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METHOD FOR REAL-TIME EDGE EXTRACTION USING HARDWARE OF LATERAL INHIBITION TYPE OF SPATIAL FILTER

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Abstract It is useful to simulate the human visual function for the purpose of image-processing. In this study, the hardware of the spatial filter with the sensitivity of lateral inhibition is realized by the combination of optical parts with electronic circuits. The diffused film with the characteristics of Gaussian type is prepared as a spatial filter. An object's image is convoluted with the spatial filter. From the difference of the convoluted images, the zero-cross position is detected at video rate. The edge of object is extracted in real-time by the use of this equipment. The resolution of edge changes with the value of the standard deviation of diffused film. In addition, it is possible to extract a directional edge selectively when the spatial filter with directional selectivity is used instead of Gaussian type of spatial filter.

Keywords Image-processing, Hardware, Edge, Spatial filter

1. INTRODUCTION

The edge-information is utilized for the recognition of object in image-processing field. Although the ability of computer progresses rapidly, it is not easy to extract the edge from an object in real-time. The chip of LSI simulating visual cells is made recently[1][2]. By the use of the image-processing system including this chip, the edge is detected fast. There are, however, some problems. It is difficult to change the resolution of edge. In addition, the extraction of specific orientation is not easy in real-time. It is useful to simulate the human visual function for the purpose of image-processing. The mechanism of lateral inhibition of human retina and simple cell is concerned with edge extraction[3].

In this study, the hardware of the spatial filter with the sensitivity of lateral inhibition is realized by the combination of optical parts with electronic circuits. The edge of object is extracted in real-time by the use of this equipment. It is possible to change the resolution of edge and to extract a directional edge selectively.

2. METHOD FOR EDGE-EXTRACTION

2.1 Extraction of Edge

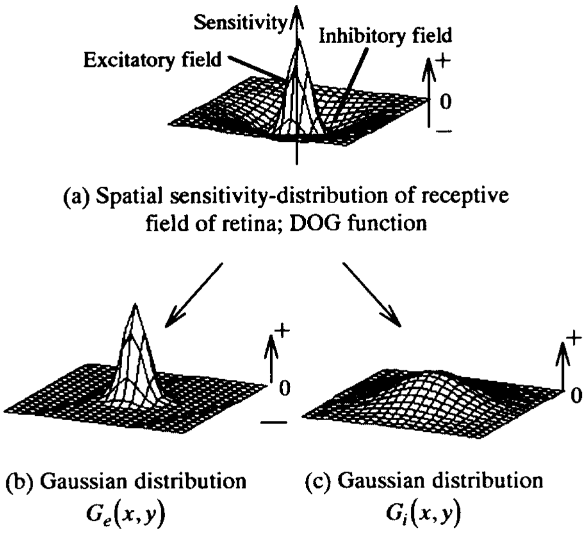
The spatial sensitivity-characteristics of receptive field of retina are approximated by $DOG(x,y)$.

$$DOG(x,y) = G_e(x,y) - G_i(x,y), \quad (1)$$

$$G_e(x,y) = A \cdot \exp\left(-\frac{x^2+y^2}{\sigma_e^2}\right),$$

$$G_i(x,y) = Q \cdot \exp\left(-\frac{x^2+y^2}{\sigma_i^2}\right),$$

where A and Q are constants, σ_e and σ_i are the standard deviations which represent the spread of the excitatory field and the inhibitory field in retina receptively. Let the object's image be $I_0(x,y)$ and let the image obtained by the convolution of $I_0(x,y)$ with $DOG(x,y)$ be $I_{DOG}(x,y)$, then zero-cross position of $I_{DOG}(x,y)$ corresponds with the edge of object. From this thing, the edge is detected by the use of two Gaussian types of spatial filters. Figure 1 explains that DOG function is represented by the difference between Gaussian distributions $G_e(x,y)$ and $G_i(x,y)$. Representing the images obtained by the convolution of object's image $I_0(x,y)$ with Gaussian function $G_e(x,y)$ to be $I_1(x,y)$ and the one obtained by the convolution of $I_0(x,y)$ with $G_i(x,y)$ to be $I_2(x,y)$ respectively, then we can get the relationship of $I_{DOG}(x,y) = I_1(x,y) - I_2(x,y)$. Zero-cross position of $I_{DOG}(x,y)$ means the edge of object. Thereby, it is possible to extract the edge by the use of the spatial filters



(a) Spatial sensitivity-distribution of receptive field of retina; DOG function

(b) Gaussian distribution $G_e(x,y)$

(c) Gaussian distribution $G_i(x,y)$

Fig .1 Explanation that the spatial sensitivity-distribution of receptive field of retina is represented by the difference between Gaussian distributions $G_e(x,y)$ and $G_i(x,y)$.

