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# Image Nonlinear Resizing Algorithm Based on Salient Region

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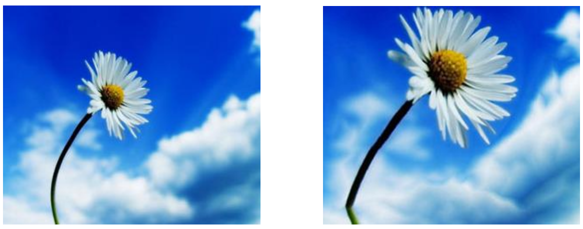
***Abstract***

*Visual attention model has a good visual attention characteristic, which can accurately detect the salient region in image. Image resizing algorithm based on salient region will be studied. The salient region of original image is firstly detected, and the different region will be resized by the different resizing rules. At last, the resized image will be obtained by the fitting function. The salient region is resized by the nonlinear resizing rules adjust the resizing weights, which avoid the linear resizing method causing image morphing, ensure the visual attention regional image no distortion. The other region is resized by the linear resizing rules use the interpolation. Experimental results validate that this paper algorithm can not only achieve image resizing, and ensure the image no distortion and the integrity of salient region content, show good visual effect, and improve the quality of image zooming.*

***Keywords:*** *salient region; linear zooming; nonlinear zooming; zooming image*

## 1. Introduction

With the continuous progress of modern science and technology, new display devices with different resolutions or aspect ratio are becoming more and more popular. The new equipment has provided people with convenient, at the same time, with the different aspect ratio also led to the distortion of display screen. As shown in figure 1, the scene on television with original format 4:3 showed in format 16:9 of display devices, the image in screen becomes fat, even appear the image deformation and distortion.



(a) 4:3 Format (b) 16:9 Format

**Figure 1. Television Images of Format 4:3 and Format 16:9**

In order to avoid image deformation or distortion that produced by a display device with different aspect ratio, image zooming technology is becoming more and more attention. Image resizing is a process to adjust the size of the digital image. At present, there are many kinds of algorithms about this technology, and it usually can be summarized four classes as following: the first class is the interpolation method. 2009, Su *et al.* put forward a kind of image zooming based on interpolation algorithm [1]. This method copied the original pixel intact maps to the nearest four pixels. This method has the advantage of magnified image and retains all the information of original image; The disadvantage is that method can produce saw tooth phenomenon, and even cause the

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distortion of image content. The second class is image zooming method based on the cut. In 2003, Suh *et al.* were first put forward image reconstruction algorithm based on cutting salient region map [2]. Later, Tao *et al*. put forward a dynamic image reconstruction algorithm [3]. Usually, the method using visual attention model [4] determined interested area in the image, and selected an optimal rectangular area as the zooming result. This method has advantage when the interested area is concentrated, can keep interested area not distorted; Defect is that when the interested area is sparse, cutting method can destroy image content as a whole. The third class is a method based on seam carving. Agarwala put forward a kind of interactive digital image synthesis algorithm [5] in 2004. The idea of this method is that by iteratively removing the less important juncture to implement content sensitive image zooming. Later, He *et al*. proposed a new improved seam carving content aware image resizing method [6] in 2013. This new combined energy is utilized to describe the content of the image, and to accelerate the algorithms. The method has the advantage of image zooming result with many content sensitive can be generated, and ensured the image important area is not destroyed; the disadvantage is that discrete method processes the area with obvious structure easy to cause defects. The fourth class is that image zooming method based content sensitive. In 2007, Avidan presented a seamless carved image zooming algorithm based on sensitive content [7]. This method overcomes zooming defects in large scale image of the non-uniform resizing method [8] and random walk [9]. This method not only effectively uses less important areas of the image, but also to carry on the reasonable drawing or extrusion for the important area of image. Thus, it effective uses relatively unimportant area in all directions to hidden the distortion caused by the size changes of image. Later, Inspired by conformal energy in geometric processing field applications [10], Zhang proposed a method based on extension conformal energy [11]. The advantage of this method is not only can effectively spread the distortion, but also can keep global and local characteristics of the image; The disadvantage is that the method does not consider possible rotation of important area, which can lead to generates distortion of important areas in image.

