Evaluation of the Relationships between Saliency Maps and Keypoints

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1. INTRODUCTION

In recent years, many attempts have been done such as the selection of desired information in input information [1,2]. If attention models can be constructed to select information, the intelligence and awareness of human can be implemented in computers. According to Itti et al., saliency is defined as the property of images, which triggers bottom-up attentions. Saliency occurs by the local conspicuity over the entire visual scene [3]. In this model (Figure 1), input image is decomposed into luminance, color, and orientation components, then, each component is processed individually with Gaussian filter.

Considering that the saliency map is applied to environment recognition by mobile robots, various changes in photographing condition are expected to affect the input image. The change affects spatial frequency components of the image. If the spatial frequency changes, the response of Gaussian filter also changes, then, the effect reflects saliency map. Considering that the saliency map is used to select the keypoints of the image, changes in the saliency map affect the results of feature selection, then, input data of detectors vary. Thus, recognition results are influenced according to the change in photographing conditions.

For keypoint extraction, small influence is desirable in spite of the variety of object size, angle and luminance. In case of the keypoint application for object detection, repetitively extracted keypoints are ideal to select.

In our research, we propose a method for generating saliency maps, which can absorb the effect of spatial frequency changes. If the parameters of the filters can be determined automatically, the effect of the spatial frequency change can be diminished in saliency maps (Figure 2 Bottom). We evaluated the relationship between saliency and keypoints.

2. RELATED WORK

2.1. Saliency Map

Itti et al. [3] simulated human eye movement, and expressed the result as saliency maps (Figure 1). In the process of saliency map creation input image is reduced by 1/2\(^n\) and nine resolutions of the images are obtained. The Center and the Surround can be obtained through the smoothing operation by a common Gaussian filter. This signal process is similar to the different responses from fovea and its neighbor in retina for the common stimuli. All the reduced images are enlarged to the same size, and the across scale difference image of the two components is normalized and added to obtain a map for each component (i.e. Luminance, Color, Orientation). Saliency map is obtained through the addition of all the maps of the three components.

According to Frintrop et al. [4], saliency map changes if the parameter of the Gaussian filters are changed. The ratio of filter parameter \(\sigma_r/\sigma_s\) is crucial for the determination of saliency. Arbitral selection of \(\sigma_r/\sigma_s\) enabled high granularity in saliency map. However, in Itti et al. [3] and Frintrop et al. [4], the parameters cannot be adjusted depending on the variety of spatial frequency. As the result, saliency map can be affected in the event of spatial frequency change (Figure 2 Top).
2.2. Keypoint Extraction

Keypoint extraction is often applied for object recognition tasks [5], image stitching tasks [6], etc. by robot vision. A keypoint has a co-ordinate, a descriptor which explains brightness gradient in the neighborhood. In the object recognition task, the database image and the newly observed image are searched. Recently, scale-invariant keypoint extraction methods have been proposed, such as SIFT [7], and Binary Robust Invariant Scalable Keypoints (BRISK) [8] (Figure 3). As the result, the stability of object detection has been improved. However, if photographing conditions (brightness of the environment, size of the observed object, focusing conditions, camera internal parameters, etc.) change, the number of extracted keypoints changes significantly. Stably extracted keypoints are desirable for the use of object detection tasks by robot vision.

3. PROPOSAL OF SALIENCY MAP

3.1. Outline

In this research, we developed the theory of Frintrop et al. [4] to mitigate the effect of spatial frequency variation. The strategy is automatic adjustments of $\sigma_c$ and $\sigma_s$. In the saliency map generation process (Figure 4), the input image is decomposed into luminance, color, and orientation components in advance. For each component, the Center and the Surround are generated by the combination of integral image and box filters. The parameter of the filters are automatically adjusted so that the pixel values of the across scale difference are maximized. The across scale differences of all three components are merged to form saliency map.