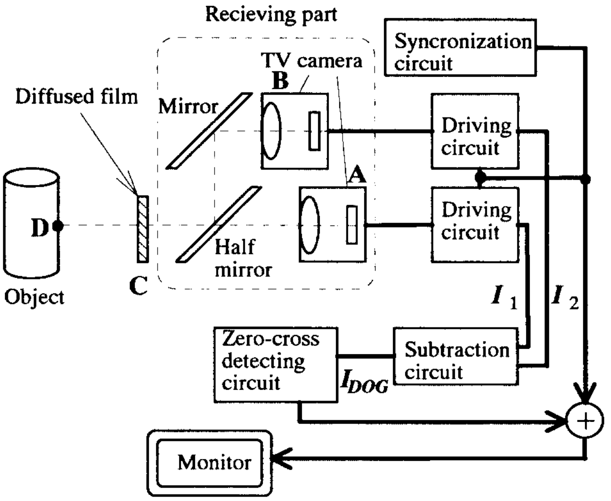
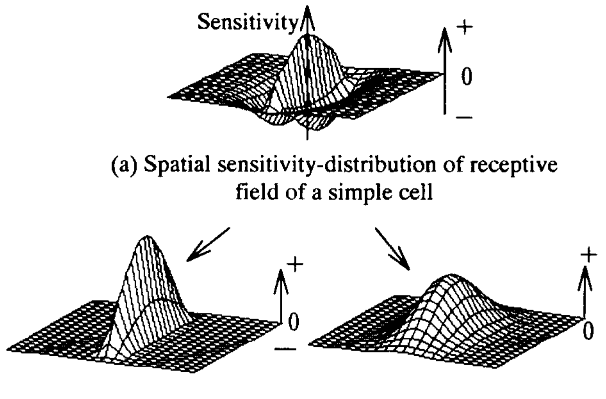


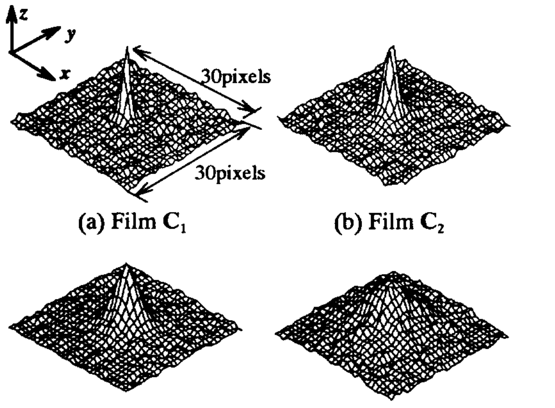
Fig. 2 Block diagram of edge extraction system.



(a) Spatial sensitivity-distribution of receptive field of a simple cell

(b) Distribution $Gcell_e(x,y)$ (c) Distribution $Gcell_i(x,y)$

Fig .4 Explanation that the spatial sensitivity-distribution of receptive field of simple cell is represented by the difference between the distribution $Gcell_e(x,y)$ and $Gcell_i(x,y)$.



(a) Film C_1 (b) Film C_2

(c) Film C_3 (d) Film C_4

Fig. 3 Point spread function of TV camera A in case of using Gaussian types of diffuse films.

such as $G_e(x,y)$ and $G_i(x,y)$. Although the make of the hardware of *DOG* filter is not easy, Gaussian type of spatial filter is easily realized. This is because Gaussian type of spatial filter do not include the inhibitory field but *DOG* filter includes it as shown in Fig. 1.

