Visual Saliency Based on Local and Global Features in the Spatial Domain

Chao Jia[1], Fang Hou[2] and Liangliang Duan[3]

**[1] College of Information Science and Engineering, Yanshan University
Qinhuangdao, HeBei，066004，China**

**[2] College of Information Science and Engineering, Yanshan University
Qinhuangdao, HeBei，066004，China**

**[3] College of Information Science and Engineering, Yanshan University,
Qinhuangdao, HeBei，066004，China**

Abstract

The human visual system can quickly and efficiently capture the salient objects in a scene. Based on the biological mechanism, a new multi-scale saliency analysis method is proposed in this paper, in which the differences of region colors and spaces are calculated in different scale and their saliency map are fused together. First, we calculate the image saliency by using the color and space information of both local and global in single scale. Then by applying the multi-scale fusion, we can effectively inhibit outstanding but not salient region in each single scale, and different scale can also reflect salient region of the images from different aspects. The experiment results show that this algorithm can effectively predict the salient region attracting human attention. Our method has the state-of-the-art performance and achieves excellent results for salient objects of different sizes and salient region with complicated background in an image.

Keywords: *local and global features，salient object detection，patch saliency，color and space difference，multi-scale fusing*

1. Introduction

Human visual system on the analysis of complicated scene taking a serial calculation strategy, quickly turn attention to stay in a few salient target object, which is processed prior and this reaction process is called visual attention. Imitating the biological mechanism of the computer vision of salient region detection algorithm in image segmentation[1][4], image classification[2][5], target recognition [3], relocation [24], etc takes the high value [6] [7] [8][23]. Generally speaking, there are two different processes that influence visual saliency, one is top-down visual attention model, it uses high-level semantic features and knowledge-driven to compute visual saliency. The other is a bottom-up visual attention model, which is data-driven, automatic processing and it relies on image features. This paper focuses on bottom-up algorithm in salient region detection, which now roughly is divided into two kinds based on local information and global information.

According to cognitive psychology [17] and neurobiology [18][22], we can know that how visual saliency and human treat and deal with salient object of image which is closely related to visual stimuli. When observing an image, the observer's cortical responses to the salient region first. By analyzing the human visual system and summary of the current popular algorithm [9] [10] [11] [12] [13] [14] [15][16], we can know the characteristic of a good visual saliency detection is as follow:

1. Saliency detection algorithm based on the region, the entire region can be separated from the surrounding environment. This method is superior to only highlight salient contour of the object than saliency detection method based on a single pixel.
2. The method based on global color and space differences tends to assign similar saliency value to the similar regions in an image and uniformly highlight the whole salient object.
3. Salient detection algorithm of single scale is able to highlight area having specific characteristics in the image, but they are not all salient region. So using multi-scale salient detection algorithm can inhibit the region obtained at a signal scale which is outstand but not salient.

Based on the analysis of the human visual system and the current problems resolved existing in the algorithm, this paper propose a new detection algorithm by calculating difference between global region colors in different scales and fusing the saliency map in each scale. This algorithm has very good effects to process natural scene, and it can highlight the salient object in the complicated background or salient object repeatedly disturbed by background. The method in a new data set is tested, through the experiments, the proposed detection algorithm have good results and have achieved better accuracy with the current popular algorithms. It can effectively predict the region human pay attention to.

The remained of the paper is organized as follows: section 2 gives the description and review of related work. In section 3, we elaborated the framework of our salient detection algorithm in details by calculating the image saliency values of single-scale and fusing saliency map of different scales. In Section 4, we demonstrated our experiment results by comparing Ground truths and the results with another three currently popular algorithms. The conclusions are given in Section 5.

2. Related work

Many bottom-up models have appeared in the literature. In [9], by imitating human visual bottom-up attention mechanism, Itti proposed IT model based on the local color, brightness, and other information, through the multi-scale image characteristics of the center-around deviation. The defects of this model are that the effect is poor in the dynamic space. This theory became the base of salient region detection model. Walther [19] expanded the Itti model, through the hierarchical feedback connection made fixed size round of salient region in IT model extend into the shape of salient region in image, which can better guide target recognition, but whose efficiency decline. Liu [8] propose the multi-scale contrast to calculate image saliency based on Gaussian image pyramid contrast linear combination. The advantage of this method is to be able to use the existing mature region segmentation algorithm to carry on the calculation, but it relies on region segmentation algorithm too much. The above methods are based on local information, and these methods tend to give the edge of salient region higher saliency value, not fully highlight the whole object.

