one of which was used for SVM training and the other for testing. During the additional seam carving, the images were reduced by seam carving 3%, 5%, 10%, 15% and 20% of original image.

We conducted a series of experiments. First we evaluated the performance of similarity feature both on image seam reduction and enlargement. Then the performance of three features was evaluated. Last, we made comparisons with previous works.

3.1. The Performance of Similarity Feature

Table 1 and Table 2 show the detection results with similarity feature about seam reduction, and seam enlargement, respectively. From the Table 1 and Table 2, we can find that detection results of applying additional seam carving by 3% are better than that of 5%, 10%, 15%, and 20%. The accuracies of seam carving by 3% are 67.963%, 76.25%, 86.115%, 93.295%, and 96.227% for 10%, 20%, 30%, 40%, and 50% of reduced images, respectively. For enlarged images, the accuracies of seam

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carving by 3% are 56.7%, 63.75%, 65.65%,68.75%, and 73.25% for 10%, 20%, 30%,40%, and 50%, respectively.

Table 1. Detection Results with Similarity Feature about Seam Reduction

Reduction / Additional carved	Classification accuracy for seam reduction of				
	10%	20%	30%	40%	50%
3%	67.963%	76.25%	86.115%	93.295%	96.227%
5%	59.9%	73.02%	83.53%	90.57%	96.28%
10%	58.3%	70.85%	81.45%	87.82%	93.05%
15%	58.8%	68.2%	80.40%	86.58%	92.75%
20%	55.57%	70.05%	78.82%	85.62%	91.75%

Table 2. Detection Results with Similarity Feature about Seam Enlargement

enlargement / Additional carved	Classification accuracy for seam enlargement of				
	10%	20%	30%	40%	50%
3%	56.7%	63.75%	65.65%	68.75%	73.25%
5%	55.65%	60.2%	64.85%	68.98%	73.4%
10%	55.36%	59.95%	64.33%	68.05%	71.52%
15%	53.3%	58.1%	64.1%	67.98%	72.79%
20%	53.92%	58.45%	64.35%	69.25%	72.63%

3.2. The Performance of Mixed Features

The detection results of applying additional seam carving by 3% with all features about seam reduction and seam enlargement are shown in Table 3 and Table 4, respectively. It is observed that similarity is the most effective feature for seam reduction, and energy relative error is the most effective feature for seam enlargement, and significant improvement of seam carving detection can be achieved when three features are combined. Detection accuracies with all features reach 69.54%, 84.44%, 93.81%, 97.83%, and 98.85% for 10%, 20%, 30%, 40%, and 50% of reduced images, respectively. For enlarged images, detection accuracies with all features are 73.75%, 87.4%, 92.83%, 97.32%, and 98.63% for 10%, 20%, 30%,40%, and 50%, respectively.

Table 3. Detection Results with all Features about Seam Reduction

Features / Reduction		Similarity (1D)	Energy relative error (2D)	Difference of seam distance (8D)	Mixed features (11D)
10%	Acc	65.66%	61.81%	60.69%	69.54%
	FNR	42.02%	34.3%	35.65%	25.52%
	FPR	26.65%	42.07%	42.98%	35.43%
20%	Acc	76.59%	62.38%	65.69%	84.44%
	FNR	28.43%	25.65%	33.35%	9.38%
	FPR	18.4%	49.6%	35.28%	23.75%
30%	Acc	86.02%	66.7%	72.4%	93.81%
	FNR	13.13%	22.98%	28.68%	4.37%

Features / Reduction		Similarity (1D)	Energy relative error (2D)	Difference of seam distance (8D)	Mixed features (11D)
	FPR	14.82%	43.62%	26.52%	8%
40%	Acc	93.26%	71.94%	75.46%	97.83%
	FNR	5.2%	12.78%	27.07%	0.15%
	FPR	8.28%	43.35%	22%	4.2%
50%	Acc	96.14%	75.8%	79.5%	98.85%
	FNR	3.02%	9.45%	25.7%	0%
	FPR	4.7%	38.95%	15.3%	2.3%