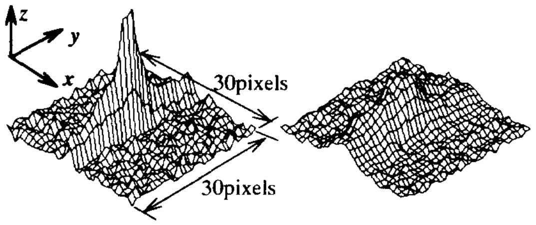
For realizing this method in real-time, we have made experimentally an equipment which consists of optical parts, two TV cameras and electronic circuits. The setup is shown in Fig. 2. Two TV cameras **A** and **B** are set to be on the same optic axis. TV camera **A** is focused on the object's surface but TV camera **B** is defocused a little. A diffuse film **C** with the point spread function (*PSF*) of Gaussian distribution is placed in front of TV cameras **A**. Since TV camera **B** is defocused, the variance of *PSF* of TV camera **B** is different from that of **A**. The point spread function of TV camera involves the spatial filtering characteristic. As the results, the output-images $I_1(x,y)$ and $I_2(x,y)$ of TV camera **A** and **B** correspond to the images which are gotten by the convolution of the input-images with Gaussian type spatial filters. The difference image $I_{DOG}(x,y)$ between $I_1(x,y)$ and $I_2(x,y)$ is obtained by the subtraction-circuit. The output of subtraction-circuit is connected to zero-cross detecting circuit. The zero-cross detecting circuit in this experiment is a pulse-generation-circuit when the value of $I_{DOG}(x,y)$ changes from a positive threshold voltage I_{Th}^{+} to a negative threshold voltage I_{Th}^{-} along horizontal scanning or from I_{Th}^{-} to I_{Th}^{+}. Zero-cross position is regarded as the edge of object.

We make an experiment for confirming the validity of the diffused film. A spot light is irradiated by laser diode on the point **D** on object in Fig. 2. The diameter of the spot is about 1 mm. The various diffused films are set in front of TV camera **A**. The obtained images are shown in Fig. 3. From this figure, we see that the spatial distributions are approximated as Gaussian distributions. In addition, the spreads of the distributions are different one other. The distribution on TV camera **B** is gentle compared to that of TV camera **A** because of defocus. It is approximately considered that the distribution on TV camera **B** is also regarded as Gaussian distribution.

2.2 Extraction of Edge along a Direction

In the visual area of the cerebral cortex, there is a simple cell whose receptive field is long along a specific direction. This cell is concerned with the extraction of a directional edge. Figure 4 indicates the spatial sensitivity-distribution of receptive field of simple cell. Figure 4(a) displays the spatial sensitivity-distribution of receptive field of a simple cell. As understood from Fig. 4(b) and (c), the spatial sensitivity-characteristic is expressed by the difference of two distributions $Gcell_e(x,y)$ and $Gcell_i(x,y)$; these distributions are regarded as the extensions of Gaussian distributions along a direction. Thus, a edge along a specific orientation is extracted by the use of the spatial filters in Fig. 4(b) and (c).

Making sure of this validity, we make a diffused film. Figure 5 displays the point spread function of the diffuse film. This distribution is measured by the same procedure as the diffused films used in Fig. 3. The distributions in Fig. 5 agree well with those of Fig. 4(b),(c), therefore we can extract the specifically



(a) *PSF* of TV camera **A** (b) *PSF* of TV camera **B**

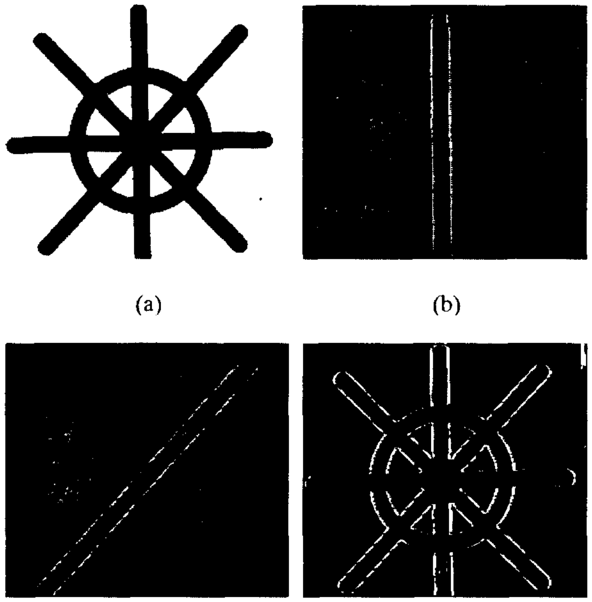
Fig. 5 Point spread functions of TV cameras in case of using the diffuse film with directional selectivity.

