A Method of Resolving Handwritten Chinese Characters and its Computer Simulation

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Abstract

For the present the notion of taking in the excellent picture-resolving and-contrasting faculty of biological visual systems is of fundamental importance in processing Chinese characters. In this paper a kind of spatial circuits are designed, which is possessed of two faculties of resolving and contrasting pictures. By the computer simulation we shall experimentally confirm whether or not the faculties of the designed spatial circuits are satisfactory for the above purpose. The aim in this paper is to find that the circuits are useful for constructing the recognition system of handwritten Chinese characters.

We shall explain a technique for converting the analog information-processing system into a digital information-processing system by means of the Fourier transformation for additive operators. The study is characterized by our having attached great importance to that the recognition with invariance under the expansion-and-contraction transformation group is able to be carried out by using the above-mentioned circuits.

1 . Introduction

In recent years researchers have frequently made an attempt to secure the excellent pattern recognition faculties of biological visual systems . In this paper , a family of image-resolving and -contrasting circuits $\overrightarrow{f(H)}=\{f_\ell(H)\ ;\ell\in L\}$ is designed so that we may obtain an image-processing technique with invariance under the expansion-and-contraction transformation group $\{T_t\}_{-\infty<t<+\infty}$ defined as $(T_t\varphi)\ (x_1,x_2)\triangleq\varphi(e^{-t}x_1,e^{-t}x_2)$.

The circuit $f_\ell(H)$ is represented as $f_\ell(H)=f(H)\cdot\theta_\ell(H)$. $\overrightarrow{\theta(H)}=\{\theta_\ell(H)\ ;\ell\in L\}$ means a family of image-resolving spatial circuits . The circuit $\theta_\ell(H)$ is a projection operator and it is used as an ideal band pass spatial filter having an angular frequency transmission band S_ℓ . The circuit f(H) is a positive operator constructed with a self-adjoint operator $H=\sum_{j=1}^{2} x_j(i^{-1}\partial/\partial x_j)$ and is named an image-contrasting circuit.

The computer simulation will show the faculties of the designed spatial circuits are satisfactory for the above purpose .

2 . Handwritten Chinese characters

In this simulation , a set of thirty Chinese characters $\{\varphi_m;\ m=1\sim30\}$ is used . We then choose the rectangular coordinate system x_1-x_2 and consider that each image φ_m is in the area $\{(x_1,x_2);|x_1|\leqq 12,|x_2|\leqq 17\}$ of the plane R^2 . The axes x_1 and x_2 are horizontal and vertical one respectively and the amplitudes of each image $\varphi_m=\varphi_m(x_1,x_2)$ are

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given only on inter-valued x_1-x_2 . Each φ_m is an eight-valued image taking integer values from -3 to +4 , and for example , φ_{21} is shown in fig. 1 .

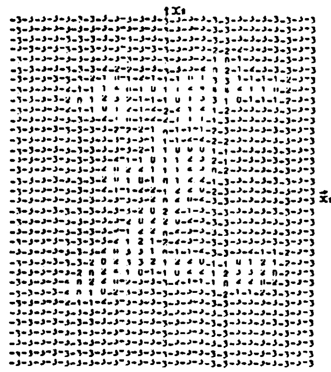

Fig. 1 An example φ_{21} of the eight-valued input patterns. The axis x_1 and the axis x_2 are horizontal and vertical respectively.

3 . An expression of an ideal low pass filter and a condensation of a spectral band

Let $\varphi=\varphi(x_1,x_2)$ be an image which represents a hand-written Chinese character , and let a system of complex-valued functions defined on the plane R^2 constitute a Hilbert space $\mathfrak{H}$ in terms of the inner product

$$(\varphi,\eta)=\int_{-\infty}^{+\infty}dx_1\int_{-\infty}^{+\infty}dx_2\ (x_1^2+x_2^2)^{-1}\ \varphi(x_1,x_2)\cdot\overline{\eta(x_1,x_2)}$$

, where $\overline{\eta}$ is a complex-conjugate function of η .