3.2. Decomposition of Input

We utilize CIE-Lab color system to simplify the difference of complimentary color channel. $I_l$, $I_a$ and $I_b$ indicates luminance, color (Red-Green), color (Blue-Yellow) component, each other. For the obtainment of orientation component, Haar-Like Filters (Figure 5 [9,10]) are convoluted on $I_l$. The operations are expressed as Equation (1).
\[ I_\theta(p_p) = \left| I_c(p_p) - \frac{1}{2} I_{cl}(p_p) - \frac{1}{2} I_{cl}(p_p) \right| \] (1)

3.3. The Center and Surround

We align two box filters \(F_{bc}, F_{sc}\) centered with point \(p_p\) as shown in Figure 6. The filters are used for convolution to generate the Center and Surround. The filter widths \(W_{bc}, W_{sc}\) can be variable up to \(W_{\text{max}}\) and fulfill \(W_{bc} > W_{sc}\). This arrangement is same as Mochizuki et al. [11].

3.4. Filter Adjustment

To obtain across scale difference of luminance, color components, we maximize the pixel value of the difference \(I_c(p_p)\) as in Mochizuki et al. [11] by changing \(W_{bc}(p_p), W_{sc}(p_p)\) according to Equation (2) and Figure 6.

\[ I_c(p_p) = \max_{W_{bc}(p_p), W_{sc}(p_p)} I_c(p_p) \]

\[ I_{c\theta}(p_p) = \max_{W_{bc}(p_p), W_{sc}(p_p)} \left| I_{c\theta}(p_p) - I_c(p_p) \right| \] (2)

Here, \(W_{bc}(p_p), W_{sc}(p_p)\) satisfies \(W_{bc}(p_p), W_{sc}(p_p)\).

On the other hand, for orientation component, to obtain across scale differences the sizes of the Haar-like Filters are set to \(W_{bc}(p_p), W_{sc}(p_p)\), then, the filters are convoluted with \(I_c\). The responses of the Center and the Surround are denoted as \(I_{c\theta}(p_p), I_{c\theta}(p_p)\). The across scale differences of all directions are obtained and merged to map \(M_{c\theta}(p_p)\).

3.5. Saliency Map Generation

Map \(M_c\) (for Color), and \(M_\theta\) (for Orientation) are obtained by Equations (4) and (5). Saliency map \(M_{\text{Sal}}\) is formed through the merge of \(M_c, M_\theta\) with Eq. (6). The functions \(f_{\text{mix}}, g_{\text{mix}}, h_{\text{min}}\) for merging maps can be selected arbitrarily.

\[ M_c = f(M_{cb}, M_{ch}) \] (4)

\[ M_\theta = g(M_{\theta h}, M_{\theta e}, M_{\theta v}, M_{\theta s}) \] (5)

\[ M_{\text{Sal}} = h_{\text{min}}(M_1, M_2, M_3) \] (6)

4. EVALUATION OF THE RELATIONSHIP BETWEEN SALIENCY AND KEYPOINT EXTRACTION

4.1. Outline of the Experiment

In this experiment, we assume that the selected image keypoints are used for object detection. Thus, we evaluate the relationship between saliency \(M_{\text{Sal}}\) and feature stability \(F_{\text{Stb}}\). Suppose the number of small regions is \(N_q, F_{\text{Stb}}\) and \(M_{q\text{Sal}}\) are expressed in line vector of \(N_q\) dimensions. However, we treat \(M_{q\text{Sal}}\) and \(F_{\text{Stb}}\) as two dimensions (Figure 7). Then, we calculate the relationship \(\phi\) by obtaining inner product \(F_{\text{Stb}} \cdot M_{q\text{Sal}}\). The saliency maps were generated by conventional methods (i.e. Itti method, VOCUS2) and our proposal to compare \(\phi\). The source codes for the experiment are Simpsal [12] by Caltech for Itti method, and [13] for VOCUS2. We chose BRISK [8] as keypoint extraction method because descriptor is expressed in binary system. Such system is reported to require shorter time for matching than SIFT [7]. Furthermore, the descriptor has properties of rotation and scale invariance.

4.2. Evaluation Function

We consider two conditions of keypoints which have high stability under photographing condition variety. First, the keypoints must extracted at the same location. We define the property as repeatability. Second, the descriptors must remain the same, that is, the similarity.

To evaluate keypoint stability, keypoint displacement have to be considered because of image flicker, resize of observed object size. For example, the combination of the same keypoints is considered as (I) or (II) in Figure 8 in different photographing condition. We define a small region of \(W_q \times H_q\) [Pixels] to search identical keypoints.