Recently, some researchers begin to focus on the global information of the image. R. Achanta et al. proposed a frequency-tuned salient region detection algorithm (FT) in [13]. The FT first converts image to Lab color space then defines the saliency at each location as the difference between the Lab pixel value and the mean Lab value of the entire image. This method proposes a new direction of detecting salient region. In [14], Hou et al. propose a simple and fast algorithm based on spectrum residual (SR) in frequency domain, but the saliency map of SR only use the information contained in the amplitude Spectrum. And in [15], the phase spectrum of the Fourier transform (PFT) was introduced and achieved nearly the same performance as the SR. But SR and PFT tend to find small salient region. When detecting a large salient object, they highlight the contour of the object while ignoring the internal details of the object. Based on SR and PFT, Li proposed HFT [16] detection algorithm based on frequency domain. HFT make full use of the information of amplitude spectrum and phase spectrum in frequency domain after Fourier transform to calculate the saliency value of image. Goferman in [12] propose context-Aware salient region detection algorithm (CA) according to differences of global feature, and the algorithm takes account of the information local and global properties of image, visual organization principle and surface characteristics to achieve salient region calculation.

The above method is based on the global information, whose efficiency has been improved in the calculation, and it considers the global relationship, while most of them ignore the existing of the spatial relationship in the image and can't even uniformly highlight objects for the larger salient objects.

3. Visual saliency model

According to the visual organization principle, each pixel of the image is not independent, and there is usually some relationship between the pixels. In the FT, only the individual pixels and global average color difference are used, and its defect is that only considers a single isolated pixels, and ignores the contact between the pixels and the pixels around, and fails to consider spatial information. According to visual organization principle, the salient region of an image is formed by one or several very important piece of composition, that is to say salient pixel in the image is concentrated. Therefore, we calculate the single scale image saliency based on the region. Here, we will first divide images into several parts according to the different scale, and the integral image is introduced to separate and describe them. Then based on the patch already divided according to each scale, we calculate the global color and space difference of each patch between and considered as image saliency value, thus obtains the saliency map of different scales.

3.1 Region division and representation

To count color features of region of the input image, we need to divide the image into multiple areas. Firstly, images of different sizes uniform converted into the image whose size is 256 * 256, So that we can divide each image at the same scale. We divide image into the multiple patch whose size is k*k, in this paper, k=4,8,16,32. The number of patch in the image is 256 / k * 256 / k.

The size of image can be random. In order to obtain the statistical input image area color characteristics the image is divided in the same scale. First of all there is need to

IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 1, No 3, January 2013
ISSN (Print): 1694-0784 | ISSN (Online): 1694-0814
www.IJCSI.org

unify different size images into the same size of 256 * 256. Then the images are divided into N non-overlapping patches with the pixel number for k * k, and the k is the scale adopted in this paper of which the four dimensions, namely k = 4,8,16,32. The number of patch diagram N is 256 / k * 256 / k. In this algorithm, each patch is represent with its region color means value, so the concept of integral image is introduction. Integral image can fast calculate the sum of all pixels on a random area of image. A random point (i, j) in a integral image refers to sum of pixels of all the points in the rectangular area from the top left hand corner of the image to the point., The formula is as follows:

$$s(i,j)=\sum_{m=0}^{i}\sum_{n=0}^{j} f(i,j) \quad (1)$$

The value of each position in the integral image can also be calculated using the following formula：

$$s(i,j)=s(i-1,j)+s(i,j-1)-s(i-1,j-1) + f(i,j) \quad (2)$$

Where， $s(i,j)$， $s(i-1,j)$， $s(i-1,j-1)$ represent the value of the position (i,j)，(i-1,j)，(i-1,j-1) in integral image. $f(i,j)$ is the value of the position (i,j) in original image. According to the integral image, we can use Eq(3) to calculate the sum of all pixels within each region of original image.