Based on the above theories, in order to avoid distortion and rotation of the important areas, this paper proposed an image zooming algorithm based on the interested area. New algorithm simulates human eye visual features which hunt for the most sensitive spots (that is, the so-called local maximum points), and by using dynamic neural network method in the artificial intelligence extracted the interested area from an image, and then use zooming rules to complete the whole image zooming.

## 2. Image Interested Area Test Based on Improved Visual Attention Model

In 1998, Itti put forward the visual attention model based on attention [4]. The model completes interested area detection by describing saliency in color channel, brightness channel and direction channel of 3d visual characteristics. However, the interested region diagram generated by the model can reflect the interested area, and it is unable to accurately describe the size of interested area, there is a deviation between the test results and the human eye observation area. In addition, when generated the interested area chart, Itti used linear synthetic method, this method does not guarantee the full representation of the saliency of characteristics of multi images.

### 2.1. Improved Visual Attention Model

In order to improve the accuracy of detection, the test result is consistent with the interest of the human eye observation area. In this paper, the traditional visual attention model was improved, and introduced edge character and linear fusion method. Therefore, the visual characteristics consist with color, brightness and edge rather than color, brightness and direction. Improved visual attention model use color and brightness respectively to detect the eye focus in input image, by the center surrounding operator to calculate the attention of focus formed corresponding color features figure and brightness characteristics figure. At the same time, through the edge detect image region of the focus, and formed edge character figure. Then, linear fusion brightness characteristic figure, color feature figure and edge feature figure into an interested region diagram, used winner-takes-all neural network method to complete interested area detection. Improved visual attention model is shown in Figure 2.

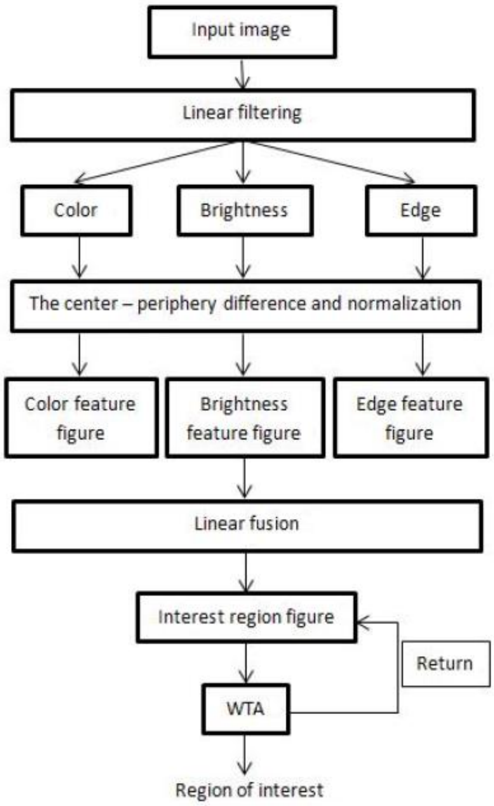



**Figure 2. Improved Visual Attention Model**

The advantage of this method is that the interested region extraction is very accurate. It is not only combined a variety of visual features [12], but also selected focus point consist with the actual focus point of human eye observes the image.

### 2.2. Interested Area Detection

Improved visual attention model first use nine layer Gaussian pyramid decomposed the color feature of input image into four types of red, blue, yellow and green. For red pyramid, blue pyramid, yellow pyramid and green pyramid, at each level of the pyramid extracting red $R$ 、 green $G$ 、 blue $B$ and yellow $Y$ characteristic respectively.

$$R = r - (g + b)/2 \tag{1}$$

$$G = g - (r + b)/2 \tag{2}$$

$$B = b - (r + g)/2 \tag{3}$$

$$Y = r + g - 2(|r - g| + b) \tag{4}$$

Where $r$ 、 $g$ 、 $b$ are red, green and blue components of image.

In the improved visual attention model, brightness feature uses the brightness pyramid for each layer of color low pass filtering processing and down sample processing to obtain brightness feature $I$ :

$$I = (r + g + b)/3 \tag{5}$$

In improved visual attention model, edge feature uses the most typical Gauss Laplace operator based on second order differential. Gauss Laplace operator is sensitive to texture boundary. Gray edge feature extracting in HSV space is very effective.

