Gradient-threshold Edge Detection based on Perceptually Adaptive Threshold Selection

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Abstract—Despite the prevalence of conventional methods for gradient-threshold edge detection, the underlying global threshold is not adaptive to the image content with respect to the human perception. To address the inherent challenges, local thresholds are adaptively selected in this paper taking into account the activity masking characteristic of the human visual system. The selected local thresholds are then utilized for edge labeling in the gradient image. Extensive experimental results have demonstrated the effectiveness of the proposed method for edge detection in perceptual quality.

I. INTRODUCTION

Edge detection plays an important role in various areas of image processing and computer vision. Among all existing related techniques, those based on gradient-threshold detectors usually underpin edge detection in conventional applications due to their simplicity and efficiency. Generally, an image is subject to three steps of operations in gradient-threshold edge detection: image smoothing, image differentiation, and edge labeling.

Conventional techniques for gradient-threshold edge detection, e.g. Sobel, Prewitt and Canny detectors, employ a global threshold for edge labeling [1-3]. However, the characteristics of the human visual system (HVS) are not well taken into account in the corresponding edge detection, regardless the fact that human observers are usually the end users. Consequently the edge images obtained using these conventional methods may not be consistent with the human perception. Improved performance could be obtained by edge detection using local feature analysis without consideration of the HVS [4], whereas edge detection based on the HVS achieves the most outstanding perceptual results [5, 6]. Although the consideration of characteristics of the HVS as in [5] and [6] has contributed to a significant improvement on the performance of edge detection, the corresponding algorithms involve large computational complexity for masking pixels in the gradient image.

In this paper a computationally efficient approach for edge detection is proposed considering the HVS. Since the HVS reacts differently to pixels with the same values in different local content, specific thresholds are selected for local areas according to the perceptual effect of their activity on the HVS. Then the obtained local thresholds are applied for edge labeling. Since the selected local thresholds are perceptually adaptive with regard to the HVS, the resulting edges are consistent with the human perception.

The remainder of this paper is organized as follows. Section II describes the motivation and implementation details of the proposed method for perceptually adaptive threshold selection and the corresponding edge detection. To validate the performance of the proposed method, simulation results are reported in Section III. Section IV closes this paper with conclusions.

II. GRADIENT-THRESHOLD EDGE DETECTION BASED ON PERCEPTUALLY THRESHOLD SELECTION

Serving as the central mechanism for gradient-threshold edge detection, the threshold in edge labeling directly controls the outcome of edge maps. After image smoothing and differentiation, conventional approaches employ only one threshold for the whole gradient image, without resorting to the perceptual effect of the characteristics of the local content. Following the example given in Fig.1, the edges obtained by the Canny detector using a global threshold are obviously not consistent with the perception of the HVS. That is, the global threshold results in an edge map preserving much texture of the lawn, which is usually not concerned by human eyes. On the other hand, however, important details such as part of the grids on the basket are already lost under such a threshold. It is therefore apparent that different thresholds should be used for different local areas for better perceptual results of edge detection.

(a) (b)

Fig.1. Edge detection using the Canny detector.
(a) original image; (b)edge image

In fact, the visibility of a stimulus is affected due to the presence of other stimuli in a surrounding spatial region of limited extent [7]. Therefore the perception to edges is
seriously influenced by the activity of the local background. For example, edges near loose edges and in flat regions are more noticeable to the HVS than those in texture areas. This characteristic of the HVS is usually referred to as activity masking.

To incorporate activity masking in perceptually adaptive edge detection, the most straightforward approach would be to mask each pixel in the gradient image, as proposed in our previous work in [5, 6]. Given a pixel \((x^*, y^*)\) in the gradient image \(\tilde{g}(x, y)\), the magnitude of \(\tilde{g}(x^*, y^*)\) can be masked by the activity as

\[
\left| \tilde{g}_m(x^*, y^*) \right| = \left| \tilde{g}(x^*, y^*) \right| \cdot \left( a_1 + \left( \frac{m(x^*, y^*)}{m_0} \right)^{r_1} \right),
\]

where \(\tilde{g}_m(x^*, y^*)\) is the gradient masked with the activity, \(m(x^*, y^*)\) is the activity of the masking regions where \((x^*, y^*)\) is related to, and \(m_0\) is the average activity of the whole frame. Parameters \(a_1\) and \(r_1\) are usually empirically estimated. Then a global threshold will be applied on the masked gradient image for edge labeling.

