# A New Image Edge Detection Method Inspired from Biological Visual Cortex

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*Abstract*: - Gabor function can be expressed as the alternate dual-function of the positioning of the characteristics and selectivity of the spatial frequency of the receptive field, which can effectively describe the property of the receptive field of the simple cells in human visual cortex. However, the existing literature provides no strict mathematical proof for this fact. This work integrates Gabor function into the integral framework, and proves that the integral transformation of Gabor nuclear possesses the quality of responding to the edge stimuli as the visual cortex. Experiments show that the integral transformation can extract the features of image edge.

*Key-Words:* - Gabor function, Integral transformation, Edge detection

## 1. Introduction

Brodmann Area 17 of the cerebral cortex, i.e. the primary visual cortex or Vision Area 1, is the area most clearly understood through researches. As early as in 1962, Huble, et al, proposed that the biological visual cortex has the structure of functional column [1, 2] and discovered that the cells in the visual cortex possess a commonality, namely, directional sensitivity to external stimuli. As shown in Fig.1, facing light stimuli, these cells are strongly responsive to directional grating, while irresponsive to diffused light. If the direction of the stimuli deviates from the “preferred” direction of the cells, the intensity of cells response will suddenly decrease or cease. In a word, the commonality of most cells in visual cortex is directional selectivity.

Based on the sensitivity of simple cells in visual cortex in terms of their reaction to gratings from different directions, literature [3, 4, 5] proposes the utilization of Gabor function in the simulation of directional selectivity, which is further applied in detecting their selectivity to image edge, where the directivity is represented by revolving of function coordinate. Furthermore, Sereno proves for the first time that the visual cortex has the functions of feedback and integral processing, which further proves the memory function of the visual cortex [10]. It is this special property of visual cells that enables the vision to show excitement to the object contour when perceiving external environment. The excitation strongly stimulates the brain and facilitates the vision in extraction of the object contour characteristics. In view of this ides, this paper integrates the Gabor function into integral framework to simulate the integral processing characteristics of the visual cortex. And starting from the characteristics of the continual function, this paper proves that the integral transformation of Gabor nuclear has the same function of visual cortex, namely, being responsive to edge-line stimuli. Experiments show that this integral transformation can extract characteristics of image edge.

## 2 Gabor-Nuclear-Based Integral Transformation and Its Properties

### 2.1 Definition of Gabor Function

Two-dimension Gabor function is a Gaussian function modulated by sine function of complex number, which is expressed as follows:

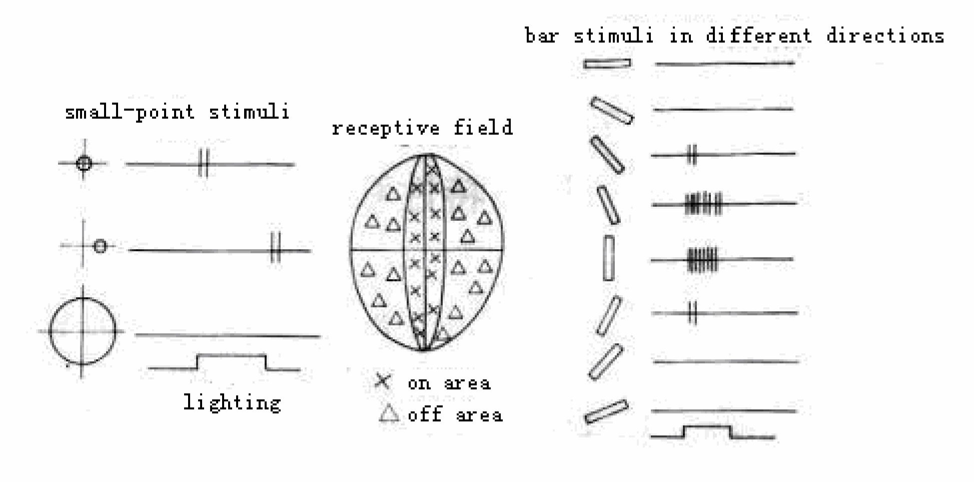


Fig. 1 Selectivity of Visual Cortex Cells to Stimuli in different directions

$$g(x,y) = h(x',y')\exp(j2\pi fx') \tag{1}$$

where,

$$\begin{cases} x' = x\cos\theta + y\sin\theta \\ y' = -x\sin\theta + y\cos\theta \end{cases} \tag{2}$$

$\theta$ is the direction of the filter. Filtering can be realized in any directions through the coordinate revolution, which is the property of cell receptive field, namely, being sensitive to direction selection; $f$ represents the central frequency, which determines the effective scope of the filter; $h(x,y)$ is Gaussian function, which is expressed as:

$$h(x,y) = \frac{1}{2\pi\sigma_x\sigma_y}\exp\left\{-\frac{1}{2}\left[(\frac{x}{\sigma_x})^2 + (\frac{y}{\sigma_y})^2\right]\right\} \tag{3}$$

$\sigma_x$, $\sigma_y$ represent covariance of Gaussian function in horizontal and vertical directions respectively, which is the scope extension of the filter in X-Y space.