Definition 1. The center - periphery operator is through the difference value between the central area and the surrounding area to describe the image features saliency (feature figure). The saliency of some kind of visual image feature is $F(c,s)$,

$$F(c,s) = |F(c)\Theta F(s)| \tag{6}$$

Where, $F(c)$ represents the visual features of center region, $F(s)$ represents the visual feature of the surrounding area. $c$ represents center scale, $s$ represents the edge area scale, $c \in \{1,2,3\}$, $s = c + \delta$, $\delta \in \{2,3\}$.

Definition 1 is difference operation for two different scales of image, through the "coarse scale" image interpolation convert to the "fine scale" and then to subtract for each one pixel achieve it.

After visual feature extraction, the definition 1 based on the color information channel, brightness information channel and edge information channel to render respectively that are 6 $RG(c,s)$ feature figures, 6 $BY(c,s)$ feature figures, 6 brightness feature figures and 6 edge feature figures.

$$I(c,s) = |I(c)\Theta I(s)| \tag{7}$$

$$RG(c,s) = |(R(c) - G(c))\Theta(G(s) - R(s))| \tag{8}$$

$$BY(c,s) = |(B(c) - Y(c))\Theta(Y(s) - B(s))| \tag{9}$$

$$E(c,s) = |E(c)\Theta E(s)| \tag{10}$$

In order to more intuitive vividly describe the attention degree of the interested region, linear normalization 24 feature figures become into 3 feature Figures [13]. Due to some feature mapping figures have more strong responses, and some feature mapping figures have a salient weak response, we will use the normalized operation to find a saliency feature figure between these hard compared feature figures. The normalized color feature figure $\overline{C}$ , brightness feature Figure $\bar{I}$ and direction feature figure $\overline{O}$ are all the concentrated reflection of visual saliency.

$$\bar{I} = \bigoplus_{c=2}^{4} \bigoplus_{s=c+3}^{c+4} N(I(c,s)) \tag{11}$$

$$\overline{C} = \bigoplus_{c=2}^{4} \bigoplus_{s=c+3}^{c+4} [N(RG(c,s)) + N(BY(c,s))] \tag{12}$$

$$\overline{O} = \sum_{\theta \in \{0°,45°,90°,135°\}} N\left( \bigoplus_{c=2}^{4} \bigoplus_{s=c+3}^{c+4} N(O(c,s,\theta)) \right) \tag{13}$$

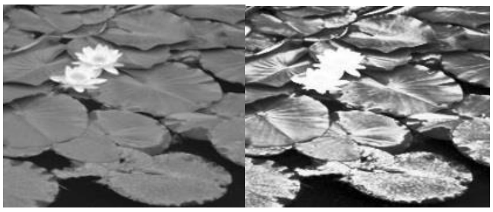
Where $\oplus$ represents the add operation between feature figures, $N$ is the normalized operation.

Finally, linear fusion processing for the three feature maps, and sampling to the Gaussian pyramid layer 4, after repeated fusion and normalized processing, get an interested region map.

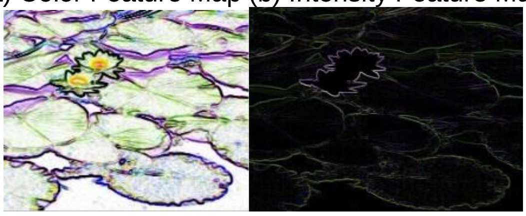
Region of interest $S$ can represents for this:

$$S = \frac{1}{3}\left(N(\bar{I}) + N(\overline{C}) + N(\overline{O})\right) \tag{14}$$

$N(\bar{I})$, $N(\overline{C})$ and $N(\overline{O})$ respectively are the brightness feature map $\bar{I}$, color feature map $\overline{C}$ and position feature figure $\overline{O}$ linear normalization.



(a) Color Feature Map (b) Intensity Feature Map



(c) Edge Feature Map (d) Salient Region Map

**Figure 3. The Salient Region Detection Process**

## 3. Based on the Interested Regions of Image Zooming

For the characteristics of the interested region, this paper uses the linear and nonlinear rules to explore image resizing.