$$F(i_p...i_q, j_p...j_q)=\sum_{i=i_p}^{i_q}\sum_{j=j_p}^{j_q}(s(i_q,j_q)-s(i_q,j_{p-1}) - s(i_{q-1},j_p)+s(i_{q-1},j_{p-1})) \quad (3)$$

Where, $F(i_p...i_q, j_p...j_q)$ represent the sum of the pixels within region among four pixels point (p,p),(p,q),(q,p),(q,q) in original image. $s(i_q,j_q)$, $s(i_q,j_{p-1})$, $s(i_{q-1},j_p)$, $s(i_{q-1},j_{p-1})$ represent the value of position (i_q,j_q) , (i_q,j_{p-1}) , (i_{q-1},j_p) , (i_{q-1},j_{p-1}) in integral image. Figure 1 (1) shows the pixels of a simplified image, and Figure 1 (2) is the integral image corresponding to Figure 1 (1). If we want to calculate the sum of pixels in gray region in figure 1(1), we just need to calculate the pixels of yellow position in (2) according to the Eq (3).

3	2	7	2	3
1	5	1	3	4
5	1	3	5	1
4	3	2	1	6
2	4	1	4	8

（1）

3	5	12	14	17
4	11	19	24	31
9	17	28	38	46
13	24	37	48	62
15	30	44	59	81

（2）

Fig 1. (1) Original image. (2) The integral image corresponding to (1).

Therefore, the mean value of pixels of the region can be calculated according to the Eq (4):

$$\overline{F}(i_p...i_q, j_p...j_q)=F(i_p...i_q, j_p...j_q) /((q-p)*(q-p)) \quad (4)$$

Where, $\overline{F}(i_p...i_q, j_p...j_q)$ represent the mean value of the pixels within region among four pixels point (p,p),(p,q),(q,p),(q,q) in original image. (q-p)*(q-p) is the size of region.

Using integral diagram can effectively calculate the mean pixel of arbitrary area and is very suitable for calculation of the region characteristics, thus it can improve the efficiency of the proposed algorithm.

3.2 Local and global different-scale image saliency

Given an image using 2.1 to do image division, the image is divided into patches and each patch can be expressed. This section will be effective to calculate the saliency value of each piece, make saliency value differences between patches clear, highlight salient region and inhibit the non-salient area. In this process, there are two factors will be considered: one is the difference of the color in the image between any two blocks; the second is distance between them, which should be considered combined with the global information.

3.2.1 The color difference between patches

Color as an important bottom feature, it can well describe the differences between the region and highlight salient region. So, in this paper, we use the mean Lab value of region to describe a region. According to the principles of visual organization, colors of salient patches are similar, and the color difference is large between non-salient patches and salient patches. So, we define the distance between a patch and others in an image as Eq (5).

$$d_c[i][j]=sqrt((\overline{F}_L(i)-\overline{F}_L(j))^2+(\overline{F}_a(i)-\overline{F}_a(j)) +(\overline{F}_b(i)-\overline{F}_b(j))^2) \quad (5)$$

Where, $d_c[i][j]$ is the color distance between the i-th patch and the j-th patch, $\overline{F}_L(i)$, $\overline{F}_a(i)$, $\overline{F}_b(i)$, $\overline{F}_L(j)$, $\overline{F}_a(j)$, $\overline{F}_b(j)$ respectively represent the mean L,a,b value of the i-th patch and the j-th patch in CIE $L*a*b$ color space.

3.2.2 Combining with the spatial distance

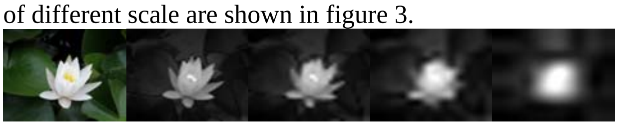
In an image, the number of salient patch is less, If the sum of color difference between a patch and all the other patches in image is larger, then it can be identified as a salient patch. Therefore, we use the sum of color difference between each patch and the other patches in the image to describe the patch saliency.

