Content-Aware Image Resizing by Seam Carving Method and Highlight Content

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***Abstract* - Content-aware image resizing technology has been in either the scientific field or contributing and showing its value to the world for a long time. We want to introduce seam carving and highlight the main content by image enhancement technique. There have already been many algorithms in the computer science field to extract the importance of the image already. Content-aware image resizing approaches are mainly categorized into four groups: content-aware cropping, warping-based, segmentation-based, and seam carving methods. In this paper, we will introduce an efficient method based on seam carving then highlight the main content of the image. Because most of the algorithms do not do quality increment after resizing. However, this technique aims to show the details and main content to the image readers directly. And it can help people to understand the content of the image, and what the image wants to show us quickly. This technique fills up the blanks of the previous algorithms**

Keywords: Content-aware image resizing, seam carving, content highlighting

I. INTRODUCTION

Nowadays, image is an essential part of people's daily life. Against the scientific technology advances by leaps and bounds, image processing technology has advances with each passing day. Image resizing can be found everywhere, for example, when you want to post something interesting, the moment you love, then you want to share it with everyone in your friend list on social media, such as Instagram, Whatsapp, Snapchat, etc. However, the size of the picture is not the one you wish, the applications do not allow you to post them, this must be a sad thing to you, then you need to adjust and cut the image. Meanwhile, you do not want to reduce the resolution, and keep the original proportion. You may use the built-in tools to adjust the size of images, most of the time, the results do not meet the expectation as you wish. There are two ways for you to do this, the first one is to give up, then just post the imperfect pictures to the platform. The second one is to find a better tool to help you to meet your expectations. Without doubt, most people may choose the second one. It may be hard for you to adjust with your hands. The approach first comes to your mind, probably, cropping the image, cutting off the parts that do not affect what you want to show. Another way, potentially, you want to make the image as fixed size, which means enlarge or shrink the image with the same ratio of width and height, this is the geometrical way to resize. Indeed, these are the most common approaches, maybe they can accomplish the work.

Image resizing is a very frequently used tool, not only it can be used in daily life but also it can be used in professional works. For example, some companies want to use real- time scaling, in CCTV area, a criminal is on the run, a CCTV captured him by face recognition, but the original image is too small, and lose many details, police want to zoom in the captured image, it will help them to get the details of the criminal, then they can use this technique to accomplish the goal.

There are still so many uses among other applications, web browsers, image viewers, digital zoom, and output the image through screens or printers, etc. The requirement has been established, then tools or applications need to be developed as soon as possible. For technological developers we need to set users' requirements as the top priority.

Therefore, publishing a more efficient way to crop and resize images is critical. Content- aware image resizing approaches show us the possibility to solve the problem. This technology aims to determine what information is in a specific file, folder, or any other types of data, no matter what the situation of the information is. For content- aware technology in the image resizing field, it is to extract the importance of an image, then resize the image by automatically cropping and filling without losing the importance, which we extracted before. There are four categories of the content-aware image resizing algorithm. Cropping method, warping-based method, segmentation-based method, and seam-based method. We are going to introduce one of them, the seam-based method. It is a simple and strong algorithm, it can handle most of the situations.

The main idea of Seam Carving is to find the seam that does not have too much contribution of content. In other words, any changes here (seam) that cannot lead to any big difference with the original picture. But how to determine it has less effects on input image, it is the main problem we will discuss in this paper. After this, to prevent changing the importance of the picture, we can find continuous pixels, then remove the pixels, which have small differences by using gray level and energy map. We will discuss details later on. The concept of Seam Carving algorithm is mainly based on [1]. To implement the algorithm, we will use JavaScript and Matlab. There are four steps required to implement the Seam Carving algorithm as follows:

1. Calculate the energy map of the current version of the image.
2. Find the seam with the lowest energy according to the energy map.
3. Remove the seam with the lowest energy seam from the image.
4. Repeat until the image width is reduced to the desired value.