### 3.1. Nonlinear Resizing Rules of Interested Region

Image resizing complete by adjusting parameter weights of image resizing and the width of the image, realize the image composition again. This article uses resizing parameter [14]: interest area, energy parameters, visual balance and three points rules.

(1) Interested region resizing parameter ( $E_{SZ}$ )

There are two advantages by using visual attention model to extract the interested region: One is that to provide accurate interested area for image zooming. Interested area is the main target of image zooming, and the focus of the image zooming, and as the prospect of new image, other areas belong to the irrelevant information as a background, the background can be size adjustment according to the outlook demand. The second is to provide region of interested zooming parameters for image zooming fitting function. Interested region parameter is the gist of interest region in the image.

$r(S_i)$ is the size of interest region $S$. Interest region zooming parameter can be expressed as:

$$E_{SZ} = \sum_i \max e^{-\frac{r^2(S_i)}{2\tau}} \qquad \tau = 0.07 \tag{15}$$

(2) Energy zooming parameters ( $E_{H_i,H_i'}$ )

In the process of image zooming, in order to avoid the interested area deformation and rotation, we introduced the energy zooming parameter [15]. It includes similar deformation energy and scaling deformation energy.

$\varepsilon_1(H_i, H_i')$ is the similar deformation energy, $\varepsilon_2(H_i, H_i')$ is the zooming deformation energy, $\alpha_i = 1 - \omega_i^{\beta}$ , $\beta \in [0,1]$ is control parameter, $\omega_i$ is the weight of $H_i$ compute from the attention. The energy zooming parameter expression is:

$$E_{H_i H_i'} = \alpha_i \varepsilon_1(H_i, H_i') + (1 - \alpha_i)\varepsilon_2(H_i, H_i') \tag{16}$$

For the attention unit $H = \{(x_j, y_j)\}$,it has $n$ attention points. Attention unit $H$ can become into:

$$H' = \{(x_j', y_j')\} \tag{17}$$

Due to $b_H = (x_1', y_1', \cdots, x_n', y_n')^T$ , let

$$\varepsilon^*(H, H') = |C_H b_H|^2 \tag{18}$$

$C_H$ has some differences between $\varepsilon_1(H, H_i')$ and $\varepsilon_2(H, H_i')$ , signed them are $C_{1,H}$ and $C_{2,H}$ . $C_{1,H} = A_1(A_1^T A_1)^{-1} A_1^T - I$ , $I$ is the unit matrix, defined $A_1$ as follow:

$$A_1 = \begin{bmatrix} x_1 & -y_1 & 1 & 0 \\ y_1 & x_1 & 0 & 1 \\ M & O & M & M \\ x_n & -y_n & 1 & 0 \\ y_n & x_n & 0 & 1 \end{bmatrix} \tag{19}$$

In order to prevent the rotation of image important content, zooming transforms part of not rotating in transform set $G$ . Attention point $P$ in the attention unit $H_i = \{P_{i,j}\}$ of $\varepsilon_2(H_i, H_i')$ after deformation was:

$$P' = g(P) = \begin{bmatrix} c' & 0 \\ 1 & c' \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix} \tag{20}$$

$\varepsilon_2(H_i, H_i')$ is the minimum distance between attention unit $H_i$ and $H_i$ . Scale transform $g(P)$ is determined by $X_g [c' \ \ t_x \ \ t_y]^T$ . If $H_i = \{P_{i,j}\} = \{(x_{ij}, y_{ij})\}$,

$$g(P_{i,j}) - P_{i,j}' = \begin{bmatrix} x_{i,j} & 1 & 0 \\ y_{i,j} & 0 & 1 \end{bmatrix} x_g - \begin{bmatrix} x_{i,j}' \\ y_{i,j}' \end{bmatrix} \tag{21}$$

$$\varepsilon_2(H_i, H_i') = \min_{g \in G} |A_2 X_g - b_{H'}|^2 \tag{22}$$

Solve $A_2 X_g = b_H$ will get the optimal $X_g$

$$X_g = A_2^T A_2^{-1} A_2^T b_H \tag{23}$$

So that, we will get

$$C_{2,H} = A_2\left(A_2^T A_2\right)^{-1} A_2^T - I \quad (24)$$

(3) Visual balance scale parameter ( $E_{VB}$ )