Gabor function can be expressed as an alternate dual-function of feature positioning of receptive field and its space frequency selectivity; therefore, it can effectively describe the property of the simple cells in human visual cortex. The property of directional selectivity is elaborated in the simulation in the following section.

### 2.2 Definition and Quality of Integral Transformation

**Definition:** for a two-dimension function $u(x,y)$, the integral transformation based on Gabor nuclear is:

$$Y(x_0, y_0, f_0, \theta) = \iint_{\partial s} g(x - x_0, y - y_0, f_0, \theta) u(x,y)dxdy \tag{4}$$

where $Y(x_0, y_0, f_0, \theta)$ is the filtering output of a specific parameter, and $\partial s$ is filtering scope.

**Quality:** if there are edge lines in the same direction with the filter in the input space $u(x,y)$, then the integral transformation will output the maximum value. On the contrary, when the central line in the space is perpendicular to the filter, the output of the integral transformation approximates 0.

**Proof:** let the line in $u(x,y)$ be $y = mx + b$, and the input function is expressed as:

$$u(x,y)=\begin{cases}1, & if \quad y=mx+b\\ 0, & else\end{cases} \tag{5}$$

Obviously, the angle of the line direction is $\phi=\tan^{-1}(m)$.

Let the direction of filter be $\theta$, so the difference between the directions of the line and the filter is $\delta=\phi-\theta-\pi/2$, (here the difference between the reference direction of the two-dimension coordinate and the actual direction of the real image is $\pi/2$).

Let the central position be $(x_0,y_0)$, and the integral transformation of Equation (4) is:

$$Y(x_0,y_0,f_0,\theta)=\iint e^{-\left[(x-x_0)^2/2\sigma_x^2+(y-y_0)^2/2\sigma_y^2\right]+j2\pi f_0\left[(x-x_0)\cos(\theta)+(y-y_0)\sin(\theta)\right]}u(x-x_0,y-y_0)dxdy) \tag{6}$$

Let $\chi=x-x_0$, $\psi=y-y_0$, and Equation 4.6 can be further expressed as:

$$Y(x_0,y_0,f_0,\theta)=\iint e^{-\left[(\chi)^2/2\sigma_x^2+(\psi)^2/2\sigma_y^2\right]+j2\pi f_0\left[(\chi)\cos(\theta)+(\psi)\sin(\theta)\right]}u(\chi,\psi)d\chi d\psi \tag{7}$$

And Equation (5) can be further expressed as:

$$\hat{u}(\chi,\psi)=\begin{cases}1, & if \quad \psi=m\chi+b-y_0+mx_0\\ 0, & else\end{cases} \tag{8}$$

Let $\chi=\rho\cos(\vartheta)$, $\psi=\rho\sin(\vartheta)$, $\sigma=\sigma_x=\sigma_y$, Equation (6) can be expressed as:

$$Y(x_0,y_0,f_0,\theta)=\iint e^{-\left[(\rho)^2/2\sigma^2+(\rho)^2/2\sigma^2\right]+j2\pi f_0\left[\rho\cos(\vartheta)\cos(\theta)+\rho\sin(\vartheta)\sin(\theta)\right]}\hat{u}(\rho\cos(\vartheta),\rho\sin(\vartheta))d\rho d\vartheta\ , \tag{9}$$

Obviously, points in the detection line meet the condition: $\vartheta=\phi$; otherwise, based on Equation (8) $\hat{u}(\chi,\psi)=0$. Therefore:

$$Y(x_0,y_0,f_0,\theta)=\int e^{-\left[(\rho)^2/2\sigma^2\right]+j2\pi f_0\rho\cos(\phi-\theta)}\rho d\rho\ , \tag{10}$$

And because $\delta=\phi-\theta-\pi/2$, Equation (10) can derive:

$$Y(x_0,y_0,f_0,\theta)=\int e^{-\left[(\rho)^2/2\sigma^2\right]-j2\pi f_0\rho\cos(\delta)}\rho d\rho\ , \tag{11}$$

The real part of Equation (11) is:

$$\Re\{Y(x_0,y_0,f_0,\theta)\}=\int e^{-\left[(\rho)^2/2\sigma^2\right]}\cos(2\pi f_0\rho\sin(\delta))\rho d\rho \tag{12}$$

Equation (12) shows that, when $\delta=0$, namely, when the filter and the edge line are in the same direction, $\Re\{Y(x_0,y_0,f_0,\theta)\}$ has the maximum value. This means the stimuli are effective to the cells.

