THE COMBINATION OF STEERABLE FILTERS AND CNN FOR EDGE DETECTION APPLICATION

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ABSTRACT

This paper proposes a new approach for edge detection by combining steerable filters and cellular neural networks (CNNs) where the former yields the local direction of dominant orientation and the latter, provides iterative filtering. For this purpose steerable filter coefficients are used in CNN as a B template. The better simulation results are provided by this approach.

1. INTRODUCTION

In the image processing literature all of the methods dealing with the detection of discontinuities in an image, are normally classified under the general edge detection where the traditional techniques are based on the computation of local derivative [1]-[3].

One edge detector that has gained popularity is Canny's edge operator [4], which is optimized to detect step edges.

However, another approach for edge detection is the use of orientation techniques. The structure where these techniques are used are known as steerable filters and have been used for image processing tasks, such as texture analysis, edge detection, image data compression, motion analysis, image enhancement and hand-written character recognition [5]-[7]. These structures were first introduced by Freeman and Adelson [5] who studied the design and use of steerable filters. But this technique suffers from some drawbacks. For instance, undesired edges may occur in an image. Also the edge to be detected is shifted version of original one.

Also several authors used CNN for the same application [8]. In the case of determination of edges rotated at specific orientation, it is necessary to train the CNN. If steerable filter coefficients are used in CNN, this training process can be avoided.

In this paper, our proposed approach exploits the use of steerable filters and CNN for edge detection. For this purpose, steerable filter coefficients are used in CNN as a B template. The iterative filtering property of CNN provides better results in edge detection application. Another motivation for this approach is that the CNN outputs can be computed in less time than required by serial digital computer implementations.

The organization of this paper is as follows: Section 2. presents brief definition of steerable filters. In Section 3. our proposed approach is described. Simulation results of this approach are presented in Section 4. Finally, conclusions and discussions are given in Section 5.

2. BRIEF DEFINITION OF STEERABLE FILTERS

Steerable filters basically provide directional edge detection since they behave as band-pass filters in a particular orientation [5], [9]. The edge located at different orientations in an image can be detected by splitting the image into orientation sub-bands obtained by basis filters having these orientations. In the structure, $h^{\theta_i}(t_x, t_y), 1 \leq i \leq M$ is the rotated version of impulse response $h(t_x, t_y)$ at θ_i, the filter orientation and $k_i(\theta_a)$, $1 \leq i \leq M$, are called interpolation functions which control the filter orientations.

Definition: $h(t_x, t_y)$ is said to be steerable if it can be expressed at an arbitrary rotation θ_a, as a linear sum of fixed rotated versions of itself, $h^{\theta_i}(t_x, t_y)$, i.e.

$$h^{\theta_a}(t_x, t_y) = \sum_{i=1}^{M} k_i(\theta_a) h^{\theta_i}(t_x, t_y) \qquad (1)$$

where $h^{\theta_a}(t_x, t_y)$ is the rotated version of $h(t_x, t_y)$ at θ_a direction and $k_i(\theta_a)$, $1 \leq i \leq M$, are interpolation functions. These functions are obtained by solving the following equation [5]:

$$\begin{bmatrix} 1 \\ e^{j\theta_a} \\ \vdots \\ e^{jN\theta_a} \end{bmatrix} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ e^{j\theta_1} & e^{j\theta_2} & \cdots & e^{j\theta_M} \\ \vdots & \vdots & \ddots & \vdots \\ e^{jN\theta_1} & e^{jN\theta_2} & \cdots & e^{jN\theta_M} \end{bmatrix} \begin{bmatrix} k_1(\theta_a) \\ k_2(\theta_a) \\ \vdots \\ k_M(\theta_a) \end{bmatrix} \tag{2}$$

It is well known that the directional derivative operator is steerable [10], [11]. Therefore we consider the first derivative of the Gaussian function in this study.