We may consider the transformations $p=\sqrt{x_1^2+x_2^2}$ and $q=\tan^{-1}(x_2/x_1)$ as a change of coordinates from the x_1-x_2 system to the p-q system . For any image $\varphi=\varphi(x_1,x_2)$, define its expansion-and-contraction transformation T_t by

$$(T_t\varphi)\ (x_1,x_2)=\varphi((e^{-t}p)\cos q\ ,\ (e^{-t}p)\sin q\ )\ . \qquad (1)$$

The importance of the notion of the transformation group $\{T_t\}_{-\infty<t<+\infty}$ is due to the fact that $(T_t\varphi,T_t\eta)=(\varphi,\eta)$ holds true for any t . Thus it can be concluded that the transformation group $\{T_t\}$ is an one-parameter group of unitary operators . The unitary operator T_t is representable as $T_t=\exp(-itH)$, where $i\hat{=}\sqrt{-1}$ and $H=p\cdot i^{-1}\partial/\partial p=\sum_{j=1}^{2}x_j(i^{-1}\partial/\partial x_j)$ is a self-adjoint operator with continuous spectra on the Hilbert space $\mathfrak{H}$.

According to the Fourier transform for additive operators[2)], an ideal low pass spatial filter $\theta(H)$ with the transmission band $S\hat{=}\{\lambda\ ;\ |\lambda|\leq 2\pi W\}$ is expressible as

$$(\theta(H)\varphi)\ (x_1,x_2)=\int_{-\infty}^{+\infty}du\ 2\pi W\cdot\pi^{-1}(2\pi Wu)^{-1}\cdot\sin\ (2\pi Wu)\cdot\varphi(e^{+u}x_1,e^{+u}x_2)\ . \qquad (2)$$

This simulated model is

$$(\theta(H)\varphi\ )(x_1,x_2)=\sum_{u=-\log_e 17}^{\log_e 17}(\Delta u)\cdot(V_0-\delta)\cdot\pi^{-1}\cdot\{(V_0-\delta)u\}^{-1}\cdot\sin\{(V_0-\delta)u\}\cdot\varphi(e^{+u}x_1,\ e^{+u}x_2) \qquad (3)$$

, where we approximated the integral in (2) by the Riemann sums under the following conditions : The band $V_0-\delta$ takes the value $2\pi W=10\pi/\log_e 17$ = 11.0884 ($\delta=10^{-4}$) . The line element Δu takes the value $(2\cdot\log_e 17)/20$ = 0.2833 . The variable u varies from $-\log_e 17$ = -2.833 to $+\log_e 17$. The interval is divided into twenty equal parts . The supremum $\log_e 17$ of the sum is concerned with the fact that $\mathrm{Max}\{|x_1|\ ,\ |x_2|\}$ = 17 .

Then we found that $(\theta(H)\varphi_m)=\varphi_m$ holds for all m (=1~30) , rounding off $\theta(H)\varphi_m$ at tenth's place . That is , each image φ_m is band-limited on the u axis having the sampling interval $1/(2W)=\Delta u$, where the u axis is used to measure the natural logarithmic length of the radius p .

4 . A design of an image-contrasting circuit which has a lateral inhibition structure

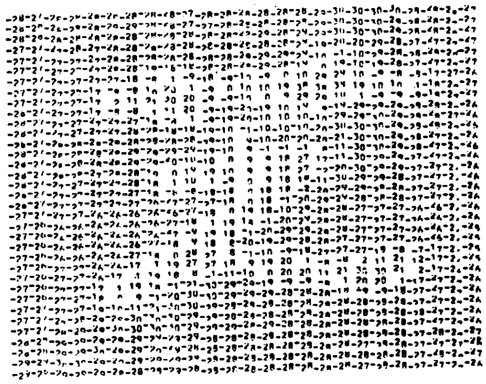

Fig. 2 The output pattern $f(H)\theta(H)\varphi_{21}$ from the picture-contrasting circuit $f(H)$.

Let an impulse response q(t) and a spatial circuit G_t be given respectively by

$$q(t)=\nu_0\, e^{-\nu_0 t}\{a_0+b_0^{-1}\sin(b_0 t)\}+Y(t-t_1)\left[\nu_1 e^{-\nu_1(t-t_1)}\{a_1+b_1^{-1}\sin\{b_1(t-t_1)\}\}\right]$$

and

$G_t=c_0+c_1\cdot\cos(t+t_1)H - c_2\cdot\cos(tH)$, where

$Y(t)=1$ for $t\geq 0$, $=0$ otherwise .