After re-perceiving the image content and resizing, we will implement image enhancement technology through Matlab. Image enhancement is achieved by using Laplacian filter; Sobel filter; Image Smoothing filter in spatial domain, and Histogram Equalization; Lowpass and Highpass filters; Image Sharpening in frequency domain. Due to resizing can lead to details lost, we will enhance the content or the main structure of the image. These operations can help image viewers easily understand what the images want to express.

II. RELATED RESEARCH WORK

In this section, we will review the related research work for the image resizing and the image quality improvement. Since the major goal of this paper, as mentioned in the abstract, will mainly focus on highlighting the important content of the image-by-image enhancement technique, we will have a detailed explanation on the algorithms of image enhancement.

There have been many approaches put forward, based on different purposes and concepts, different algorithms showing their features and efficiency in different situations. In Dr. Xu, and Dr. Kang's paper [3], they used quasi-conformal mapping to resize the images. They found most of the previous methods lack theoretical assurance of a rigorous bijective map between the input image and output image. The approach they proposed, mapping between these two images such that saliency features of the image are uniformly scaled, greatly reduce the possibility of distortion.

From the Shai Avidan' paper [1], we will use his strategy to implement the Seam Carving. Hashemzadeh, M''s paper [2] also discusses the optimization of shadows in Seam Carving, and we will use his algorithm to help us resize our images. After resizing the images, it is possible to make the image distorted. According to Xu, J's paper [3], we can try to change the size of the image and restore the original appearance of the image.

The main content of an image is selected by the Seam Carving algorithm which is an image processing operator. To determine the important pixel, the basic operator is:

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

where I reference the image with size $n \times m$. The vertical seam is defined as Eq. (2):

$$s^x = \{s_i^x\}^n_{i=1} = \{(x(i), i)\}^n_{i=1}\text{, s.t.} \quad (2)$$
$$\forall i, |\, x(i) - x(i-1)\, | \le 1$$

where x is a mapping x: $[1,...,n] \rightarrow [1,...,m]$. The horizontal seam is defined similarly:

$$s^y = \{s_j^y\}^m_{j=1} = \{(y(j), j)\}^m_{j=1}\text{, s.t.} \quad (3)$$
$$\forall j, |\, y(j) - x(j-1)\, | \le 1$$

where y is a mapping y: $[1,...,n] \rightarrow [1,...,m]$. According to [1], the significant impact on the image will only present along the path of the seam. To find the least cost of the seam, we use an energy function e to define the cost of a seam as $E(s) = E(Is) = \sum^n_{i=1} e(I(s_i))$, and the optimized seam s^* is:

$$s^* = \min_s E(s) = \min_s \sum_{i=1}^{n} e(I(s_i))$$
(4)

The optimized seam can be found by the calculation:

$$M(i, j) = e(i, j) + \min(M(i-1, j-1), M(i-1, j), M(i-1, j+1))$$
(5)

For image enhancement, many effective algorithms have been introduced and accepted by many research reports. In this paper, we mainly focus on the frequency domain and spatial domain. For the spatial domain, we consider Laplacian filter; Sobel filter; Image Smoothing filter. Meanwhile, for the frequency domain, we use Histogram Equalization; Lowpass and Highpass filters; Image Sharpening. More techniques will apply depending on the circumstance of the image. Since we don't have enough knowledge to analyze the colorful images, we will focus on the gray-level operation in this paper.

III. PROPOSED METHOD

1. *Energy Stage*

a. Energy Functions on Original Paper

In the energy level, the energy describes the local change of a certain quality of the image, it can be a measurement of intensity or brightness. By Mr. Ebker's words [4], the place contains a lot of energy means there is a lot of information. Otherwise, the lower energy zone means there is less information. To examine how much it will affect the result of different methods, we use the average energy value of all the pixels in the picture, then randomly remove the pixels and compare the results before and after removing. The results of average energy value should be increased. Since the high energy value section keeps in the original image, but the low energy section will be removed, they are detected as unimportant. As in [4], during the whole process of image resizing, the important parts of the image should not change, or else, the operation will not successfully meet the requirement. In [1], they used L_1 and L_2-norm of the gradient, saliency measure, Harris-corners measure in 1988, eye gaze measurement in 2002.

