EDGE DETECTION USING HOLLADAY’S PRINCIPLE

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ABSTRACT

We propose herein a new contour detection algorithm based on the human visual system. Using the proposed method, one can automatically select the thresholds that define the significant edges, such as perceived by the human eye. The threshold value is adapted to the background and surround intensities, according to criteria involved by Holladay’s principle.

THEORY OF THE APPROACH

The basic idea of the proposed method is to adapt to actual digital images some known laws governing the human visual perception. An important work has been devoted to the modeling of relevant data from psychovisual experiments. The intensity discrimination experiment explaining the ability of the eye to discriminate between changes in brightness is governed by the law of Fechner-Weber [1]. If \( B \) is the background intensity and \( B + \Delta B \), the object intensity, \( \Delta B \) being as small as possible and yet visible, then \( \Delta B \), the just noticeable intensity difference, is such that \( \frac{\Delta B}{B} = C_w \) is constant over a large range of intensities or luminances (\( C_w \) is the Weber’s constant). Experiments show that this constancy is somewhat effective for high luminances, but that unfortunately, as \( B \) decreases, \( \frac{\Delta B}{B} \) slowly increases.

Unfortunately, these results are obtained from a simple and unusual situation in practice. Indeed, an actual image may be composed of objects of different brightness on a nonuniform background. Thus, it becomes necessary to perform local analysis where such inhomogeneity in brightness should be taken into account. The original work of Moon and Spencer [2] fills this gap. It would be too lengthy to detail this work and we shall content ourselves with the essential results recalled in [3]. Using previous results, Moon and Spencer [4] have proposed a new expression for the just noticeable contrast \( C_{\text{min}} \), represented by:

\[
C_{\text{min}} = \left( \frac{B-B_0}{B} \right)_{\text{threshold}} = \frac{C_w}{B} \left( A + B^{1/2} \right)^2 \tag{1}
\]

where the constant \( A \) is equal to 0.8, and \( B_0 \) is the object intensity. Figure 1 adapted from reference [3] describes the observation field, the limited luminance test, its short range background area and its long range surround area. Equation (1) corresponds to the case of a uniform surround \( B_s \) (\( B_s(\theta, \phi) = B \)). The perception of differential thresholds is also much influenced by the surround intensity, which is often different from the background intensity. The effect of a nonuniform surround has been studied by many researchers and an overview is presented in [2-4]. A nonuniform surround
is equivalent to a uniform one (Holladay’s principle), the adaptation luminance $B_A$ of which is:

$$B_A = K \int_0^{\pi/2} \theta^{-2} \sin \theta \cos \theta \, d\theta \int_0^{2\pi} \Delta B_s(\theta, \phi) \, d\phi \quad (2)$$

Introducing again the equation (1), one obtains:

$$C_{min} = \frac{C_w}{B} (A + B_A^{-1/2})^2 \quad \text{if } B_A \geq B$$

$$= \frac{C_w}{B} \left( A + \left[ \frac{B^2}{B_A} \right]^{1/2} \right)^2 \quad \text{if } B_A < B \quad (3)$$

For a constant intensity $B_s$ different from $B$ and for the geometry of Fig.1, one gets [2-4]:

$$B_A = 0.923 B + 0.077 B_s$$

When the surround intensity $B_s$ is different from the background intensity $B$, the just noticeable contrast varies according to the curves in Fig.2 (see [5]). Each parabolic curve corresponds to a given intensity $B_s$. For complex images, one cannot refer to a uniform background, since the image is composed of several regions, with different intensities. However it is reasonable in practice to consider that the average gray level of the image faithfully approximates the surround intensity $B_s$ [5]. Let us recall the contrast $C$ as defined by Weber-Fechner:

$$C = \frac{B_0 - B}{B} = \frac{\Delta B}{B}, \quad \text{where } \Delta B$$

is the gradient intensity, $B_0$ is the object intensity, and $B$, is the background intensity. In the present case, we assume

$$C(x,y) = \frac{\Delta B}{B} = \frac{\sum_{p,q} F^k(x,y)}{N} \quad (4)$$

where

$$F^k(x,y) = I(x,y) * G^k(x,y)$$

is the response associated with a series of Gabor’s filters. $I(x,y)$ is the gray level of the current pixel $(x,y)$, $G^k(x,y)$ is the impulse response of the filter on the $\partial_k$ direction [6], $N$ is the total number of directions. Finally, $B$ represents the average gray level of the neighbors of the considered pixel $(x,y)$ (see Fig3), which resumes in:

$$B(x,y) = \frac{1}{N_2} \sum_{p,q} \frac{I(x-p,y-q)}{\sqrt{(x-p)^2 + (y-q)^2}} \quad (5)$$

$N_2$ is the total number of pixels in $R_2$ background area. The use of directional filters allows a better detection of the contour lines, whatever their direction.

From the geometry of Figure.1, the relation between the object area and the background area is $d_1 = 2 \cdot d_2$, where $d_1$ is the half-width of the object area, and $d_2$ is the width of the background (as shown in Fig.3). As following the idea of Kundu and Pal [7], an image element is considered as a contour point if its contrast is greater or equal to $C_{min}$. The following decision rule is performed:

$$E(x,y) = \begin{cases} 
255 & \text{if } C(x,y) \geq C_{min} \\
0 & \text{elsewhere}
\end{cases}$$

EXPERIMENTAL RESULTS

The method has been tested on a set of images, two of them, a building scene and a portrait are illustrated in Fig 5 and Fig.6. Each figure includes the test image (a), our method (b), and the results obtained through the Kundu and Pal’s method [6], given as a reference (c). The parameters $C_w$ used in the comparison correspond to the optimization of both methods. It is to be noticed that the Kundu and Pal’s method does not give an efficient result, when the image is composed of several regions, like a building image. In such situation, the surround and background intensities are different, so that the Weber’s law, which is used by Kundu and Pal is inadapted. The Holladay’s principle looks better in such case (see Fig.5b and 6b), since, it takes into account the difference existing between the surround and the background intensities. In conclusion for images such as given above, our method improves the contour detection, as compared to Kundu and Pal’s method, which is also based on the human visual perception.
BIBLIOGRAPHY


Fig. 1: The field of view for contrast threshold experiment on non-uniform surround (adapted from [3]).

Fig. 2: Contrast sensitivity measurements.

Fig. 3: The analysis window scheme.
Fig. 4: Comparison of our method with the one of Kundu and Pal

a: Original image

b: Our method
$C_w=4\%$

c: Kundu and Pal's method
$C_w=4\%$

Fig. 5: Building scene: the same comparison

a: Original image

b: Our method
$C_w=2\%$

c: Kundu and Pal's method
$C_w=2\%$