Table 4. Detection results with all Features about Seam Enlargement

Features / Enlargement		Similarity (1D)	Energy relative error (2D)	Difference of seam distance (8D)	Mixed features (11D)
10%	Acc	56.43%	62.1%	52.1%	73.75%
	FNR	43.8%	50.15%	52%	28.7%
	FPR	43.35%	25.65%	43.8%	23.8%
20%	Acc	64.15%	71.55%	50.68%	87.4%
	FNR	38.8%	39%	33.9%	18.1%
	FPR	32.9%	17.9%	64.75%	7.1%
30%	Acc	66.2%	81.1%	53.9%	92.83%
	FNR	41.2%	28%	31.9%	10.1%
	FPR	26.4%	9.65%	60.3%	4.25%
40%	Acc	68.5%	85.9%	56.3%	97.32%
	FNR	34.15%	21.8%	26.75%	5.35%
	FPR	28.85%	6.4%	60.65%	0%
50%	Acc	73.2%	89.5%	59.4%	98.63%
	FNR	32.7%	13.8%	27.65%	1.8%
	FPR	20.9%	7.2%	53.55%	0.95%

Besides that evaluating classification performance between original images and seam carving by 10%, 20%, 30%, 40%, and 50%, we also evaluate the performance between 10%, 20%, 30% and 50% seam carved image. Table 5 and table 6 show the detection results of applying additional seam carving by 3% with all features about seam reduction, and seam enlargement, respectively. It is observed that our proposed method is still effective.

Table 5. Detection results with all features between seam reductions of 10%, 20%, 30% and 50%

Reduction / Reduction	10%	20%	30%	50%
10%	——	74.625%	86.49%	98.275%
20%	74.625%	——	66.928%	94.4%

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Reduction \ Reduction	10%	20%	30%	50%
30%	86.49%	66.928%	——	89.363%
50%	98.275%	94.4%	89.363%	——

Table 6. Detection Results with all Features between Seam Enlargements of 10%, 20%, 30% and 50%

Enlargement \ Enlargement	10%	20%	30%	50%
10%	——	73.125%	86.25%	96.6%
20%	73.125%	——	71.93%	91.65%
30%	86.25%	71.93%	——	86.4%
50%	96.6%	91.65%	86.4%	——

3.3. Comparisons with Previous Works

We also compared the proposed method to other existing methods using the same image dataset UCID. The results are shown in Table 7, where some results are refereed from [3-5, 7]. Our results are based on applying additional seam carving by 3%. The results demonstrate that our proposed method combining with similarity, energy relative error and difference of seam distance features outperforms the other methods although our proposed method has lower feature dimensions. However, our proposed method achieves accuracy of 69.54% for 10% seam carved images, which is lower than 73.25% of [4] and 71.52% of [5], and accuracy of 84.44% for 20% seam carved images, which is lower than 92.2% of patch analysis method [7]. The reason is that it is difficult to detect between original images and 10% seam carved images in our method because the dissimilarity between original images and 10% seam carved images is small, and the difference of energy change little in case of removing few lowest energy seams.

Table 7. Performance Comparing with Other Existing Methods about Seam Carving

	Sarkar et al.2009[3]	Fillion and Sharma 2010[4]	Seung-Jin Ryu 2013[5]	Jyh-Da Wei et al.2014[7]	Our proposed method
Dimensions	324	72	14	252	11
Reduction(10%)	65.75%	73.25%	71.52%	64.87%	69.54%
Reduction(20%)	70.36%	84.03%	80.42%	92.2%	84.44%
Reduction(30%)	77.31%	91.31%	85.96%	92.6%	93.81%
Reduction(40%)	——	——	90.51%	——	97.83%
Reduction(50%)	86.72%	——	93.50%	95.8%	98.85%

4. Conclusions

In this paper, we focus on the discussion of detection of content-aware image resizing by seam carving and seam insertion. We proposed a new detection method of seam carved image using a set of features including the similarity, the difference of seam distance and energy relative error between the testing image and its additional seam carved version. The accuracies of applying additional seam carving by 3% in our proposed method are 69.54%, 93.81% and 98.85% for 10%, 30% and 50% seam carved images, respectively. Our proposed forensic method achieves not only better detection rate but also lower dimensional features compared with other existing seam carved detection methods. In the future, we will further research on the detection of removal object by seam carving, especially the location of the removal traces.

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