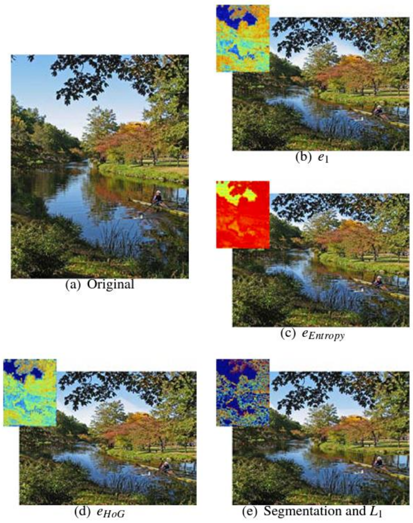

Fig. 1 Different energy functions for content aware resizing

The results of 4 functions mentioned above, e_1 error, $e_{entropy}$, $e_{segmentation}$, and e_{HoG}, e_{HoG} is defined as follows:

$$eHoG(I) = \frac{\left|\frac{\partial}{\partial x} I\right| + \left|\frac{\partial}{\partial y} I\right|}{max(HoG(I(x,y))}$$

Based on the result of [1], the results of different energy functions for content aware resizing are as shown in Fig. 1.

b. Energy functions of this paper

However, there are multiple ways to get energy maps. In this research, here are the details of it. Assuming, the color of a pixel uses 4 digits to illustrate the color, R- red, G-green, B-blue, A-alpha, all the intervals are from 0 to 255. Then lR means the left pixel's red channel, mR means the pixel at the middle's red channel, rR is the pixel at the right red channel, by parity of reasoning. Alpha channel is for the transparency channel. However, we ignore this channel temporarily, there is no transparent pixel of the image.

At the beginning of the algorithm, we have obtained the values as follows: the size of the image; pixel coordinates; seam's location and these values are a set of pixels' coordinates; energy map, a 2D array that has the same width and height as the image is calculated for. We have gotten the energy of each pixel, then we can calculate the energy map, because each iteration, the energy is changing, so we need to recalculate the energy map every time, and the value should stay the same. The higher energy of a pixel means it is more likely to be the edge of the picture, and it is more related to the main body of the picture. The possibility of removing it becomes lower.

2. *Discrete Image Resizing*

After we get the energy map, it is the time to find the seam of pictures. There are multiple ways to implement, basic approach, dynamic programming, and greedy approach. The first approach is to find each possible path. From top to bottom, for each pixel there are 3 directions, left-bottom, bottom, and right bottom. Therefore, the time complexity is

$$O(w \times 3^h) \text{ or } O(3^h),$$

w is the width of the image, h is the height of the image. However, based on the time complexity, using this algorithm to find a seam is quite slow. Secondly, there is a greedy way to find the seam, we can try the next pixel to be the lowest pixel, and the energy of the seam becomes lowest. This approach probably cannot get an optimal solution. However, there is a merit of it, the consumption of time is less, it is fast, because the time complexity is

$$O(w + h).$$

We need to iteratively search h times of each row for 3 adjacent pixels. The approach of this algorithm we used dynamic programming. From the two approaches mentioned above, we noticed that there are some repeated calculations of pixels' energy. So, we can store the energy we have calculated before to a seamsEnergies table. By this algorithm, the time complexity is

$$O(w \cdot h).$$

As for the time complexity comparison, dynamic programming is the fastest approach.

IV. RESULTS AND DISCUSSION

For the experiments we imported 10 images as the database, and we divided them into several groups. There are 6 groups of images in total, the groups are: one object; multiple objects; solid color images; two colors interlace; background and object differences are insignificant; and spectrum. We use the system developed by Javascript to run the experiment. In the original version, the utilities are good enough, it can detect and show the seam. The process can be stopped manually, when we stop the process, the seam of the current version of the image will show on the image, it is drawn with a red curved line. There are four types of current version's image: Original(color); energy; min sum; and minx. We mainly used color, energy, and minx to show how it works. For the original type, it shows what the image exactly is in human eyes. The energy type, it shows the energy map of the image, the energy of a pixel is its contrast of surrounding pixels, more white means higher contrast. These types of functions can help us to show how it works. However, during the process, we noticed the image size does not show on the canvas, so we do not know what the current size of the image is. Based on the original system, we added a new feature to help us distinguish the process of resizing, by the seam carving approach. In the following paragraphs, we will introduce and discuss the different results we got based on our custom grouping.