The spatial distance between the patches is a very important factor when calculating image saliency. Because spatial distribution of most salient patches is concentrated on the adjacent areas of the center of the image, however, non-salient patches can be distributed within the whole image. According to the spatial features of the salient region, if a region is salient, the possibility that its surrounding region is salient is larger and the possibility that regions far away from it are non-salient is larger. For regions in image, with the increase of the space distance between them, the influence between them will be smaller. By integrating the information of region color differences and space distance, image salient formula based on the single-scale is given. The formula as follows:

$$S[i] = \sum_{j=0}^{n} (1/(1+d_p(i,j)) * sqrt((\overline{F}_L(i) - \overline{F}_L(j))^2 + (\overline{F}_a(i) - \overline{F}_a(j))^2 + (\overline{F}_b(i) - \overline{F}_b(j))^2) \quad (6)$$

$$d_p(i,j) = \sqrt{(i_x - j_x)^2 + (i_y - j_y)^2} \quad (7)$$

Where, $d_p(i,j)$ is the Space Euclidean distance between the i-th patch and the j-th patch. S[i] is the image saliency value. By add in space distance, we can control the interaction among all regions in the image. Saliency map of different scale are shown in figure 3.



(1) (2) (3) (4) (5)

Fig 2. (1) The input image. (2) The saliency map that size is 4*4. (3) The saliency map that size is 8*8. (4) The saliency map that size is 16*16. (5) The saliency map that size is 32*32.

3.3 Analysis of saliency map of each scale

When a scene is very far away from observers, the human visual attention mechanism will more focus on the whole salient regions in the image. When a scene is close to us, human visual attention mechanism can pay more attention on more salient or detail part in the salient region. Our method adopted multi-scale to mimic the biological mechanisms. In this section, we analyze the characteristic of single-scale saliency map.

When image was divided by small scale, we can clearly highlight the whole salient region as well as details of the region. If image was divided by larger scale, we can very accurately locate the position of the salient region (Figure 2). Original image is shown in figure 2(1). Figure 2(2) is saliency map whose original image is divided at a scale of 4*4 and we clearly see the contour and details of salient region. The figure 2(5) shows the saliency map at a scale of 32*32, and we can accurately locate the position of the flower in image which is the most significantly bright region. The figure 2(3) and 2(4) is saliency map at scale 4*4 and 8*8, their contour gradually blurred but the positions of salient region increasingly clear. In addition, when image was divided by small scale, we can clearly highlight the more salient part in salient region. However image was divided by larger scale, we can highlight the position of salient region. In figure 2(2), we also can find the stamen portion is brighter and it is more salient. The stamen portion is longer highlight in figure 2(5) and the whole flower is salient.

We can highlight a patch having a specific characteristic according to the color and spatial characteristics of the image by using single-scale, but these patches are not all salient. When image was divided by small scale, saliency map tend to highlight contour and details of the salient object. However, when larger scale is adapted, we can very accurately locate the position of the salient region in image.

3.4 The integration of the salient region in the multi-scale

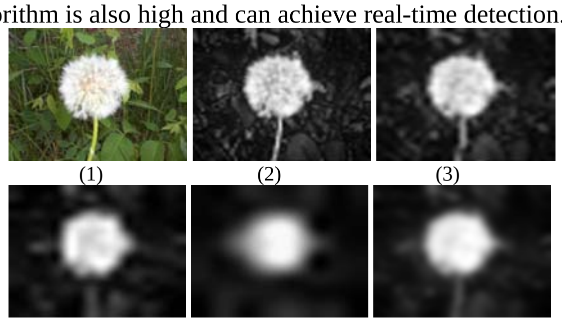
Natural images contain wide content and degree of complexity is diversified. The salient detection effect of a single scale is not very ideal. Recently, it has been noticed and the multi-scale detection algorithm was introduced. In [6], multi-scale model based on frequency domain has been proposed and achieves good results. By using the multi-scale salient detection algorithm, we can analyze the region of interest and calculate the image saliency at different scales， thus we can do a comprehensive analysis of the salient region of the image and highlight salient region of different sizes in images.

