IMPROVED SEAM CARVING FOR IMAGE RESIZING

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ABSTRACT

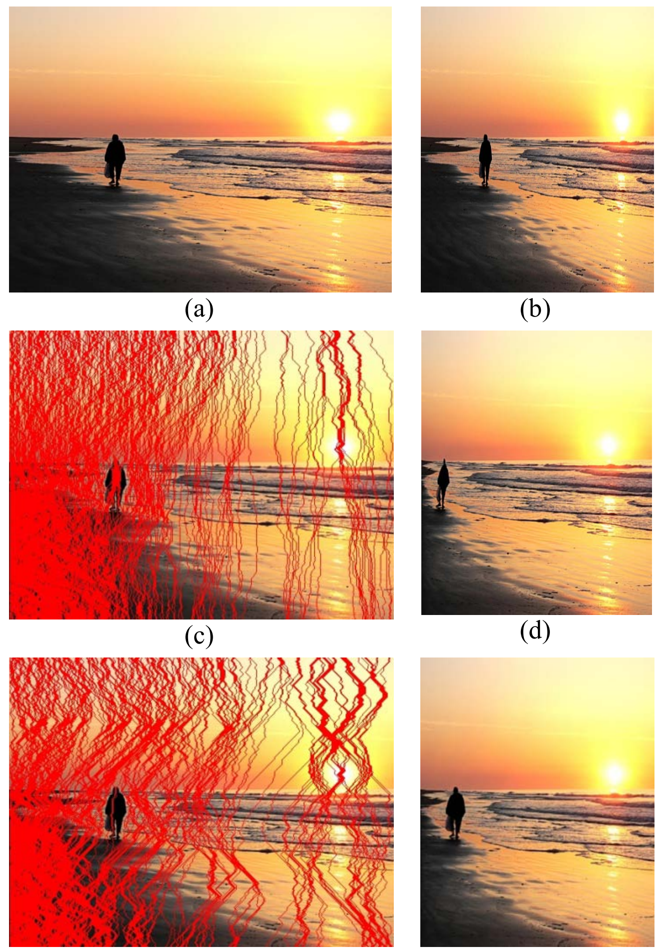
As displays become cheaper and are incorporated into more and more devices, there has been an increased focus on image resizing techniques to fill an image to an arbitrary screen size. Traditional methods such as *cropping* or *resampling* can introduce undesirable losses in information or distortion in perception. Recently, content-aware image retargeting methods have been proposed ([1][2][4][6][7]) which produce exceptional results. In particular, *seam carving,* proposed by Avidan and Shamir, has gained attention as an effective solution. However, there are many cases where it can fail. In this paper we propose an improved seam carving algorithm which incorporates anti-aliasing and thresholding techniques. Experiments have demonstrated superior performance over the current seam carving methods.

Index Terms— image resizing, seam carving, image retargeting

1. INTRODUCTION

With the rise of mobile media devices (cell phones, smart phones, PDA's, etc.), content-aware image resizing, or image retargeting, is fast becoming an important research area. More than ever there is a need to resize images and videos to fit various device displays with different aspect ratios in a way that maximizes information and minimizes distortion. Traditional methods including resampling and cropping had been the only option up until a few years ago.

In their seminal work of 2007, Avidan and Shamir proposed a rather elegant solution called seam carving, which operates in a discrete fashion, reducing (or enlarging) an image's dimension by one row or column at each step [1][2]. Later solutions by Wolf et al. [7], Simakov et al. [6] and Guo et al. [4] produce good results by employing global optimization techniques but are generally more computationally expensive. Furthermore, global solutions are not well-suited for multi-scale media applications – those that allow an image or video to be retargeted to any size on the fly [1] – because they would require reprocessing for each change in size. Seam carving, on the other hand,



(a) (b) (c) (d) (e) (f)

Figure 1: (a) Original image and a 40% width reduction using (b) resampling, (d) forward-energy seam carving and (f) our algorithm with $\alpha = 3$. Seams highlighted in red in (c) and (e) correspond to locations of removed pixels in (d) and (f), respectively.

only requires a single preprocessing stage to prepare images or video such that real-time retargeting is possible [1].

