LETTER

Salient Edge Detection in Natural Images

Yihang BO[†a)], ***Student Member***, **Siwei LUO**[†], ***Member***, ***and*** **Qi ZOU**[†], ***Nonmember***

SUMMARY Salient edge detection which is mentioned less frequently than salient point detection is another important cue for subsequent processing in computer vision. How to find the salient edges in natural images is not an easy work. This paper proposes a simple method for salient edge detection which preserves the edges with more salient points on the boundaries and cancels the less salient ones or noise edges in natural images. According to the Gestalt Principles of past experience and entirety, we should not detect the whole edges in natural images. Only salient ones can be an advantageous tool for the following step just like object tracking, image segmentation or contour detection. Salient edges can also enhance the efficiency of computing and save the space of storage. The experiments show the promising results.

key words: *salient edge detection, boundary detection, salient point detection*

1. Introduction

Given a new natural image, even though with complex background or noise, people can perceive the contours between the objects or surfaces and determine which is salient or not quickly and exactly. Figure 1 shows the natural images and boundary images human marked which are selected from Berkeley Dataset.

While it is not easy for computer to do the work mentioned above, computer does not know what saliency means, where the boundaries are and whether they are salient ones or not. The only thing we can do is that tell the computer what saliency means and how to compute the saliency which is an interesting work in computer vision.

There are many kinds of remarkable methods of saliency detection all of which follow the Gestalt Principle [10] of proximity and good-continuation, for example, the salient points, salient shapes, salient boundaries or other structures detection. A method of region enhanced scale-invariant saliency detection is proposed by Liu [1], which provides robust scale-invariant saliency and suitable to get the meaningful regions not contours. Hou [2] developed a spectral residual approach for saliency detection. Zh Wang [3] proposed a two-stage framework for saliency detection involved in human vision. A graph-theoretic method developed by Song Wang [4] is used to extract perceptually salient boundaries from a set of noisy boundary fragments detected in real images. Tensor voting, proposed by Tang [5], is also an excellent approach for salient point detections.

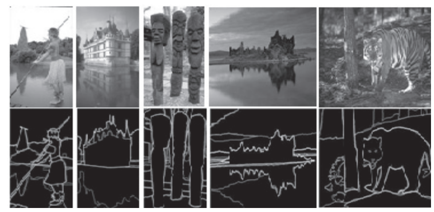


Fig. 1 Human marked images. The first row are the original images, and the second row are the human marked images.

Recently, interest points [6] are more and more popular in computer vision because of their particular quality in images. Furthermore, so many saliency detection methods also appear which are helpful for boundary detection, contour organization and other subsequent processing. There is a small difference between interest points and salient points. The points we are interested may not be salient, oppositely, salient points may not the ones we are interested. Nevertheless, they are both the ones who have a well-defined position in image space and are used for further processing in the vision system. So many methods of edge detection [7] which is not a new terminology are developed started from Canny edge detection which uses a multi-stage algorithm to detect a wide range of edges in image. Nevertheless, it often includes many uselessness edges we do not need.

In our paper, we propose a new salient detection, salient edge detection, in natural images which is a useful cue for object tracking, image segmentation or contour detection. Section 2 introduces the boundary detection [8]. Section 3 shows the salient point detection method. Section 4 is salient edges detection and experiments. Section 5 gives the future work.

2. Boundary Detection

According to David R. Martin [8], a boundary is "a contour in the image plane that represents a change in pixel ownership from one object or surface to another", and an edge is "most often defined as an abrupt change in some low-level image feature such as brightness or color". Edges are basis of boundaries.

David R. Martin [8] used brightness, texture and color to detect boundaries in natural image. They trained a classifier using human marked images as ground truth to combine the cues in an optimal way. Then the posterior probability

Manuscript received November 10, 2008.
Manuscript revised December 30, 2008.

[†]The authors are with Beijing Jiaotong University, China.
a) E-mail: yihang_bo@126.com

DOI: 10.1587/transinf.E92.D.1209

of a boundary is obtained.

2.1 Image Features

One oriented energy (oriented energy), three gradient-based features (brightness gradient, color gradient and texture gradient) are used to detect the local discontinuities in natural images.