According to gestalt law, the visual organization form is due to one or a few region that is highlight and causes the attention of the visual system. It implies that the region attracting attention of visual system is obviously salient. The region that the algorithm of different scales all can highlight most likely is salient, then we should highlight this region and suppress other regions of the image in final saliency map. So we superimposed saliency map obtained at different scale by pixel to get our final saliency map. The experiments show saliency maps of four scales all contain important information. The final saliency is calculated as Eq (8).

$$S = \sum_{i=1}^{k} r_i * S_i \quad (8)$$

Where, S is saliency value of final saliency map, S_i is saliency value of saliency map obtained at different scale. r_i is corresponding weight of each saliency map. r_i =1/4 in our experiment. Our final saliency map is shown in figure 3(6), the whole salient region is highlighted and the contour is very clear. At the same time, the dandelion stems which is non-salient but highlighted in figure 3(2) and 3(3) and redundant parts figure 3(5) in are inhibited.

Multi-scale can make better use of the local and global feature information in image. The single-scale saliency map can highlight the region which contains special features and reflect salient objects from different aspects. After fusing the saliency map of different scale, we can highlight unusual region which is belong to salient object and the final saliency map inherit the advantage of most saliency map. By using multi-scale, the accuracy that predict salient region is improved, the efficiency of the algorithm is also high and can achieve real-time detection.



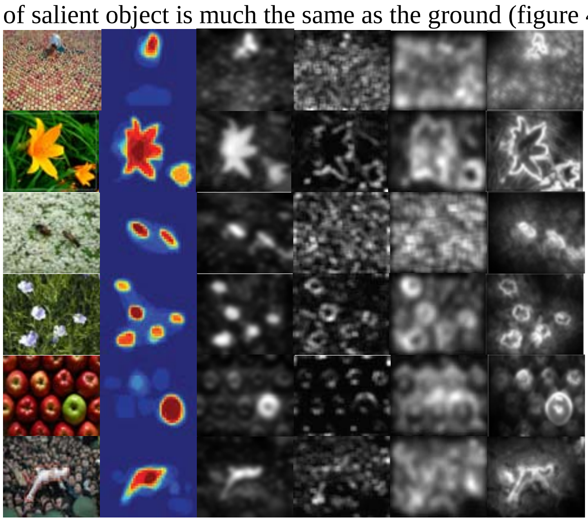
(1) (2) (3)
(4) (5) (6)

Fig 3. (1) The input image. (2) The saliency map that size is 4*4. (3) The saliency map that size is 8*8. (4) The saliency map that size is 16*16. (5) The saliency map that size is 32*32. (6) The final saliency map

4. Experiment

In this section, we introduce a new database set containing 126 images was collected using Achanta[13] and Li's database [16] as well as the recent literature. Images of the database include salient objects of different sizes, background of some images is complex or repeated interferes with salient object and other images contain more than a salient object. At the same time, the database also provides salient region maps labeled by humans as ground truth. We evaluate our algorithm in the database by comparing with ground truth and three classic and novel algorithms of SR, CA and Itti. In compute vision, the human fixation most concentrated in salient region. So the salient detection algorithm should accurately be able to predict the region human pay attention to [14][20]. Our algorithm use multi-scale fusion and it make the advantage of the saliency map of each scale converge to the final saliency maps. It can clearly highlight the position as well as details of salient object. Therefore, we will analyze the feasibility of our salient region detection algorithm based on region.

We will qualitative evaluate the implementation of our algorithm by using the ground truth of region and compare with SR, Itti and CA. The figure 5 shows the comparison among them. We can clearly find when detecting lager region, SR places extra emphasis on edge detection (figure 4(4)), and also Itti have same characteristic (figure 4(5)). Our algorithm can highlight the edge of salient region as well as details of the region (figure 4(3)).The third column of Figure 4 are the saliency map by using our method. The experimental results show our method can highlight salient object in image, whether complex background or foreground disturb background, besides, shape and detail of salient object is much the same as the ground (figure 4).



(1) (2) (3) (4) (5) (6)

Fig 4. (1) Original image.(2)Ground Truth.(3)Our method.(4)SR.(5)Itti.(6)CA.