While seam carving remains an important tool for image retargeting, it has its limitations (cf. Figure 1). High-level features such as face detection were suggested in [5] as a way to improve the seam carving algorithm, but little work has been done to improve the use of low-level features. Moreover, the detection of such high-level features may fail in practice and thus cause the entire scheme to fail. Still, high-level features can be augmented with any seam carving algorithm and ours is no exception. In this paper we propose a new seam carving algorithm which improves edge preservation and decreases artifacts.

Section 2 gives an overview of the seam carving algorithm and discusses its limitations. Section 3 presents our algorithm and section 4 provides simulation results. Section 5 gives concluding remarks.

2. BACKGROUND

Seam carving works by finding the lowest-energy connected path of pixels from either left to right (*horizontal seam*) or top to bottom (*vertical seam*), removing those pixels, and repeating the process until the desired image size is achieved. In order to maintain the rectangular structure of an image, it is also required that each path of pixels include exactly one pixel per column for horizontal seams, or one pixel per row for vertical seams. In a similar manner, pixels can be added along these seams to increase the image size. While image enlargement and reduction are both important, seam carving applies very similar objectives for both [1] and so for the sake of brevity we focus on image reduction.

Section 2.1 gives an overview of the primary criteria used to find seams. Section 2.2 discusses the major problems facing seam carving.

2.1 Seam Criteria

There are two primary criteria for describing the energy of a seam: backward-energy and forward-energy. The backward-energy criterion uses an energy map defined in [1] as

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

which is the L1-norm of the image gradient. This generally works well because important objects usually have a well-defined edge and, consequently, a high gradient value along that edge. Using this map, dynamic programming is employed to find the minimum-energy path. A vertical path of pixels of an $m \times n$ image is defined as the set of locations

$$\boldsymbol{s} = \{s_i = (i, x_i)\}_{1 \le i \le m} \qquad (2)$$

where x_i is determined during the dynamic programming stage as defined in [1].

The forward-energy criterion as described in [2] does not directly use an energy map. Instead, it finds the seam that minimizes the absolute differences between the pixels brought together upon the removal of the seam. Yet we can still measure the energy of individual seam pixels using the cost map M as defined in [2]. Since each point of this map corresponds to the minimum cumulative energy of a seam ending at that point, we can define the individual energy of each point along a seam as

$$e(I; s_i) = M(s_i) - M(s_{i-1}) \qquad (3)$$

where s_i is the location of the i-th pixel in the seam $\boldsymbol{s}$.

Indeed, other seam criteria can be used; however, these are the premiere methods, having been introduced with the invention of seam carving itself. For our purposes, it does not entirely matter which criterion is used provided it meets the aforementioned seam requirements – a path of pixels with one pixel per row or column.

2.2 Limitations

Here we explicate two major limitations of the seam carving algorithm.

2.2.1 Aliasing

Removing pixels from an image can be thought of as a localized downsampling which leads to the problem of aliasing. When spatially-disjoint and dissimilar pixels are brought together through seam carving, new edges can result (cf. Figure 2). While the forward-energy criterion tries to minimize this phenomenon, it does so globally and therefore cannot always be avoided. The seam carving algorithm says that when you find the minimum-energy seam, you just throw it out. In smooth areas this is usually unnoticeable, but in other areas this can result in jagged edges. One way to deal with aliasing is to apply a low-pass filter, which we will discuss more in Section 3.1.

2.2.2 High-Energy Pixels

Another problem with seam carving arises from the use of

Figure 2: Original image (left) and a 30% width reduction using backward-energy seam carving (middle). The red boxed areas are enlarged to show detail (right).

cumulative energy without regard to the energy of individual pixels. The cumulative energy or cost of a seam is defined as

$$E(\boldsymbol{s}) = \sum_i e(I; s_i)\ . \tag{4}$$

Minimizing this cost using either the backward- or forward-energy criterion puts no requirement on the individual pixel energies, namely, $e(I; s_i)$, which could be very large.

Figure 1 presents a case that clearly illustrates this problem. Under the original seam carving algorithm, seams sometimes pass through important objects set against a high-energy background – even if the object has a strong edge – because the cumulative energy would be higher through the background.

3. OUR ALGORITHM

Considering the problems discussed above, we propose two modifications to the seam carving algorithm to be described in the following subsections. For the sake of brevity, we only detail the removal of vertical seams; the removal of horizontal seams is done in a similar manner.