The oriented energy (OE) approach [9] is used to detect and localize composite edges (e.g., see Eq. (1)).

$$OE_{\theta,\sigma} = (I * f^e_{\theta,\sigma})^2 + (I * f^o_{\theta,\sigma})^2 \quad (1)$$

Where $f^e_{\theta,\sigma}$ and $f^o_{\theta,\sigma}$ are even and odd filters at orientation θ and scale σ separately, the first term of Eq. (1) is a Gaussian second-derivative and the second term is a Hilbert transform.

Gradient is used to detect local changes in brightness, color, and texture. At any location labeled (x, y) in one image, there exist a circle with radius of r, divide the circle into two halves along the diameter at orientation θ, compare the cues in the two halves. The larger the difference is, the more discontinuity along the diameter is.

The three cases (brightness, color and texture) of the half-disc region are described by histograms, which are compared with the χ^2 histogram difference operator (e.g., see Eq. (2)).

$$\chi^2(g, h) = \frac{1}{2} \sum \frac{(g_i - h_i)^2}{g_i + h_i} \quad (2)$$

Where g and h represent the histograms mentioned above. For brightness and color, kernel density estimates of the distributions of pixel luminance and chrominance in each disc half are binned, so here i indicates the index of bins. For texture, i means the texton type which obtained by clustering the vector of each pixel which is computed by convoluting with a filter bank containing both even and odd filters at multiple orientations.

The gradient computation includes 8 different orientations and 3 half-octave scales at each pixel in the image.

2.2 Cue Combination

Cue combination is seemed as a supervised problem whose combination rules are learned from the ground truth data. In order to combine the content from these features in an optimal way, they trained a classifier using human marked images as ground truth.

2.3 Result Images

They used the cues of BG (brightness gradient), TG (texture gradient) and CG (color gradient) in color images. Figure 2 shows the final results of this method. The first row shows original images, the second row shows boundary detection images using BG, TG and CG in color images.

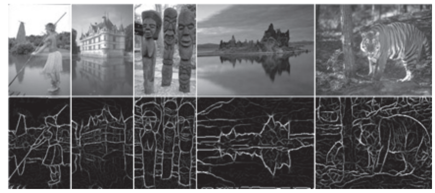


Fig. 2 The first row shows original images, the second row shows boundary detection images using BG, TG and CG in color images.

3. Salient Point Detection

The goal of salient point detection (SPD) is to find whether the point on the edge detection image belongs to the contour or the outliers. In this paper, we define salient point as the point that on the boundary or contour between regions or discontinuity which can help us to find the salient edges in natural image. Here, we use the result of scale space edge detection [11] or Sobel edge detection to be the input of tensor voting to get the salient points in natural images.

3.1 Scale Space Edge (SSE)

Scale Space Edges is an edge detector that identifies maximal spatial intensity transitions in images. Its design emphasizes edge segment continuity and accurate characterization of edges for use in image segmentation and feature extraction. It can be configured to find the most salient edge segments early in the full search, and/or exhaustively search a given range of scale space. The normalized strength of edge response which defined as follow equation (e.g., see Eq. (3)).

$$NStrength = \sqrt{scale} * |gradient| \quad (3)$$

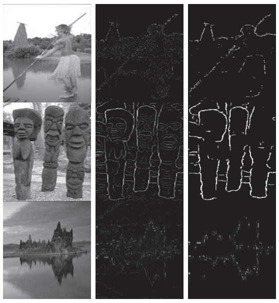
3.2 Tensor Voting

Tensor voting [5] is a good method which can inference the multiple salient structures such as points, junctions, curves, regions, and surfaces in 2-D or 3-D images simultaneously. This method is based on two facts: one is tensor calculus for representation and the other is voting for data communication. It needs no initial guess or threshold, and is noniterative with only one free parameter.

A second order symmetric, non-negative definite tensor is proposed to represent the type and the saliency of the token. Tokens cast second order votes to each other according to the tensors they are associated with in their neighborhood.

3.3 Salient Point Detection

We use the result of SSE to be the input of tensor voting which can get more beautiful result of salient points. Figure 3 shows the results of salient point detection. Column (a) are the original images, column (b) are edge detection result of SSE, and column (c) are the final result of tensor voting—salient point detection images.