1. One Object

When there is only one object in the picture, the Seam Carving algorithm will remove the seam that contributes the least to the image content. This process can be repeated to both change the scale of the image (reduce the width while maintaining the height) and preserve the scale of the object at the same time.

Fig. 2(a) Single object

Fig. 2(b) Resized single object image

As shown in figure. 2, the proportion of the chameleon has not changed, and the seam carving algorithm deletes the "unimportant" part.

2. Multiple Objects

When a picture has two or more objects, the Seam Carving algorithm will detect these objects at the same time (the energy of these objects will be significantly higher than other backgrounds) and will retain the original proportions of these objects.

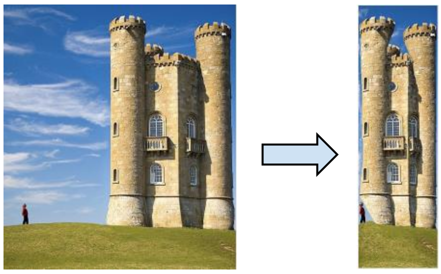

Fig. 3(a)(b)(c) Multiple Objects

When the Seam Carving algorithm cuts these two objects, it will calculate the pixel energy of these two objects. If there is an object with higher pixel energy, regardless of size, the Seam Carving algorithm will treat the object with lower energy as seams.

This algorithm leads to the distortion of Figure 3(c). This shows one of the shortcomings of the Seam Carving algorithm - It only considers the energy size of the object's pixels energy, not the proportion of the object in the picture, which leads it to retain the original proportion of the person who is not very relevant to the picture, while deleting the building, which accounts for most of the picture.

3. Solid Color

For solid color pictures, the seam-carving algorithm does not present a useful result since the energy function cannot detect objects within the pictures. The energy of each pixel within the picture is equally distributed, so there is no significant content that is more important or salient than other pixels. Therefore, the algorithm will continuously remove vertical seams (red vertical line in Fig. 4) from one side of the pictures until the entire picture has been removed.

Fig. 4 Solid color image with detected seam (red line)

4. Two Color Interlace

This example shows the energy function of the Seam Carving algorithm that detects the objects based on their identical features which are not affected by regular factors such as object size, object color, etc. The process of resizing this example using the Seam Carving technique presents equal elimination on each line. Although the algorithm has priority to choose which part to eliminate first for the resizing purpose, eventually, the image will have an equal distribution of each line. Therefore, the algorithm has successfully evaluated the energy level for different detection within the picture.

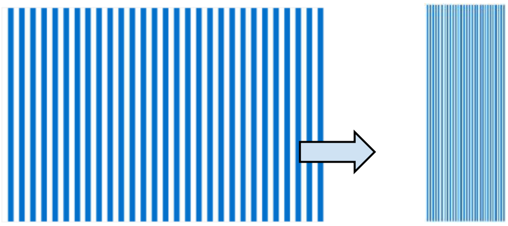

Fig. 5 Two color interlace original (Left) and processed (Right)

5. Background and Target Differences are non-significant (Noise)

The one we tested was a noisy image with pepper -salt noise in figure. 6(a). The original image and the initial state energy image as shown below:

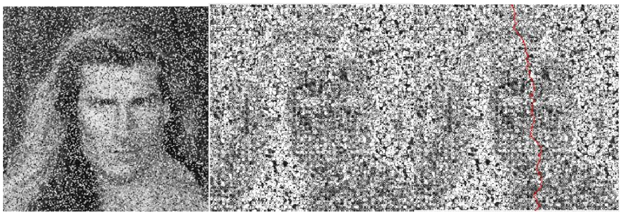

Fig. 6(a) Noisy image(b) energy image(c) seam image

As the pictures in figure. 6(b), we can see, the energy image contains more high contrast parts, which means the energy is extremely high. Then, when we add the seam in figure. 6(c), the line occurs at the middle of the man's face. However, along with the progress, the seam changes from left to right and periodically repeats. It is because the man’s face is squeezing, and the system can not distinguish which is the lower energy part of the image. The difference of each pixel’s energy level is small. Hence, the seam was chosen randomly.