3.1 Anti-aliasing

Typically, seam carving will find paths through smooth areas. Removing seams from these areas is mostly unnoticeable because the pixels adjacent to the seam will have similar values and appear to be continuous. However, sometimes a seam may be forced through a region with a higher image gradient. In this case, removing the seam will be more noticeable because the adjacent pixels will have less-similar values.

As mentioned above, aliasing is one way to describe this effect since we are removing a sample from a part of the image with high frequency; the result is undersampling. Anti-aliasing tries to avoid this problem by applying a low-pass filter before downsampling. This is usually done when linearly downsampling an entire image, but seam carving only removes samples from a single path across the image at each step. Therefore, being only concerned with aliasing along the seam, we have implemented a simple 2-point average as shown in Figure 3. Other low-pass filters could also be used to similar benefit, but we found that a simple average worked well.

3.2 Thresholding

To preserve important object edges and reduce artifacts, it may seem enough to simply threshold the individual pixel energies as defined by (1) or (3), depending on which criterion is used. However, we found that this approach did not always work well. Therefore, we sought a secondary energy map to address the main cause of artifacts.

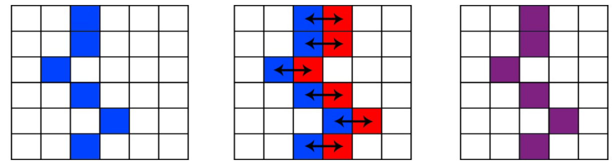
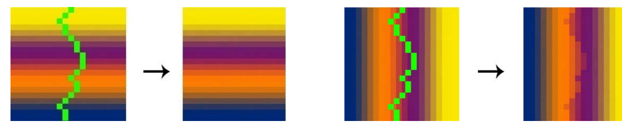


Figure 3: An optimal seam (blue, left) and its adjacent seam (red, middle) are both replaced by their average (purple, right).



(a) (b)

Figure 4: Effect of removing a vertical seam (shown in green) from an image with (a) low horizontal energy and (b) high horizontal energy.

When removing vertical seams – those that run from top to bottom – the differences in pixels along the horizontal direction appear to cause the most distortion (cf. Figure 4). Since the magnitude of the gradient includes both horizontal and vertical directions, it still might seem like a good candidate, but it turns out that the extra information can result in too many false positives.

We consider again the silhouette image from Figure 1 and look at the L1-norm of the image gradient (Figure 5 (a)). We would like to preserve the person's silhouette, but because of the high-frequency in the waves, the magnitude of the gradient is insufficient. Based on our observations, and as demonstrated in Figure 4, we look at the absolute pixel differences in the horizontal direction (Figure 5 (c)). As desired, the result shows large differences around the silhouette because of the abrupt change at the edge of the person in the horizontal direction, and small differences elsewhere. In particular, the waves generally have higher differences in the vertical direction, but not in the horizontal direction.

Essentially, looking at absolute pixel differences is an estimate of the partial derivative based on a 1-pixel interval. In the horizontal direction we have

$$\left|\frac{\partial I(x,y)}{\partial x}\right| = \left|\lim_{\Delta x \to 0} \frac{I(x+\Delta x, y) - I(x,y)}{\Delta x}\right| \tag{5a}$$

$$\left|\frac{\partial I(x,y)}{\partial x}\right| \cong \left|\frac{I(x+1, y) - I(x,y)}{1}\right| \tag{5b}$$

and define the secondary energy map for vertical seam thresholding as

$$e_{T,v}(I; x, y) = |I(x+1, y) - I(x,y)|\ . \tag{6}$$

The secondary energy map for horizontal seam thresholding is defined similarly. While there are indeed other ways to