directional edge in real-time using the spatial filter in Fig. 5.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 6 shows the examples of measured results using Gaussian type of spatial filter. A picture of object is shown in Fig. 6(a). The edge extracted by the film $\mathbf{C}_1$ in Fig. 3 is displayed in Fig. 6(b), and the edge by the film $\mathbf{C}_3$ is shown in Fig. 6(c). As understood from these figures, the edge of object is extracted in real-time by the use of this method. In this experiment, the real-time implies the video rate of TV camera. The detailed edge is not included in Fig. 6(c) but included in Fig. 6(b). From the comparison between Fig. 6(b) and (c), we can say the resolution of edge changes with the exchange of diffused film. According as the decrease of the absolute values of the threshold voltage I_{Th}^{+} and I_{Th}^{-}, the outline of object becomes sharp but noise such as dot increases in edge-information. On the other hand, the edge-information decreases as the increase of those of I_{Th}^{+} and I_{Th}^{-}. Therefore, the optimum values of I_{Th}^{+} and I_{Th}^{-} exist. The values of I_{Th}^{+} and I_{Th}^{-} are, however, determined experimentally so that the extracted edge-data can correspond well with the real object's edge. The only edge along horizontal scanning disappears in Fig. 6(b). This is because zero-cross detecting circuit detects the zero-cross position along horizontal scanning. We have to extract the zero-cross position along vertical scanning for the extraction of horizontal edge. These problems will be studied in the future.

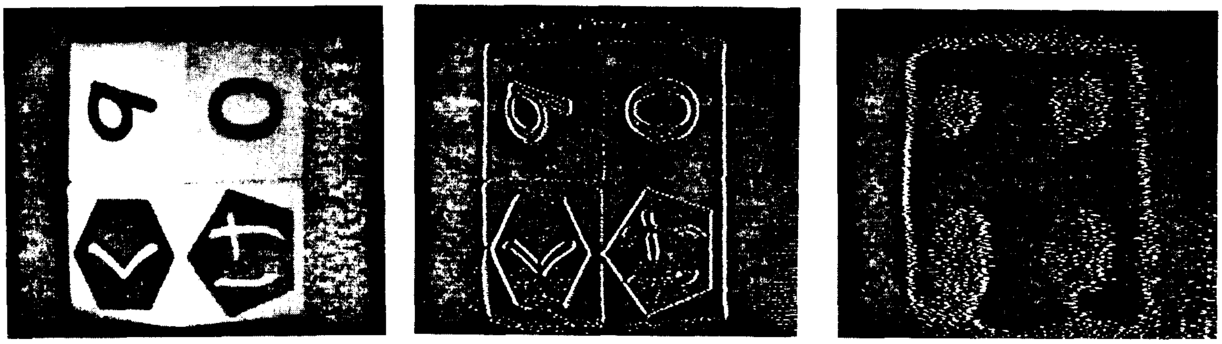
Some examples of the results using the spatial filter with directional selectivity are shown in Fig. 7. The film with the characteristics in Fig. 5 is used as the diffused film **C** in Fig. 2. A picture of object is shown in Fig. 7(a). This is the picture of black design drawn on a white paper. Figure 7(b) is the result obtained by the extraction of vertically directional edge. For getting the edge along vertical direction, we set the diffused film so that ***y*** axis in Fig. 5 may agree with vertical direction in Fig. 7(a). Figure 7(c) is the result when the diffused film is place at 45° to ***y*** axis. In this case, the only edge with the inclination of 45° is selected. The edge along a direction is selectively extracted in this method as understood from these results. We can get all directional edges by removing the diffuse film; however, the output voltage of TV camera is saturated when the diffused film



(a) (b)

(c) (d)

Fig. 7 Examples of measured results, (a) picture of an object, (b) edge extracted along vertical direction, (c) edge extracted along the inclination at 45° to vertical direction, (d) edge extracted toward all direction.



(a) (b) (c)

Fig. 6 Examples of measured results, (a) picture of an object, (b) edge extracted by the film $\mathbf{C}_1$, (c) edge extracted by the film $\mathbf{C}_3$.

is removed, so we adjusted a diaphragm so that the lightness is not saturated. The result is shown in Fig. 7(d). This method is useful for only the binary image and relatively long line along a direction. The accuracy of this setup is inadequate for the extraction of the specifically directional edge at present. The adaptations for gray image and for short line need future considerations.

4. CONCLUSIONS

In this study, the hardware of the spatial filter with the sensitivity of lateral inhibition such as *DOG* function is realized by the combination of optical parts with electronic circuits. The diffused film with the characteristics of Gaussian type is prepared for *DOG* filtering. By the use of the equipment including diffused film, the edge of object is extracted in real-time. The resolution of edge changes with the value of the standard deviation of diffused film. In addition, it is possible to extract selectively the edge along a specific direction when the spatial filter with directional selectivity is used instead of Gaussian type of spatial filter.

Though the edge is extracted in real-time, the detection-accuracy is inadequate compared to digital image-processing. This will be studied in the future.

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