Meanwhile, Equation (12) can also show that when $\delta\to\pi/2$, namely, when the filter and the edge line are in perpendicular directions, $\Re\{Y(x_0,y_0,f_0,\theta)\}\to 0$, namely, the minimum output value.

To sum up, integral transformation based on Gabor nuclear has directional selectivity, and it is because of this property that this transformation can detect edge lines in different directions. This result simulates the visual cells' response to outside edge stimuli in directional selection. In other words, this integral transformation has the same property of sensitivity to directions with the cells in human visual cortex. Furthermore, to integrate Gabor function into integral framework has strict mathematic meaning, namely, the integral transformation has the characteristics of boundedness and astringency.

## 3. Simulation of Directional Selection of Gabor Function and Verification of Image Edge Detection of Integral Transformation

The feature detection of external information by human vision system starts from the calculation of local energy of interest points of images in retina, and proceeds to searching for local maximum value [11]. The energy generated by stimuli to the cortex from external information can represent the basic characteristics of complex cells, so as to realize the perception in perceptive field. Gabor filter simulates the response property of odd or even symmetric cells and its output energy represents the directional selectivity of cells.

$$Y_g(x,y,\theta)=\sqrt{Y_e^2(x,y,\theta)+Y_o^2(x,y,\theta)}\quad , \quad (13)$$

where $Y_o(x,y,\theta)$ and $Y_e(x,y,\theta)$ respectively represent the result of the integral transformation of the image and the imaginary and real part of Gabor filter.

### 3.1 Simulation of Gabor Filter to Perceptive Field of Simple Cells

Fig. 2 shows the energy distribution of Gabor filter with different scales, different angles and different bandwidth. Among these, Column (a) represents the effect of wave length on filter distribution: with the increase of wave length, filter has wider response scope and more activated cells; Column (b) represents the simulation of Gabor filter to the directional sensitivity of cells: stimuli in different directions produce different response energy; Column (c) represents the effect of bandwidth of Gabor filter to cells response: bandwidth is not only restricted by wave length, but also relevant to the covariance of Gaussian filter; The first and second images in Column (d) respective are the energy distribution of the real and imaginary part of Gabor filter; and the third image represents the modulus of the energy in the real and imaginary parts, standing for the local maximum value of the whole energy. The representation of energy in Fig. 2 shows that Gabor filter can well simulate the property of the perceptive field of simple cells.