Visual balance scaling parameter adjusts the position relations of image interest area; ensure the visual effect of image zooming [16]. Visual balance parameter can be expressed as:

$$E_{VB} = e^{-\frac{d_{VB}^2}{2\sigma_1}} \quad (25)$$

$d_{VB} = d_M\left(C, \frac{1}{\sum_i M(S_i)} \sum_i M(S_i) C(S_i)\right)$, $M(S_i)$ is the set of interest region $S$, $d_M$ is the Manhattan distance, $\sigma_1 = 0.2$.

(4) Trisection rule zooming parameters ( $E_{RT}$ )

Trisection rule zooming parameters can adjust the relationship between interested areas and not interested areas, ensure the rationality of the image zooming. Trisection rule is using two level parallel lines and two vertical parallel lines uniform divided input image into nine equal parts, four intersect points of four parallel lines was known as "power point", the area in "power point" is the interested area. Trisection rule zooming parameter consist of $E_p$ and $E_l$.

$$E_p = \frac{1}{\sum_i M(S_i)} \sum_i M(S_i) e^{-\frac{D^2(S_i)}{2\sigma_2}} \quad (26)$$

$D(S_i) = \min_{j=1,2,3,4} d_M\left(C(S_i), G_j\right)$ is the minimum distance function that from interest region center to the four "power point", $\sigma_2 = 0.17$ 。

$$E_l = \frac{1}{\sum_i I(L_i)} \sum_i I(L_i) e^{-\frac{D_R^2(L_i)}{2\sigma_3}} \quad (27)$$

$D_R(L_i) = \min_{j=1,2,3,4} d_L(L_i, R_j)$ is the minimum distance from horizontal line $L_i$ to $R_j$, $I(L_i)$ is the value of horizontal line $L_i$, $\sigma_3 = 0.17$.

Trisection rule zooming parameter can be express as:

$$E_{RT} = \gamma_p E_p + \gamma_l E_l \quad (28)$$

$\gamma_p = \frac{1}{3}$ and $\gamma_L = \frac{2}{3}$ is the weight, $E_p$ and $E_l$ can be obtained from formula (25) and (26).

### 3.2. Not Interested Region Linear Scaling Rules

Linear interpolation is according to the color of the closest points to linear calculated and estimate color of the point. It has the characteristics of the fast operation speed. In most cases, the accuracy of this method is higher than the nearest domain method, and the effect is much better. Especially, when magnified, image edge serrated produce more small than nearest neighbor domain method, the image will appear to be soft. Therefore, this article adopts the method to zoom in or out for the interest region.

Let $i$ and $j$ are nonnegative integers, $u$ and $v$ are the floating numbers in $[0,1]$, $f_{(i,j)}$ is the pixel value of source image position $(i, j)$, the expression of interpolation function $f_{(i+u,j+v)}$ is that:

$$f_{(i+u,j+v)} = (1-u)(1-v)f_{(i,j)} + (1-u)vf_{(i,j+1)} + u(1-v)f_{(i+1,j)} + uvf_{(i+1,j+1)} \tag{29}$$

For each point in the target image does a series of complex floating point arithmetic in RGB space, which will lead to its low computation efficiency, so it needs to be optimized.

Assumes that the zooming ratio of target image in $x$ axis and $y$ axis respectively is floating $u$ and $v$, $dw$ and $dh$ are the width and height of target region, $sw$ and $sh$ are the width and height of source region, The scores of floating numbers form can be represented as:

$$u = \frac{dw}{sw}, v = \frac{dh}{sh} \tag{30}$$

Take the formula (29) into the formula (28), can be written as a new linear interpolation function is:

$$F = \left(1-\frac{dw}{sw}\right)\left(1-\frac{dh}{sh}\right)f_{(i,j)} + \left(1-\frac{dw}{sw}\right)\frac{dh}{sh}f_{(i,j+1)} + \frac{dw}{sw}\left(1-\frac{dh}{sh}\right)f_{(i+1,j)} + \frac{dw}{sw}\frac{dh}{sh}f_{(i+1,j+1)} \tag{31}$$

Whole image zooming is done common by linear zooming and nonlinear zooming rules, it completes through image fitting function to adjust zooming parameters of the linear zooming and nonlinear zooming rules, the image fitting function are given in theorem 1.