Then we can define $\quad T_G^{[q]}(t)\psi \triangleq \int_0^t d\tau\cdot q(t-\tau)\cdot G_\tau\psi \quad (0<t<+\infty) \qquad (4)$

as the convolution integral of q(t) and G_t . It is convenient for the calculation of eq.(4) to use the Laplace transformation for additive operators[1) , but it is spared here . By considering the fact that the amplitude on the point x_1-x_2 of the output $T_G^{[q]}(t)\psi$ is determined in dependence on the amplitudes on the other concentric circles , it becomes evident that the spatial circuit $T_G^{[q]}(t)$ is simulating a lateral inhibition structure of biological visual systems .

To tell the truth , q(t) and $g_t(\lambda) = c_0+c_1\cdot\cos(t+t_1')\lambda-c_2\cdot\cos(t\lambda)$ are always conditioned on $a_j>b_j^{-1}>0$ (j=0 , 1) and $\nu_0,\nu_1,c_0,c_1,c_2>0$. These conditions lead to the following $\quad f(\lambda)\triangleq\int_0^t d\tau\; q(t-\tau)\cdot g_\tau(\lambda)\geq 0$. Therefore , provided that t , t_1 , $t_1'>0$, the operator $f(H)\triangleq T_G^{[q]}(t)$ becomes a self-adjoint positive operator . The computer simulation necessitates an approximation by Riemann sums of f(H) shown in (4) . We obtain the sums by setting $\Delta\tau$(the width) $=\Delta u(1/(2W))$ and t(the parameter of the receptive field) $= 9\cdot\Delta\tau$, provided that the variable τ of integration takes the value $k\cdot\Delta\tau$ $(k=1\sim9)$.

Let the amplitudes of output images be rounded off at tenth's place . The output image $f(H)\cdot\theta(H)\varphi_{21}$ from the image-contrasting circuit f(H) applied to the input image $\theta(H)\varphi_{21}$ shown in fig.1 is shown in fig.2 .

5 . A family of image-resolving and -contrasting spatial circuits

We construct a family $\overrightarrow{\theta(H)}=\{\theta_\ell(H);\ell\in L\}$ of ideal band pass spatial filters , and we obtain an image-resolving process " $\varphi(x_1,x_2)\rightarrow(\overrightarrow{\theta(H)}\varphi)(x_1,x_2)\triangleq\{(\theta_\ell(H)\varphi)(x_1,x_2);\ell\in L\}$ "

The family $\overrightarrow{\theta(H)}$ is called a family of image-resolving spatial circuits . The ℓth filter $\theta_\ell(H)$ has $S_\ell\triangleq\{\lambda\,;\,2\pi W_{\ell-1}<|\lambda|\leq 2\pi W_\ell\}$ as the transmission band . We selected $2\pi W_0$ and $2\pi W_\ell$ $(\ell=1\sim25)$ such that $2\pi W_0=0$ and $2\pi W_\ell=(V_0/25)\cdot\exp[2(\ell-25)/25]\cdot\ell-\delta$. The approximate Riemann sums of $\Theta_{\ell}(H)$ for the simulation are obtained by using the same transformation as that of (2) and (3) .

The output image $\theta_{22}(H)\cdot\theta(H)\varphi_{21}$ from the 22nd filter $\theta_{22}(H)$ to which the input image $\theta(H)\varphi_{21}$ is applied is shown in fig.3 . The output is also rounded off at the tenth's place , so that three values -1 , 0 and +1 are printed as a result . Although it is difficult for us to see how the components of Chinese character φ_{21} is extracted and resolved , it becomes clear when we look over the component $f(H)\cdot\theta_{22}(H)\cdot\theta(H)\varphi_{21}$ contrasted with f(H) . The component $f(H)\cdot\theta_{22}(H)\cdot\theta(H)\varphi_{21}$ thus revealed out is shown in fig.4 . It can be concluded that two rectangle-like patterns are extracted from the image $\theta(H)\varphi_{21}$ with the spatial circuit $\theta_{22}(H)$ and that the image $\theta_{22}(H)\cdot\theta(H)\varphi_{21}$ is contrasted by making use of the lateral inhibition structure of the spatial circuit f(H) .