To evaluate our algorithm, we introduce Receiver operating characteristic curve (ROC) and the area under ROC (AUC). ROC curve is that the true positive rate (TPR) between saliency map and region human relabeled is as the horizontal axis and the false positive rate (FPR) is as the vertical axis.

$$TPR = TP / (TP + FN) \quad (9)$$

$$FPR = FP/(FP + TN) \quad (10)$$

TP is true positive，FP is false positive，TN is true negative，FN is false negative.

In this experiment, besides ROC, we also use the DSC (Dice Similarity Coefficient) as a measure to evaluate the overlap between the threshold saliency map and the ground truth. The peak value of the DSC curve (PoDSC) is an important index of performance, as it corresponds to the optimal threshold and the best possible algorithm performance [21].

Table 1 and Figure 5 show the experimental results of our method and other algorithms in the entire database. We can see the value of AUC and PoDSC of SR, CA, Itti and our algorithm and they are calculated under the same conditions. Figure 5 shows corresponding ROC curve. By comparing two values in table 1 and ROC curve of figure 5, we find our algorithm can get better detection effect on the entire database, our algorithm have higher AUC and PoDSC. It indicates that our algorithm can more accurately predict region that human pay attention to and highlights the position and details of the region.

Table 1. Performance of each method.

	The value of AUC	*The value of PoDSC*
Our method	0.9353	0.6363
SR	0.8074	0.4720
Itti	0.9120	0.5602
CA	0.9252	0.6196

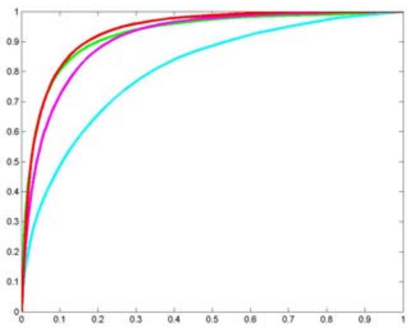


Fig 5.The ROC curves of our model and the other three approaches on dataset of this paper.

5. Conclusions

In this paper, we propose a new saliency detection method. To measure the saliency, we actually combine the color and spatial distance information of image in different scale space, then fusing saliency map of each scale. Experiment results show that our method outperforms some state-of-the-art saliency detection approaches on predicting the region that human pay attention to. One of the limitations of our method is that we focus on regions possessing distinct low-level features. Therefore, next, we will introduce high-level semantic information or increase texture, shape and other information to improve our saliency detection approach. The goal of our research is develop a system for detection of signpost and license plate.

Acknowledgments

This work is supported by the Natural Science Foundation of Hebei Province (No. E2011203212).

References

[1]J. Han, K. Ngan, M. Li, and H. Zhang. "Unsupervised extraction of visual attention objects in color images", IEEE TCSV, 16(1), 2006, pp.141–145.
[2] E. Nowak, F. Jurie, and B. Triggs. "Sampling strategies for bag-of-features image classification", Lecture Notes in Computer Science, 3954:490, 2006.
[3] U. Rutishauser, D. Walther, C. Koch, and P. Perona. "Is bottom-up attention useful for object recognition? ", In CVPR, 2004 ,pp. 37–44.
[4] KK Singh, A Singh, "A Study Of Image Segmentation Algorithms For Different Types Of Images", IJCSI,vol.7, September 2010, pp 414-417.
[5] B Shinde, D Mhaske, AR Dani ,"Study of Image Processing, Enhancement and Restoration", IJCSI, vol. 8, no. 3, November , 2011,pp.262－264.
[6] X. Hou, J. Harel, and C. Koch,"Image Signature: Highlighting Sparse Salient Regions", IEEE Trans. Pattern Analysis and Machine Intelligence, 2012, pp. 194－201.
[7] D. Gao, S. Han, and N. Vasconcelos, "Discriminant saliency, the detection of suspicious coincidences, and applications to visual recognition", IEEE Trans. Pattern Analysis and Machine Intelligence, 2009, pp. 989－1005.
[8] T. Liu, Z. Yuan, J. Sun, J. Wang, N. Zheng, X. Tang, and H. Shum, "Learning to detect a salient object", IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 33, no. 2, 2011,pp. 353－367.
[9]L. Itti, C. Koch, and E. Niebur, "A model of saliency-based visual attention for rapid scene analysis", IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 20, no. 11, Nov 1998, pp. 1254－1259.
[10]J. Harel, C. Koch, and P. Perona. "Graph-based visual saliency" 2006, In NIPS, pp. 545–552.