6. Spectrum

In this experiment, we used a spectrum diagram to detect, which color is the highest energy at the beginning, and how the process will go.

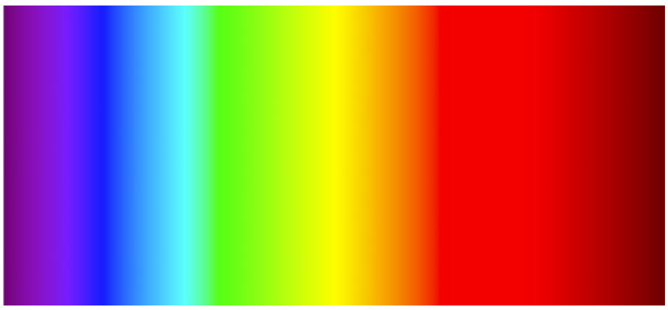

Fig.7 Spectrum

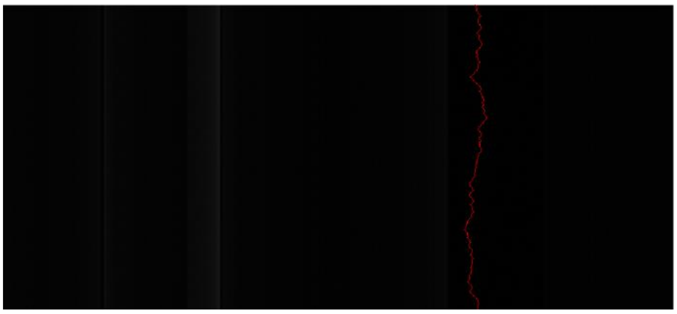

Fig. 8. Energy image and its seam of spectrum

In this experiment, the spectrum is the standard diagram that shows the magnitude of energy changing from left to right. In figure.8, the energy spectrum, there are 3 contrast lines. From left to right, matched with the zone of dark blue we noted as Seam 1, the next one at light green we noted it as Seam 2, finally, the rightmost one at red zone, we noted Seam 3. By the definition of the energy spectrum, the white space is the place which contains high energy, in other words, deep blue, light green and red are the high energy zones. RGB, red, green, and blue are the three primary colors. In RGB color values, R is (255, 0, 0), G is (0, 255, 0), and B is (0, 0, 255), these three values are at the highest level of the spectrum, which means their energy is highest at their channels. Therefore the contrast band shows in the Min Sum map among these zones. Then the seams will be chosen in any area other than these. Initially, we can see the seam was chosen at the red zone. To illustrate the comparison of energy maps clearer, we added a Min Sum map to show in Figure. 9.