3. THE PROPOSED APPROACH

In this study, we introduce a new approach which is based on the combining steerable filters and CNNs for edge detection. As introduced in Section 2., steerable filters can be used for edge detection. But some undesired edges may appear in an output image. To avoid this drawback, we tried to combine steerable filter and CNN. It is well known that the use of CNNs in the signal processing applications provides dynamic and iterative filtering. The output signal changes until this signal converges stable point. Here we use this property of CNN for edge detection application.

The simplest CNN is an analog circuit which consists of units called cells. The dynamics of CNN are described by

$$\begin{aligned} \frac{d}{dt}x_{i,j}(t) &= -x_{i,j}(t) + \sum_{p,q\in(N\times N)} A_{p+i,q+j}y_{p,q}(t) \\ &+ \sum_{p,q\in(N\times N)} B_{p+i,q+j}u_{p,q} + I, \qquad -N_1 \le i,j \le N_1 \\ y(x) &= 0.5(|x+1| - |x-1|) \end{aligned} \tag{3}$$

where $u_{i,j}$, $x_{i,j}(t)$ and $y_{i,j}(t)$ represent input, state and output, respectively [12], [13]. N_1 is radius and $N_1 = (N-1)/2$. Also $A_{N\times N}$ is called as feedback template while $B_{N\times N}$ is called as feedforward template. N represents dimension of CNN and I is bias term.

In the linear region i.e. $|x_{i,j}| < 1$, $y_{i,j}(t) = x_{i,j}(t)$, whole system behaves as a linear system. Therefore the linearized template masks can be defined as:

$$a(n_1,n_2) == \begin{cases} A_{0,0} & (n_1,n_2) = (0,0) \\ A_{-n_1,-n_2} & (-n_1,-n_2) \in N\times N \\ 0 & otherwise \end{cases} \tag{4}$$

$$b(n_1,n_2) == \begin{cases} B_{-n_1,-n_2} & (-n_1,-n_2) \in N\times N \\ 0 & otherwise \end{cases} \tag{5}$$

for simplicity while obtaining the dynamics in the convolution form. In this case, since 3 is independent of initial values as time goes infinity and also bias term I, is dropped from 3. The transfer function of the central linear system can be written as

$$H(w_1,w_2) = -\frac{B(w_1,w_2)}{A(w_1,w_2)} \tag{6}$$

where $B(w_1,w_2)$ and $A(w_1,w_2)$ are the DSFT of B and A templates, while w_1 and w_2 are spatial frequencies. This transfer function have two important properties; zero-phase and infinite impulse response (IIR). If the A template has radius zero with $A_{0,0} = \alpha$, 6 becomes

$$H(w_1,w_2) = -\frac{1}{\alpha-1}B(w_1,w_2) \tag{7}$$

This transfer function is equivalent to the FIR filtering of B template with a weight $-1/(\alpha-1)$.

In this study, steerable filter coefficients which are obtained from the first derivative of Gaussian function are used as a $B_{N\times N}$ template in CNN.

4. SIMULATIONS

Here it is demonstrated that edges in an image can be detected using steerable filters and CNNs. Here we give simulation results obtained using CNN templates whose size are 9x9.

The steerable filter coefficients are evaluated at $\theta = 45^o$ and then sampling it from -3 to +3 by 0.67 sampling rate. As a result of this sampling process, 9 coefficients are obtained and these coefficients are used to construct 2D separable filter ones. This 2D filter is used as a $B_{9\times9}$ template in CNN. The choose of the coefficient at the center point of $A_{9\times9}$ as 1.3 guarantees that the range of output image is between -1 and 1 [13]. Also I is chosen as -3.05.

Fig.2 illustrates the edge detection application of this approach. Fig. 1 shows a test image whose size is 256× 256. Fig. 2 shows the results. As shown in this figure, only the edge rotated at $\theta = 45^o$ is detected, other edges are filtered. The same input image is filtered by only steerable filters. As illustrated in Fig. 3, while desired edge is detecting, some unwanted edges has occurred at the output image. Also the edges are shifted versions of original ones.