(a) (b) (c)

Fig. 3 Results of salient point detection. Column (a) are the original images, column (b) are edge detection result of SSE, and column (c) are the final result of tensor voting—salient point detection images.

4. Salient Edge Detection (SED)

This paper presents a quality method for salient edge detection. Here we give our definition of edge and salient edge: edge is the combination element of boundary which detected by the method showed in Sect. 2. Salient edge is the salient element on the boundary which is useful for object tracking, image segmentation and so on in terms of past experience and entirety in Gestalt Principle. So we use mid-level technique—boundary and low-level technique—salient point to find the salient edge which is a key part in natural image and a new cue for subsequent processing.

4.1 Past Experience in Perceptual Organization

Not like other principles in perceptual organization, the past experience discussed by Wertheimer (1923/1950) [10] is not mentioned so frequently. The main idea of this principle is that if elements have been previously associated in prior viewings, they will tend to be seen as grouped in present situations. In other words, in the processing of perceptual, people try to make some explanation on perceptual object based on the past experience, but not record the feature of the perceptual object passively.

Figure 4 (a) shows an interesting image which explains the principle of past experience. Initially, you may see some random black points in the image and nothing can attract your attention. Nevertheless, if you are told that there is a dog with his head down lie in a street, you will continue to see it that way in the future. How dramatic the past experience is, especially with the image which is ambiguous. Another example is showed in Fig. 4 (b). There are many discontinuous fragments in the image, when you are told that there is a girl play with a dog, you will organize these fragments together in a meaningful way. In our paper, we consider these fragments as salient edges which can be organized to a meaningful image according to past experience.

4.2 Entirety in Perceptual Organization

Entirety is another principle in Gestalt Principle. People often percept the object as an entirety and fill the gaps unconsciously but the isolated parts. The key parts decide the entirety of perceptual although they are discontinuous. For instance, we can consider the fragments in Fig. 4 (b) as key parts and they can help us to percept the whole content. In our paper, we call the key parts, for example the fragments, salient edges.

(a) (b)

Fig. 4 Effects of past experience on organization.

4.3 Salient Edge Detection and Experiments

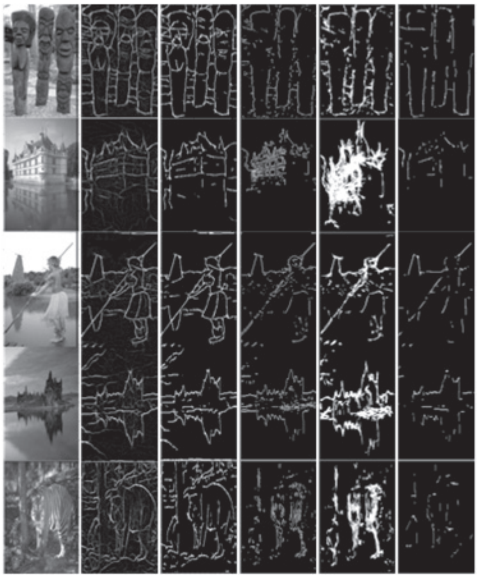
Our paper proposes a method for salient edge detection which uses boundary cue and salient point. According to our definition of salient point, the edges which contain numbers of salient points are salient edges we want to obtain. The more salient points the edge has, the more salient the edge is. So the goal of our method is to find the edges with salient points for the subsequent processing which follow the principles of past experience and entirety in natural images.

In our experiments, we use Sobel edge detection to detect the edges which are the input of tensor voting at default scale because of the future work of multi-scale salient edge detection mentioned in Sect. 5. In tensor voting, the parameter of voting scale is also its default value (18.25). The boundary images are obtained by the method of Martin [8] which combine the cues of BG, TG and CG in color images. We preserve the points on the boundaries whose pixel value is larger than 100 in its gray images, so the thin, unclear and unimportant boundaries are ignored.

We detect the boundaries and compute the total number of salient points on each of them preserve the ones whose salient point number is more than the saliency threshold (ST).

Figure 5 shows the results of our experiments. Column (a) are the original images, column (b) are boundary image using BG, TG and CG from color images, column (c) are boundary images whose pixel value on the boundary is more than 100, column (d) are edges detection images by Sobel edge detection, column (e) are salient points image, column (f) are salient edge images whose ST are more than 1. Larger ST will lead to less salient edges. Here we choose 1 which leads to the most coherent contour convenient to subsequent processing.