[11]T. Kadir and M. Brady, "Saliency, scale and image description", International Journal of Computer Vision, vol. 45, no. 2, 2001 ,pp. 83–105.
[12] S. Goferman, L. Zelnik-Manor, and A. Tal, "Context-aware saliency detection", IEEE Trans. Pattern Analysis and Machine Intelligence ,2012, pp.1915 – 1926.
[13]R. Achanta, S. Hemami, F. Estrada, and S. Ssstrunk, "Frequency-tuned Salient Region Detection", in IEEE Conf. Computer Vision and Pattern Recognition, 2009.
[14]X. Hou and L. Zhang, "Saliency detection: A spectral residual approach", in IEEE Conf. Computer Vision and Pattern Recognition, 2007.
[15]C. Guo, Q. Ma, and L. Zhang, "Spatio-temporal saliency detection using phase spectrum of quaternion fourier transform", in IEEE Conf. Computer Vision and Pattern Recognition, 2008.
[16] Jian Li, Martin D. Levine, Xiangjing An, Xin Xu, Hangen He, "Visual Saliency Based on Scale-Space Analysis in the Frequency Domain", IEEE Transactions on Pattern Analysis and Machine Intelligence, 24, 2012.
[17]S. K. Mannan, C. Kennard, and M. Husain. "The role of visual salience in directing eye movements in visual object agnosia", Current biology, 19(6) , 2009,pp.247–248.
[18]J. M. Wolfe and T. S. Horowitz. "What attributes guide the deployment of visual attention and how do they do it?" Nature Reviews Neuroscience, 2004, pp. 5:1–7.
[19]D.Walther, C.Koch. "Modeling Attention to Salient Proto-Objects[J] ". Neural Networks. 19(9), 2006, pp.1394-1407.
[20]L. Elazary and L. Itti, "Interesting Objects Are Visually Salient",Journal of Vision, vol. 8, no. 3, 2008, pp. 1 - 15.
[21]T. Veit, J. Tarel, P. Nicolle, and P. Charbonnier, "Evaluation of Road Marking Feature Extraction", IEEE Conf. Intelligent Transportation Systems, 2008.
[22] L Duan, C Wu, F Fang, J Miao, Y Qiao, J Li,"Visual Attention Shift based on Image Segmentation Using Neurodynamic System",IJCSI, vol. 8, no.3, January , 2011,pp.81 - 86.
[23] M. Cheng, G. Zhang, N. Mitra, X. Huang, and S. Hu, "Global Contrast based Salient Region Detection", in IEEE Conf. Computer Vision and Pattern Recognition, 2011.
[24] M. Rubinstein, A. Shamir, and S. Avidan. "Improved seam carving for video retargeting", ACM Trans. on Graphics, 27(3), 2008.

Chao Jia Professor, PhD supervisor, born in 1967. In 1991, he received the B.E. degree in computer profession, Northeast Heavy Machinery Institute. In 1998, he received the M.Sc degree and in 2005 he received the Doctor degree in College of Information Science and Engineering, YanShan University, China. Since 2011 he has been with College of Information Science and Engineering as a Professor. Prof. He has published numerous papers, completed more than one large-scale project. Such as his main research interests include computer graphics, computer vision and image processing, virtual reality and virtual simulation.

Fang Hou was born in 1987. She received the B.S. degree in College of Computer Science and Technology in Harbin Science and Technology University in 2011. Currently, she is a graduate student in College of Information Science and Engineering, Yanshan University, China. Her main research interests include computer vision and image processing.

Liangliang Duan was born in 1985. He received the B.S. degree in College of Information Science and Engineering in Shandong Agricultural University in 2009. He received the M.Sc degree and in 2011. Currently, he is a doctor student in College of Information Science and Engineering, Yanshan University, China. His main research interests include computer vision and image processing.