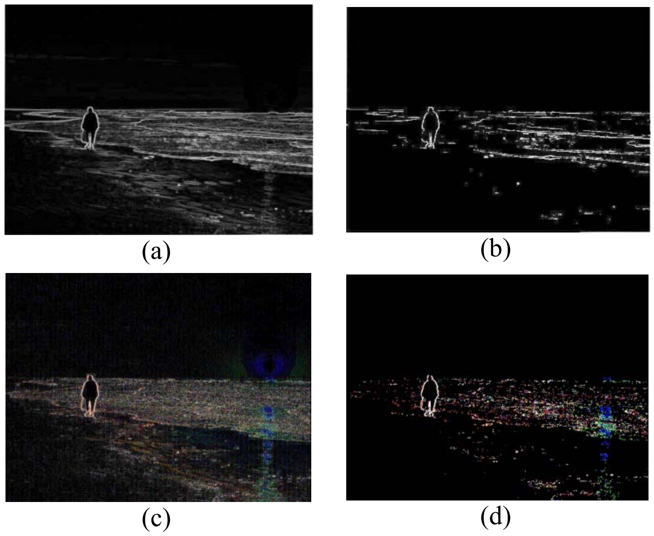


Figure 5: (a) Sobel-based L1-norm of the image gradient and (b) after thresholding. (c) Absolute pixel differences in horizontal direction and (d) after thresholding.

estimate the derivative of an image, we found that using (6) works well in identifying critical edges.

Having devised a secondary energy map, the typical thing might be to linearly combine it with either the backward- or forward-energy map to form one single energy map. However, the goal is to *prohibit* seams from passing through certain points, not merely *deter* the seams. In light of this, we propose thresholding the secondary map defined in (6) to flag restricted points in the image. Applying this to the silhouette image, we clearly see the outline of the person as being restricted ((Figure 5 (d)), which is exactly as desired. Thresholding the Sobel-based L1-norm of the gradient produces too many restricted points while missing some of the silhouette ((Figure 5 (b)).

Therefore, as each seam is discovered using some seam criterion, we check the secondary energy map along the seam. If at any point the threshold is crossed, we do not remove the seam, and flag that spot as irremovable so that future seams will avoid it as well. Although this flagging could be done globally at each step, we only flag points along the selected seam to facilitate the stopping criterion (see Section 3.3). Formally, this flagging can be accomplished using a binary map T that is updated after each discovered seam by

$$T(s_i) = \begin{cases} 0 & e_T(I; s_i) \leq \eta \\ 1 & e_T(I; s_i) > \eta \end{cases} \tag{7}$$

where η is a thresholding constant. If the threshold is not crossed, we remove the seam as described in Section 3.1. Note that the path removed from the image is also removed from the flag map T in order to keep them in sync. This process repeats until the target size is reached.

The threshold value can be chosen manually as desired to guide edge preservation. However, a simple thresholding technique based on a common image denoising technique described in [3] was found to work quite well. We define our threshold as

$$\eta = \alpha\sigma \tag{8}$$

where σ is the standard deviation of the secondary energy map e_T and α is some constant. We found that α values near 2 typically worked well, however, the threshold can be set looser or tighter by increasing or decreasing this number, respectively. In some cases, making the threshold too restrictive can force the algorithm to end before reaching the target size if there are too many restricted points.

4. EXPERIMENTS

Figure 6 shows a comparison of our algorithm with the backward- and forward-energy seam carving methods described in Section 2.1. The original image sizes are given below each image and for each case we removed 200 vertical seams. For our algorithm we used the backward-energy criterion for seam selection – using the forward-energy criterion in our algorithm did not result in any noticeable gain while costing more compute time. The thresholding factors are given under their respective images in column (d).

Despite the fact that the backward-energy seam carving results were generally much worse, our algorithm performed better or at least as well as the forward-energy seam carving method. In particular, notice the top image in Figure 6 – our algorithm was able to preserve the slope of the mountain. Looking at the middle image, we were able to preserve the stem of the flower. The bottom image show comparable results between our algorithm and the forward-energy seam carving method.

5. CONCLUSIONS

Seam carving is an important image retargeting tool that can be used to fit images to various display devices with different aspect ratios through non-linear downsampling. It stands to be very useful for multi-size media application where many different sizes of the same image or video are required without the need for reprocessing the image for each size request. Yet, the algorithm is not completely robust and can be susceptible to undesirable distortion.

We have proposed a new algorithm which incorporates anti-aliasing and thresholding. Overall, the results were very positive, being comparable or better than previous seam carving implementations. While we have only discussed using the backward- and forward-energy seam criteria for seam selection, our algorithm allows implementing any optimal seam-finding method as well as augmenting higher-level feature detectors.