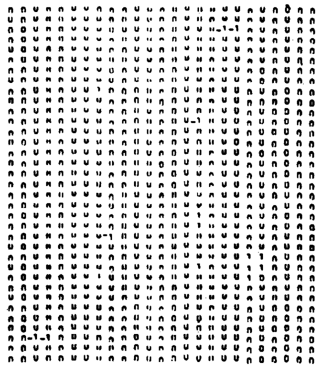

Fig. 3 The output pattern $\theta_{22}(H)\varphi_{21}$ from the 22nd ideal band pass spatial filter $\theta_{22}(H)$.

Similarly , for instance , we found out that the circuit $\theta_4(H)$ has a property to extract the components of Chinese characters in two portions $\{(x_1,x_2);\ x_1>0,x_2>0\}$ and $\{(x_1,x_2);\ x_1<0,x_2<0\}$ and it ignores the components in the other two portions , and that the circuit $\theta_{13}(H)$ has a property to extract the left downward oblique lines of Chinese characters . These facts are essentially concerned with the operator H derived from the expansion-and-contraction group $\{T_t\}$.

The circuit $f(H)\cdot\theta_{\ell}(H)$ is denoted by $f_{\ell}(H)$, and the family $\overrightarrow{f(H)} \triangleq \{f_{\ell}(H)\ ;\ell\in L\}$ is said to be a family of image-resolving and -contrasting spatial circuits . To our great regret , we do not have enough space to describe the faculties of $f_{\ell}(H)$ except $f_4(H)$, $f_{13}(H)$ and $f_{22}(H)$.

We confined ourselves to the above explanation concerning the simulation results of the 21st Chinese character φ_{21} for space limitation . The simulation results of the other characters may be explained in the same way .

These results may be attributed to the contrasting decomposition $\overrightarrow{f(H)}\varphi \triangleq \{f_{\ell}(H)\varphi;\ell\in L\}$ to the orthogonal direct sum of the input image φ , where the decomposition implies two propreties $f(H)\varphi=\sum_{\ell\in L} f_{\ell}(H)\varphi$ and $(f_k(H)\varphi,f_{\ell}(H)\varphi)=0\ (k\neq\ell)$. In fact , a cluster

$$\{(f_{\ell}(H)\cdot\theta(H)\varphi\ ,\theta(H)\varphi)/(\theta(H)\varphi\ ,\ \theta(H)\varphi)\quad ;\ \ell=1\sim25\}$$

of features is extracted from the Chinese character φ on the basis of the above two properties , and hence , the recognition system with invariance under the expansion-and-contraction transformation group $\{T_t\}$ may be possible together with the other two methods of the normalization and the classification .

By the way , these simulations are conducted by the digital computer TOSBAC-3400.

6 . Conclusion

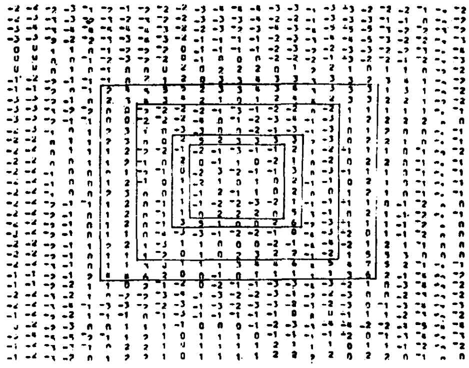

Fig. 4 The output pattern $f(H)\theta_{22}(H)\theta(H)\varphi_{21}$ from the picture-contrasting spatial circuit $f(H)$.

The above-mentioned computer simulation may consolidate a foundation of an image-processing and recognition technique which remains invariant over the expansion-and-contraction transformation group .

Full data concerning the normalization , the feature-extraction and the classification based on the quantum theory of recognition[2] are to be published later , where these thirty characters can be correctly recognized . The suitability of the normalization concerning the problem of how to restore the input image so that the restore image may be correctly recognized may be proved , which suggests the competence of the topological information restorable theorem[1),2)] .

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