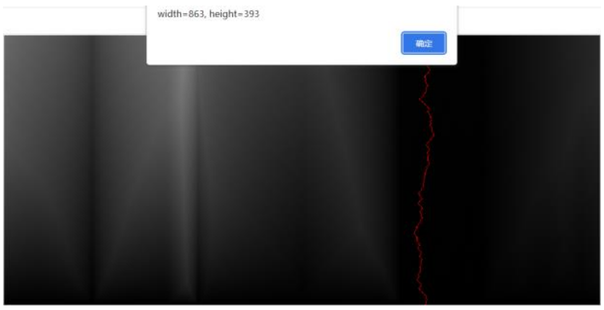

Fig. 9(a) Original size and seam

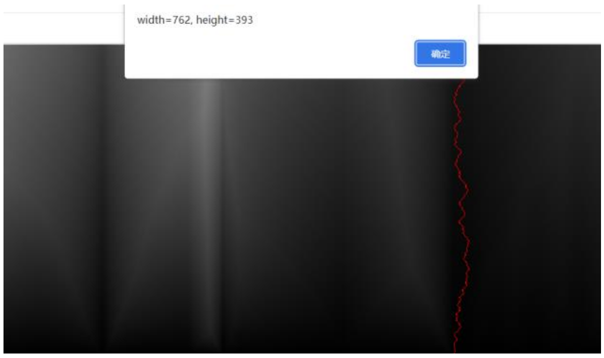

Fig. 9(b) Min Sum map and seam at mid process

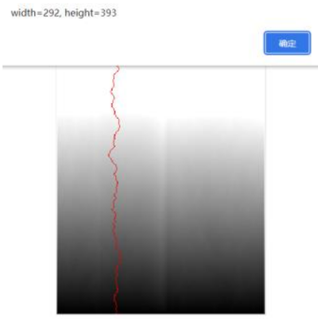

Fig. 9(c) Min Sum map and seam at late process

In figure. 9, we show the process of the change of seam in the spectrum. From the early to mid process, the seam stays in the right part, however, along with the process continuing, the low parts were removed from the image, and more and more white parts show up in the image. In figure. 9(c), at the stage of late process, high contrast of white parts becomes the main body of the Min Sum map. It is proved that the algorithm runs perfectly.

In Dr. Hashemzadeh's paper [2] of improved seam carving algorithm, focused on the shadow part of the image, their group believes the shadow part of the images probably contains important information, and it is helpful for picture viewers to understand the content easily and quickly. They use contrast cue, spatial cue, shadow map, gradient map and saliency map to resize images that possibly contain important contents in the shadow. The implementation of shadow preserved algorithm combined seam carving algorithm and shadow map together.

V. CONCLUSIONS

The proposed algorithm we presented in this paper is a very useful tool either in daily life or in professional fields. It resizes pictures while preserving the important content in pictures. The first step is to calculate the energy of each pixel, then based on each pixel's energy, we can calculate the map of energy levels of the whole picture. Pixels with a lower level of energy mean they are at a low level of importance in the current version. Higher energy means the importance of pixels is high in the current version of the image. After we get the energy map, we should find the lowest energy seam by dynamic programming. We use dynamic programming because of its high efficiency. The next step is to iteratively remove the seam by its descending order of energy level. Since this is a content-aware approach, it aims to find the objects and manipulate pixels around these objects. In part. 4 of this paper, it illustrates how this algorithm distinguishes objects and backgrounds, and proceeds to the object removal stage based on this distinction. From the experiments, this Seam Carving algorithm can be utilized in multiple situations.

There are some extensions of our current work and developments in future work. In this paper, due to time constraints and equipment limitation, we are only able to study resizing images that are static. Based on our exploration and studying, the algorithm can resize videos, which means we can resize pictures that are dynamic. As we have known, videos are made by several frames(images) and combined together. By technology leaps and bounds, 3D and higher dimensional work needs to be performed. A further study of resizing objects within a higher dimension can be investigated as long as the prerequisites of the Seam Carving have been satisfied. So, we can apply our work and discovery in higher dimensions.

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REFERENCES

[1] Shai Avidan and Ariel Shamir. 2007. Seam carving for content-aware image resizing. In ACM SIGGRAPH 2007 papers (SIGGRAPH '07). Association for Computing Machinery, New York, NY, USA, 10–es. https://doi.org/10.1145/1275808.1276390

[2] Hashemzadeh, M., Asheghi, B., & Farajzadeh, N. (2019). Content-aware image resizing: An improved and shadow-preserving seam carving method. Signal Processing, 155, 233–246. https://doi.org/10.1016/j.sigpro.2018.09.037

[3] Xu, J., Kang, H., & Chen, F. (2018). Content-aware image resizing using quasi-conformal mapping. The Visual Computer, 34(3), 431–442. https://doi.org/10.1007/s00371-017-1350-4

[4] R. Ebker, "What is 'energy' in image processing?," *Baeldung on Computer Science*, 03-Oct-2022. [Online]. Available: https://www.baeldung.com/cs/energy-image-processing#:~:text=The%20term%20energy%20describes%20the,contain%20a%20lot%20of%20information. [Accessed: 12-Dec-2022].