If $E_a = \frac{\omega_{RT}E_{RT} + \omega_{VB}E_{VB}}{\omega_{RT} + \omega_{VB}}$, whole image zooming finally through the fitting function $E = (1-\omega_{SZ})E_a + \omega_{SZ}E_{SZ} + E_{H_iH_i^{'}} + F$ to adjust image zooming parameter weight ($\omega_{RT}, \omega_{VB}, \omega_{SZ}, \omega_{H_iH_i^{'}}$) and image length and width ($h$, $w$) to complete it.

## 4. Image Zooming Algorithm Based on Interest Region

The aim of image zooming is that the processed image adjusts and conforms the size of the display area, and generate the corresponding image thumbnails. Its essence is that when image reduction, guarantee the integrity of the image content and visibility and eliminate irrelevant information in the image; when the image magnification, under the premise that ensures visibility and clarity of the image pixels, insert the similar information. The basic thought of image zooming: from simple to difficult, classification zooming; extract interest region, to compute scaling parameter using different rules; adjust zooming parameter weights, obtained the optimal zooming image.

**Steps 1** Preprocess input image, including operations such as denoising, gray level change.

**Steps 2** By Gabor filter and Gaussian pyramid obtained color, brightness and position visual features from input image respectively.

**Steps 3** After visual feature extraction, respectively obtain color feature figure, brightness feature figure and location features figure, after image linear normalization processing of feature figures generated an interested area figure.

**Steps 4** In the artificial intelligence, using dynamic neural network method extracted interest region $S$ from the interested area diagram. The extraction of $S$ distinguished the interested area and not interested region in image, provide the basis for using different image scaling rules.

**Steps 5** Using nonlinear scaling rule to process the interest area, and calculating nonlinear scaling parameters by nonlinear scaling function. Nonlinear scaling parameter is the basis of adjustment the size of interest region when image zooming, it includes interest area scale parameters, the energy scale parameters, trisection rule scaling parameters and visual balance scaling parameters.

We are using nonlinear scaling function to calculate interest area scaling parameters. Interested region scaling parameter is the basis of adjustment the size of interest region when image zooming; using nonlinear scaling function to calculate the energy scaling parameter. Energy scaling parameter is the basis of adjustment the rotation of interest region when image zooming; using nonlinear scaling function to calculate trisection rule scaling parameters. Trisection rule scaling parameters is the basis of adjustment the position of interest region when image zooming; using nonlinear scaling function to calculate the visual balance parameter. Visual balance scale parameter is the basis of adjustment the visual balance of interest region when image zooming

**Steps 6** Using linear scaling rules to process the interested area, and through linear interpolation function to complete not interested region zooming.

**Steps 7** Using image fitting function to fit the interested region processed by the linear scaling and not interest region processed by the nonlinear scaling rules respectively, and by adjusting the weights of image scaling parameters to complete the whole image zooming.

Color space convert, obtained color output image.