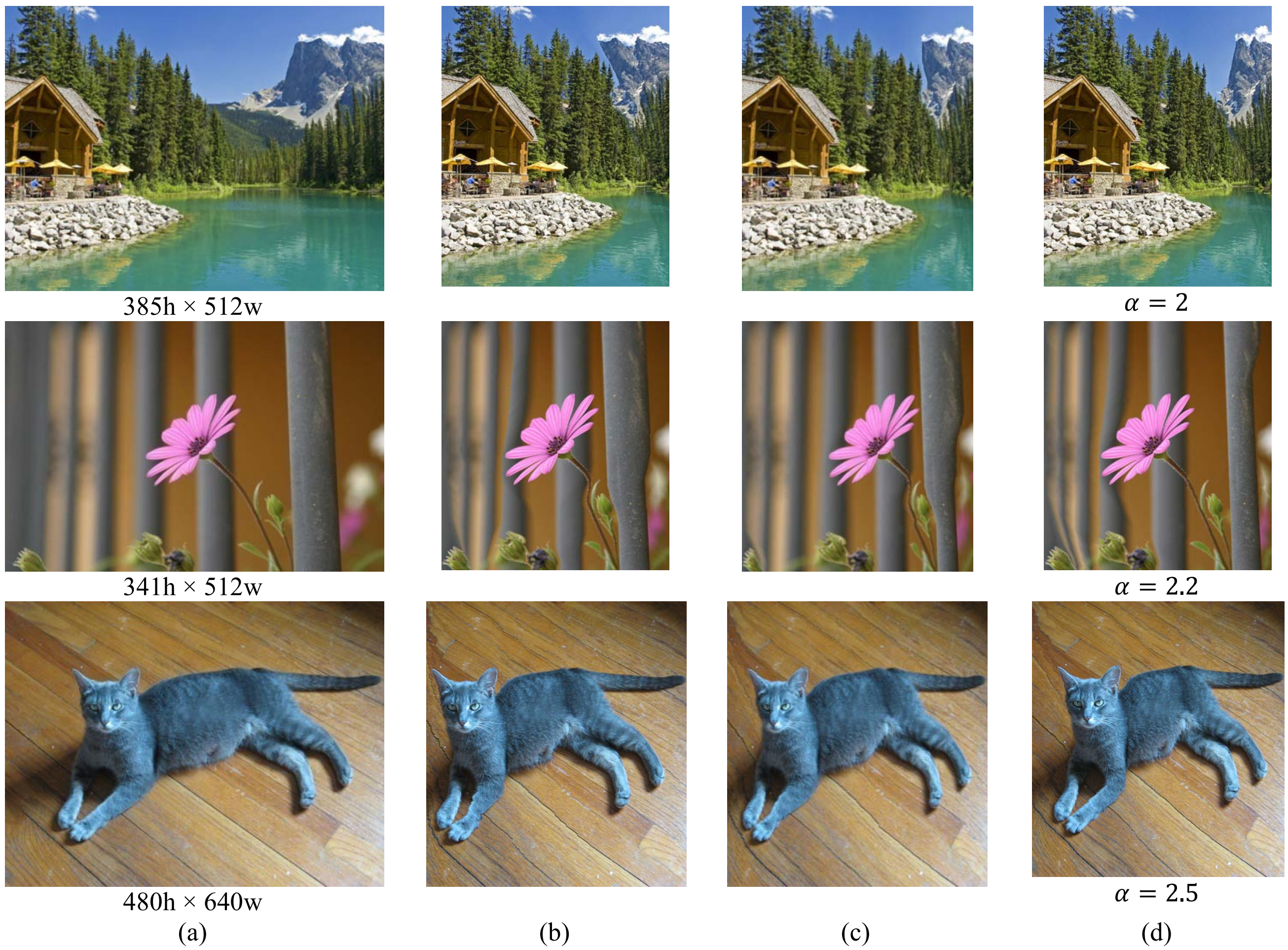


Figure 6: (a) Original image and the result of removing 200 seams using (b) backward-energy seam carving, (c) forward-energy seam carving and (d) our algorithm.

In future work, we plan to look into devising more automatics ways of determining the threshold factor. We believe that this will, in turn, lead to development of a *stopping criteria* which could decide when further seam carving would add too much distortion and switch to resampling or cropping.

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