Firstly, look at Fig. 6 (a), a boating man can be seen and it will not be strange to us. Then look at Fig. 6 (b), what can you perceive? Let the integrated boundary or contour to be the ground truth of training, then our salient edges can be used to track the object in a set of sequence images. Also they can be used to do the image segmentation and contour detection.



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

Fig. 5 Results of our experiments. Column (a) are the original images, column (b) are boundary image using BG, TG and CG from color images, column (c) are boundary images whose pixel value on the boundary is more than 100, column (d) are edges detection images by Sobel edge detection, column (e) are salient points image, column (f) are salient edge images whose ST are more than 1.

(a) (b)

Fig. 6 Boundary detection image and salient edge image. (a) is a boundary detection image, (b) is a salient edge detection image.

As we know, image segmentation in complex natural images needs local features, for example edges, that are unaffected by noise, occlusion and other disturbance. Usually, these features share similar properties with neurons in inferior temporal cortex that used for object recognition, and are required that they should invariant to any changes of the image. A staged filtering method is used to detect these features. In this paper, based on our approach of salient point detection, the salient edges can be considered as the features for image segmentation.

In object tracking, we need not find all of the boundary or edges, the only thing we should do is finding the salient edges on the images which can enhance the efficiency of tracking. For the subsequent processing, only the location of each point on salient edges should be saved. For instance, Fig. 6 (a) and (b) are binary images. The edge information should be saved are 10.3 kb and 3.86 kb respectively. The storage space is saved significantly.

5. Future Work

The results showed in Sect. 4 are single-scale detection of salient edge detection, then, we will detect the salient edges at multiple scales which will use the cues of salient points, average curvature and length of the edge, and the stability of the edge across different scales.

Salient edges which are detected by boundaries and salient points are also important cues for object tracking, image segmentation and contour detection which are interesting works we will do in the future.

Acknowledgments

This work is supported by National High Technology Research and Development Program of China (2007AA01Z168), National Nature Science Foundation of China (60773016) and Doctoral Foundations of Ministry of Education of China (20050004001). National High Technology Research and Development Program of China (2007AA01Z168), National Nature Science Foundation of China (60805041, 60872082, 60773016) and Doctoral Foundations of Ministry of Education of China (20050004001).

References

[1] F. Liu and M. Gleicher, “Region enhanced scale-invariant saliency detection,” Proc. IEEE ICME, 2006.

[2] X. Hou and L. Zhang, “Saliency detection: A spectral residual approach,” IEEE Conference on Computer Vision and Pattern Recognition (CVPR07), IEEE Computer Society, June 2007.

[3] ZH. Wang and B. Li, “A two-stage approach to saliency detection in images,” IEEE International Conference on Acoustics, Speech and Signal Processing, 2008, ICASSP 2008, April 2008.

[4] S. Wang, T. Kubota, and J.M. Siskind, “Salient boundary detection using ratio contour,” Neural Information Processing Systems Conference, 2003.

[5] C.-K. Tang, M.-S. Lee, and G. Medioni, Tensor Voting, Recent Advances in Perceptual Organization, Kluwer, 2006.

[6] K. Mikolajczyk and C. Schmid, “An affine invariant interest point detector,” Proc. ECCV, vol.1, pp.128–142, 2002.

[7] D. Marr and E. Hildreth, “A theory of edge detection,” Proc. Royal Soc. of London B, vol.207, pp.187–217, 1980.

[8] D. Martin, C. Fowlkes, and J. Malik, “Learning to detect natural image boundaries using local brightness, color, and texture cues,” PAMI, vol.26, no.5, pp.530–549, 2004.

[9] M. Morrone and D. Burr, “Feature detection in human vision: A phase dependent energy model,” Proc. Royal Soc. of London B, vol.235, pp.221–245, 1988.

[10] D.B. King and M. Wertheimer, Max Wertheimer and Gestalt Theory, Transaction Publishers, New Brunswick, NJ, 2005.

[11] T. Lindeberg, “Feature detection with automatic scale selection,” Int. J. Comput. Vis., vol.30, no.2, pp.77–154, 1998.