Suppose \(N_{q,p,v,i}\) keypoints are extracted at \(n_{q,i}\)-th small region under \(i\)-th photographing condition, the variance \(\sigma^2_{q,p,v,i}\) of...
keypoint number is obtained by Equation (7). The average \( N_{kp,q} \)
(for \( N \) variations of a parameter) of extracted keypoints is obtained by
Equation (8).

\[
\sigma_{kp,q} = \frac{1}{N} \sum_{i=1}^{N} (N_{kp,q,i} - N_{kp,q})
\]

\[
N_{kp,q} = \frac{1}{N} \sum_{i=1}^{N} N_{kp,q,i}
\]

\( r_{kp,q} \) is obtained by the normalization of \( \sigma_{kp,q} \). \( r_{kp,q} \) should be larger
if \( \sigma_{kp,q} \) is smaller as shown in Equation (9).

\[
r_{kp,q} = 1 - \frac{\sigma_{kp,q}}{\max_q \sigma_{kp,q}}
\]

To obtain similarity, we select two keypoints from the same small
region (as seen in Figure 8) and different photographing conditions,
then calculate Hamming distance between the two descriptors. To obtain
average Hamming distance of all combinations of the keypoint pairs, we use Equation (10). The similarity \( s_{Derr,q} \)
is calculated with normalization by Equation (11) so that the range satisfies [0,1], and \( r_{Derr,q} \) is smaller as the distance is larger.

\[
r_{Derr,q} = \min_{x} \sum_{j=1}^{N-1} \sum_{l=1}^{N-1} d_{j,l}(d_{j,l},d_{l,m}) \cdot \frac{1}{D_F}
\]

s.t. \( K = [k_1,k_2,k_3,\ldots,k_N], l,m = 1,2,\ldots,N, l \neq m \)

\[
s_{Derr,q} = 1 - \frac{r_{Derr,q}}{\max_q r_{Derr,q}}
\]

Keypoint stability of \( F_{sbq} \) is calculated by the weighting of \( r_{Derr,q} \)
and \( s_{Derr,q} \) as shown in Equation (12).

\[
F_{sbq} = wr_{kp,q} + (1 - w)s_{Derr,q}
\]

For the saliency \( M_{sal,j,n} \), the maximum response of \( M_{sal} \) is searched
within each small region. Maximum saliency and feature stability
are expressed as \( N \) dimensions of line vectors (denoted as \( M_{sal}, F_{sb} \)), respectively). \( \phi \) is calculated as the angle between the two vectors [Equation (13)]. To be noted that \( r_{kp}, s_{Derr} \) are calculated only for
the regions where keypoints are extracted more than twice during
\( N \) variations of photographing conditions.

\[
\phi = \cos^{-1}\left( \frac{M_{sal,j} \cdot F_{sb} }{||M_{sal,j}|| \cdot ||F_{sb}||} \right)
\]

\[
F_{sb} = [F_{sb,1}, F_{sb,2}, \ldots, F_{sb,N_f}, F_{sb,N_i}]
\]

\[
M_{sal,j} = [M_{sal,j,1}, M_{sal,j,2}, \ldots, M_{sal,j,N}, \ldots, M_{sal,j,N_i}]
\]

The average \( \bar{\phi} \) is obtained according to Equation (14).

\[
\bar{\phi} = \frac{1}{N} \sum_{j=1}^{N} \phi
\]

4.3. Method

Figure 9 shows the experimental images (Lenna, Flower, Tree, Things). These images were selected in the database of Caltech [14] and Standard Image Data Base (SIDBA) [15]. The spatial frequency spectrums of the images are shown in Figure 10. Lenna is well known for test image to be used image analysis. Flower has wider spectrum than Lenna with higher frequency component. As well as the comparison of Things and Tree, Things has higher frequency component than Tree.

The photographing condition to adjust to vary extracted key-
point number is \( I_{Max}/I_{Max} \), for luminance, \( W_{Obj}/W_{Obj} \) for object size, each other, whose range is from 0.5 to 1.0 with the step 0.1 of increase.

For changing \( W_{Obj} \), we selected images of no white background, (i.e. Tree and Flower). We selected \( T_{FAST} = 20 \) \( (T_{FAST}: \) Threshold of \( T_{FAST} \) Score [8]) and \( I_{Max} = 255 \) during the adjustment of \( I_{Max} \) and
W_{Obj}. As the setting of the proposal, for Setting 1, W_{pmax} = W_{IM}/4 and for Setting 2, W_{pmax} = W_{IM}/2. W_{IM} indicates the image width. The resolution of the image is W_{IM} \times H_{IM} = 512 \times 512 [Pixel].