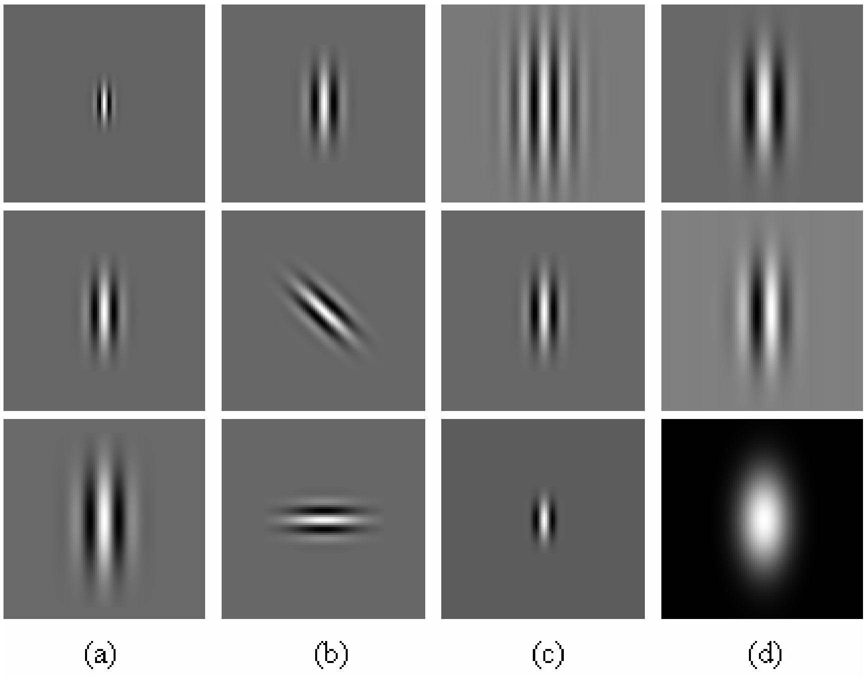


Figure 2 Gabor Filters under Different Parameters: (a) up-down wavelengths (pixel): $\lambda = 5,10,15$, direction angle (measured against the horizontal direction) $\theta = 0°$, bandwidth $B = 1$; (b) up-down direction angles $\theta = 0°,45°,90°$, wavelengths (pixel) are: $\lambda = 10$, bandwidth $B = 1$; (c) up-down bandwidths $B = 0.5,1,2$, $\theta = 0°$, $\lambda = 10$; (d) up-down: real part, imaginary part and combined energy distribution of Gabor filter with $\lambda = 15$ $\theta = 0°$, $B = 1$.

### 3.2 Simulation of Directional Selectivity to Edge Line in Composite Image

As shown in Fig. 3, Gabor filters in any directions release the largest response energy to the line stimuli in similar directions, so as to perceive the edge line in different directions and extract the contour characteristics. This figure shows that with the change of the direction of Gabor filter, the output results detect edge lines in different directions. This is exactly the function property of the primary visual cortex of organisms, as shown in Fig. 1. Experiments show that Gabor integral transformation can simulate the detection function of primary visual cortex in complicated context.

### 3.3 Edge Detection of Natural Images

To illustrate the feasibility of applying Gabor-based integral transformation in natural images to detect image edge, we choose natural images with typical elements in natural environment like grass, cloud and water as the subject, as shown in the left column in Fig. 4. The right column in Fig. 4 shows the result of Gabor integral transformation, namely the response to directional exciting stimuli to cells in visual cortex. Here, the parameter of Gabor function is: wave length $\lambda = 4$, directional angel $\theta = 0°,45°,90°,135°,180°,225°,270°,315°$, and bandwidth $B = 1$. This figure shows that energy of the contour of the objects has been increased by Gabor, so the brighter parts clearly show the contour.

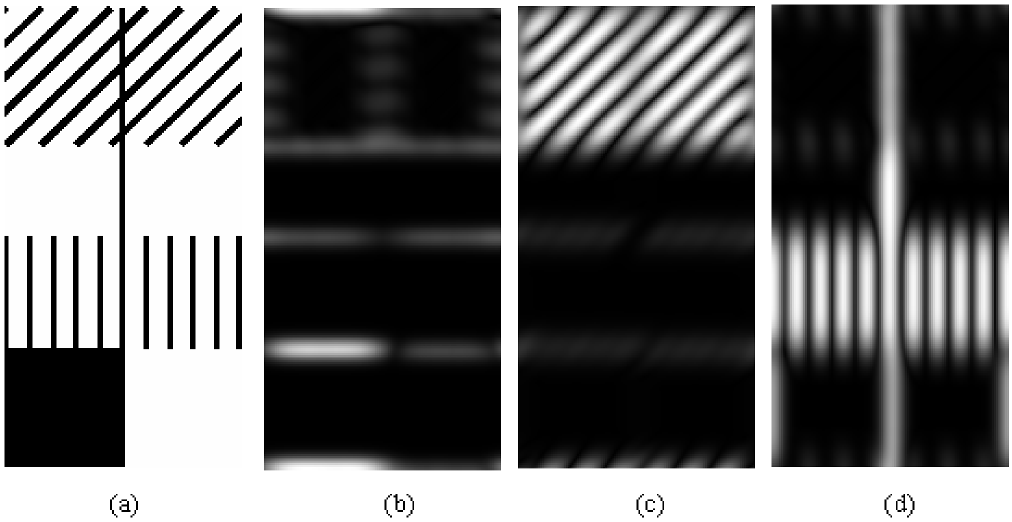

Figure 3 Energy Response of Farbor Filter in Different Direction. (a) is the synthetic original image; (b), (c) and (d) show integral conversion results between the original image and Garbor filter with 0°, 45°and 90°direction angels.