According to (1), masking each pixel in the image domain is computationally expensive. In the related techniques, masking regions need to be precisely determined for each pixel, where direction adjustment is usually involved to combat the problems caused by noise and arbitrary edges [5, 6]. Furthermore, the activity in those regions should be computed for each pixel individually. In this paper, this process is reversed by masking the threshold, and then using the masked thresholds in the original gradient image for edge labeling. In the proposed method, the threshold \(T\) can be masked to obtain \(T_m(x^*, y^*)\):

\[
T_m(x^*, y^*) = T \left( a_2 + \left( \frac{m(x^*, y^*)}{m_0} \right)^{r_2} \right),
\]

where \(a_2\) and \(r_2\) are also empirical parameters.

Since the content activity or complexity is usually similar in a local area, it is reasonable to apply a local threshold for adjacent pixels instead of computing the threshold for each pixel using (2). In this paper, the spatial activity of overlapped local areas is estimated and utilized to select the local thresholds. As shown in Fig. 2, the local threshold for pixels in a non-overlapped area is given by

\[
T_m(x^*, y^*) = T \left( a_2 + \left( \frac{m_i}{m_0} \right)^{r_2} \right),
\]

where \(m_i\) is the activity of the \(i^{th}\) local area where \((x^*, y^*)\) belongs to. Typically \(m_i\) can be computed as:

\[
m_i = \frac{1}{M_i} \sum_{(x, y) \in R_i} |\tilde{g}(x, y)|
\]

with \(R_i\) the \(i^{th}\) local area, and \(M_i\) the number of pixels in \(R_i\). For pixels in an overlapped area such as the shaded areas in Fig.2, the local threshold is adjusted as:

\[
T_m(x^*, y^*) = T \left( a_2 + \left( \frac{\overline{m}}{m_0} \right)^{r_2} \right)
\]

with \(\overline{m}\) the average activity of involved local areas where \((x^*, y^*)\) is resided in. Here the activity of each individual local area is computed using (4).

This approach significantly reduces the computational complexity as compared to the original algorithm for activity masking in the gradient image. After spatial activity masking, the local thresholds are employed for edge labeling on the original gradient image. The corresponding labeled edges are therefore consistent to the observation of the HVS.

Based on the proposed threshold selection method, edge detection can be carried out in the following steps:

1) Obtain the gradient image \(\tilde{g}(x, y)\) by image smoothing and differentiation, as other gradient-threshold related methods.
2) Split the gradient image into overlapped blocks and compute local thresholds for each local area using (3) and (5).
3) Perform edge labeling using obtained local thresholds.

III. EXPERIMENTAL RESULTS

The performance of the proposed edge detection method has been extensively evaluated. For the sake of conciseness the results reported in this paper include only two selected test images: “Basket” and “Golf cart”. Similar results can be obtained for other tested images.

In this paper, the proposed method for local threshold selection was incorporated in the Canny detector as an example. For comparison, the standard Canny detector was implemented using the Matlab function `edge(image, ‘canny’)`. The default settings were respectively used for evaluation. Specifically, the high global threshold \(T_h\) was set as a value...
higher than the gradient values of 90% pixels, the low global threshold \( T_l = 0.5 T_h \), and the standard deviation of the Gaussian filter \( \sigma = 1 \).

In the proposed method, the parameters were set as \( a_2 = 0.3 \) and \( r_2 = 1.3 \) for all experiments. These two values were obtained empirically. Since the local thresholds are supposed to be selected according to the activity of local contents, the parameters of the proposed method do not need to be adjusted for different tested images.

Fig. 3. Edge detection results for the “Basket” image. (a) original image; (b) edge image obtained by the standard Canny detector; (c) edge image obtained by the proposed method.

Fig. 4. Edge detection results for the “Golf_cart” image. (a) original image; (b) edge image obtained by the standard Canny detector; (c) edge image obtained by the proposed method.

Fig. 3 shows the original image and the edge images of “Basket”. As shown in Fig.3(b), important edges on the grid get lost using the standard Canny detector, while too much texture details were preserved. It is obviously not consistent with the human perception. Using the proposed method, however, only necessary details were preserved without a significant clutter on the lawn. The results of the image “Golf_cart” are shown in Fig. 4, where similar results can be observed.
IV. CONCLUSIONS

Since characteristics of the HVS are usually not well incorporated in gradient-threshold edge detection, conventional related methods using a global threshold may result in edges inconsistent with the perception. In this paper a method for adaptively selecting local thresholds is proposed based on the activity masking. The adaptive local thresholds in edge detection contribute to better performance in edge detection in the sense of perceptual quality. The proposed method also has the advantage of low complexity. Future work may include edge detection with consideration of more characteristics of the HVS such as luminance masking. This issue is currently under investigation.

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REFERENCES