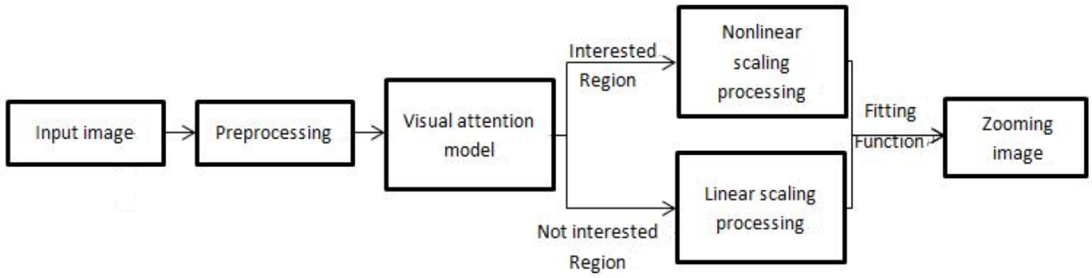



**Figure 4. This Paper Image Scaling Algorithm Flowchart**

## 5. Experiment and Analysis

In order to verify the feasibility and effectiveness of the algorithm, the experimental environment for the Intel Pentium(R) 2.8 GHz, memory 1G machine, for Windows XP operating system. In this paper, our method compared with equal scaling algorithm and the common energy algorithm for three groups of different natural scenery image. In general, equal scaling method can effectively realize image zooming, but for the interested region scaling is not obvious, cannot be directly observed interested region scaling effect. Common energy method improved the equal scaling method, realizing interested region zooming, but also lead to distorted interested region. Through the compared for the experimental results, this verified the feasibility and validity of this method.

In Figure 5 (a) - (c) as the input image in this paper. Among them, the (a) and (b) using equal scaling algorithm, the common energy algorithm and our algorithm doing shrinking experiment, (c) is magnifying experiments. Figure 6(a) and figure 7(a) and Figure 8 (a) three images are experimental results obtained by equal scaling algorithm, it can be seen that the experimental result is according to the proportion of the original image zooming, but not focus interested region scale effects. Figure 6(b) and Figure 7 (b) and Figure 8 (b) three images are experimental results obtained by common energy algorithm, the method can reflect interested region scaling, but the distortion interested area. Figure 6 (c), Figure 7 (c), Figure 8 (c) three images are experimental results obtained by our algorithm, after compared with original image and the former two methods, our approach not only can realize interested region scaling, but also can reduce or enlarge image interested region perfectly under the condition of not lower resolution, make the interested region more obvious, it is advantageous to detailed observe the target area.

(a) (b) (c)

**Figure 5. Input Image**

(a) Equal Scaling (b) Common Energy (c) This Paper Algorithm

**Figure 6. Image Narrow**

(A) Equal Scaling (B) Common Energy (C) This Paper Algorithm

**Figure 7. Image Narrow**

(A) Equal Scaling (B) Common Energy (C) This Paper Algorithm

**Figure 8. Image Magnification**

Can be seen from the above experiment results, the interested area of images (Figure 6 (c), Figure 7 (c) and Figure 8 (c)) using nonlinear scaling is not distortion, and maintain the integrity of the image content; Not interested region scaling effects is good after linear scaling, the whole image after scaling also make full use of the full display area of the screen, achieved a perfect display effect, which has obtained the good visual effect.

Besides the subjective experience visual judgment, the objective evaluation criteria also as the basis. In order to better evaluate scaling effects of different methods, this article from the rotation, global and lose true features three indexes were compared.

**Table 1. The Performance Comparison of the Different Image Scaling Methods**

| Scaling method | Rotation | Lost true | Global |
|---|---|---|---|
| Equal scaling | no | no | no |
| Common energy | yes | yes | yes |
| Our method | no | no | yes |

Three kinds of indexes, the proposed approach is the best. Therefore, in this paper, image scaling performance better than other scaling method, thus proving the effectiveness of the method in this paper.

By subjective and objective analysis of the above, the experimental results and the performance index of this paper proposes the scaling method are better than other scaling method.

## 6. Conclusion and Prospect

This paper proposes an image scaling algorithm based on interested area. In the algorithm, interested region using nonlinear rules zooming, not interested region with linear scaling rules for processing. Through the image zooming to provide detailed observations interested area in close range, also avoid distortion for different scales video conversion. Visual attention model is conducive to the automatic detection of the image area; provide the basis for nonlinear scaling of interest region. The adjustment of image zooming is completed by the linear scaling and nonlinear scaling rules, using nonlinear scaling rules adjust scaling parameters to complete interested region scaling, using linear scaling rules to complete not interested region scaling by interpolation. Finally, using fitting function to complete whole image zooming, get the optimal image. But this algorithm also unable to all of image zooming, there are a lot of works need to be done urgently. Looking forward to the future, it becomes the development trend integrated using a variety of image scaling methods, play their respective advantages in image processing. In a word, image scaling method has development goals that including automatic, accurate, fast, adaptive and robust.

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