In the case of filtering by CNN, the range of output image is between -1 and 1. But the grey levels appear at the output image if the steerable filter is used.

Fig. 4 and 5 show rotation-energy histograms for an image which contains only a line rotated at 45^o by using steerable filter and steerable filter+CNN. In Fig. 4, total energy of the image in terms of rotation if only steerable filter is used. Here total energy smears. In this case of using steerable filter+CNN, the energy reaches its maximum value around 45^o as shown in Fig. 5.

5. CONCLUSIONS

In this paper, we have proposed a new approach for edge detection application by combining steerable filters and CNNs. As a result of this study the use of steerable filters and CNNs provides better results. Here we use the iterative filtering property of CNN and the ability of steerable filters for edge detection.

If only steerable filters are used, the edge detection results are not proper. It is observed that the desired edge is shifted. The use of Gaussian filter causes this shifting effect. If CNN is used for filtering, only the desired edge is detected. Thus disadvantage of the use of only steerable filter can be compensated.

Another important point to be considered, the choose of threshold value for I. If it is chosen as very small, all edges might disappear in the output image. Also the value of $A_{0,0}$ effects the threshold level and convergence time. The determination of threshold value and $A_{0,0}$ is an optimization problem and will be studied.

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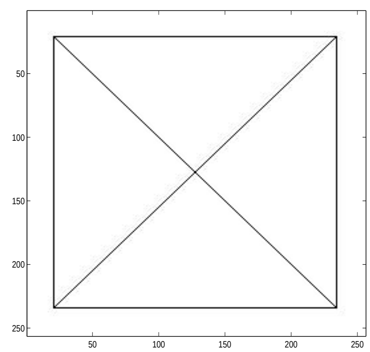

Figure 1: A test image.

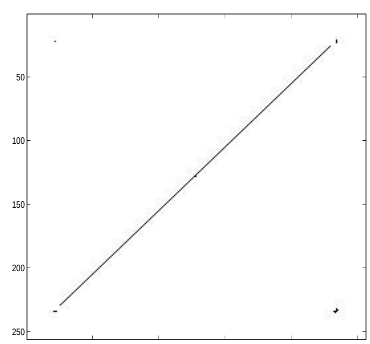

Figure 2: The output of steerable filter+CNN.

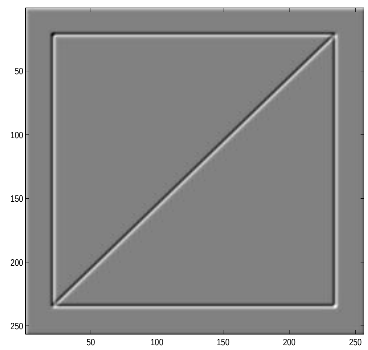

Figure 3: The output of steerable filter.

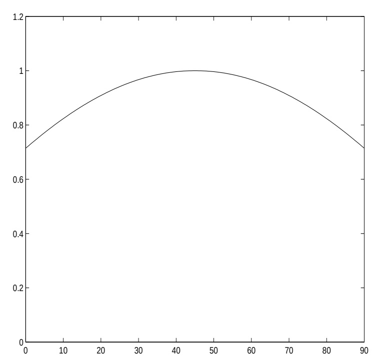

Figure 4: Rotation-energy histogram for steerable filter.

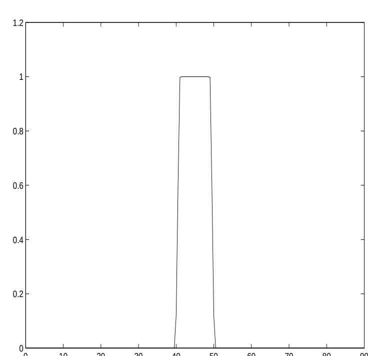

Figure 5: Rotation-energy histogram for steerable filter+CNN.