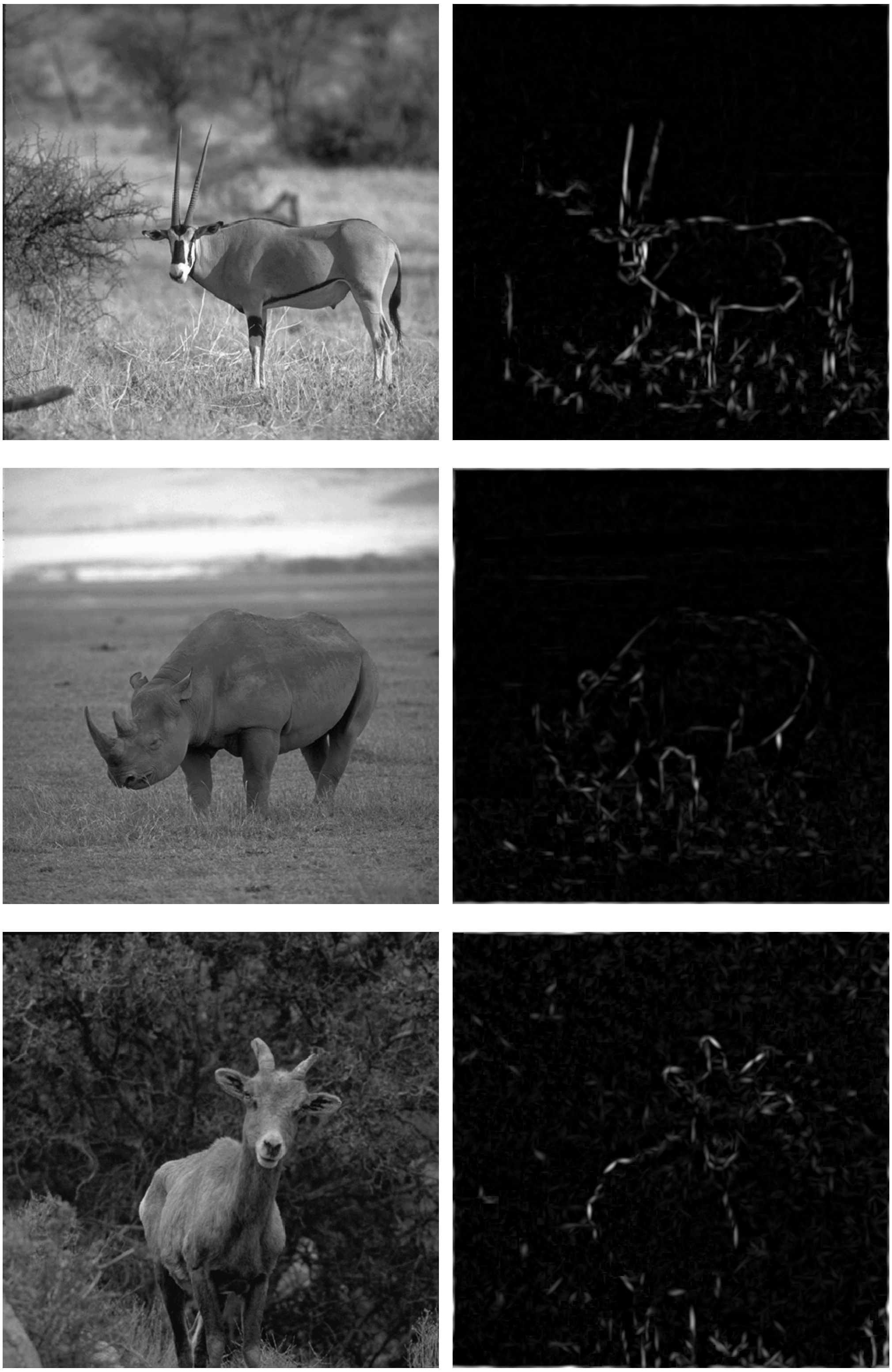

Fig.4 Examples of Integral Transformation Results of Natural Images. The images in the left column are original images and those in the right column are output results from Equation (4).

## 4. Results and Discussion

The simple cells in human visual cortex have directional selectivity and significant response to stimuli from external objects, through the integral processing of visual cortex. Based on this typical function feature of biological vision, this paper proposes integral operator based on Gabor function and strictly proves that integral transformation has the directional selectivity as biological primary visual cortex. The results of simulation and experiment show that the integral transformation proposed in this paper can simulate the selectivity of visual cells, while effectively detect the image edge in complicated natural pictures.

Meanwhile, Fig.4 also shows that the organic-vision-inspired method proposed by this paper detected the edge of non-interest objects as well as interest objects, which interferes with the targeting of the machine vision and its comprehension. But for human vision, research results in literature [12] demonstrate that, when extracting image edge, people are selective to their attribution; that is to say, human vision can retain the edge elements of interest objects while restrain those of non-interest objects. Therefore, how to introduce this special quality of human vision into the integral transformation operator proposed by this paper is a worthwhile subject in future research.

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