4.4. Results and Discussion

Tables 1 and 2 shows the relationship of $M_{Sal, r}$ and $M_{Sal, s}$ under variable $I_{Max, i}$ and $W_{Obj, i}$ each other. Flower has higher frequency component than Lenna, and Things has higher frequency component than Tree.

We discuss the comparison of $\overrightarrow{\sigma}$ under variable $I_{Max, i}$. Referring to Tables 1 and 2 for VOCUS2 and Itti, $\overrightarrow{\sigma}$ was large for high spatial frequency. While, for proposal, $\overrightarrow{\sigma}$ is less influenced by spatial frequency change compared with conventional method.

Figures 11 (for Lenna) and 12 (for Flower) show the location of keypoints on saliency map (Left), the histogram which indicates the response of saliency at the locations respectively. There is difference in frequency component, however, for the case of the proposal, the location of the peak in the histogram is higher saliency than other saliency map. Thus the inner product in Equation (13) becomes larger. The change of $W_{Obj}$ means the image reduction, then high frequency component increases. The proposal recorded smaller $\overrightarrow{\sigma}$ than others. As the results, the $M_{Sal}$ of our proposal turned out to have larger correlation in feature stability and saliency, which means our proposal is more suitable for keypoint selection.

| Image | VOCUS2 | Itti | Proposal |
|-------|--------|------|----------|
|       | 1/10   | 5/10 | Set 1    | Set 2    |
| Lenna | 18.13  | 20.63| 31.61    | 19.94    | 18.04    |
| Flower| 29.00  | 29.64| 41.39    | 19.72    | 18.98    |
| Tree  | 21.85  | 24.34| 33.97    | 20.76    | 20.10    |
| Things| 31.24  | 29.77| 28.36    | 19.60    | 18.37    |

(b) $w = 0$ ($F_{ab} = s_{im}$)

Lenna | 17.20 | 18.45| 33.15    | 20.05    | 17.65    |
Flower| 28.85 | 29.32| 42.18    | 19.66    | 18.82    |
Tree  | 18.97 | 21.53| 33.90    | 19.24    | 17.27    |
Things| 28.58 | 27.40| 26.67    | 15.21    | 13.11    |

Tables 1 and 2 shows the relationship of $M_{Sal, r}$ and $M_{Sal, s}$ under variable $I_{Max, i}$ and $W_{Obj, i}$ each other. Flower has higher frequency component than Lenna, and Things has higher frequency component than Tree.

We discuss the comparison of $\overrightarrow{\sigma}$ under variable $I_{Max, i}$. Referring to Tables 1 and 2 for VOCUS2 and Itti, $\overrightarrow{\sigma}$ was large for high spatial frequency. While, for proposal, $\overrightarrow{\sigma}$ is less influenced by spatial frequency change compared with conventional method.

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| Image | VOCUS2 | Itti | Proposal |
|-------|--------|------|----------|
|       | 1/10   | 5/10 | Set 1    | Set 2    |
| Tree  | 22.62  | 23.22| 34.06    | 21.87    | 22.16    |
| Things| 28.74  | 25.83| 29.56    | 18.96    | 17.68    |

(b) $w = 0$ ($F_{ab} = s_{im}$)

Tree  | 24.57 | 25.37| 35.30    | 23.24    | 23.88    |
Things| 28.30 | 27.06| 29.74    | 21.52    | 20.09    |

Table 1 Comparison of $\overrightarrow{\sigma}$ (variable $I_{Max, i}$)

(a) $w = 1$ ($F_{ab} = r_{im}$)

Table 2 Comparison of $\overrightarrow{\sigma}$ (variable $W_{Obj, i}$)

(a) $w = 1$ ($F_{ab} = r_{im}$)

(b) $w = 0$ ($F_{ab} = s_{im}$)

5. CONCLUSION

In this research, we proposed method of saliency map generation which consists of adaptive filter adjustment to spatial frequency to aim at preventing fluctuation of saliency caused by different input image and photographing condition change. Our saliency map method turned to be suitable for selecting keypoints less affectable by photographing condition change compared with other conventional methods.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

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AUTHORS INTRODUCTION

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