TEXTURE DISCRIMINATION USING DECONVOLUTION FILTERS†

VENUGOPAL SRINIVASAN, SADALI N. JAYARAMAMURTHY, ALOK DAS AND SASTRY V. PAPPU*

(Dept. of Electrical Communication Engineering, Indian Institute of Science, Bangalore 560012)

Received on May 28, 1977; Revised on August 27, 1977

ABSTRACT

A new experimental technique for texture discrimination is proposed and it involves the use of deconvolution filters in a coherent optical computing system.

A texture is considered as a convolution of a subpattern with an array of impulse functions. A procedure to synthesize a deconvolution filter, given a proto-sample of a texture, is described. The filter is used successfully in a coherent optical computer for recognizing a chosen texture in a mixture of textures. The discrimination caused by the deconvolution filter is identified by the presence of characteristic dot pattern in the output plane.

The results on texture discrimination obtained with conventional matched filter methods are compared with those of deconvolution techniques and it is concluded that the deconvolution techniques are superior.

Further it is shown that unambiguous discrimination of parent texture is possible with the proposed technique even in cases where seemingly different textures are generated by conditions such as overlapping and differences in background illumination.

Key words: Texture, Deconvolution filter.

1. INTRODUCTION

Texture discrimination methods that could lead to scene segmentation have potential applications in fields like remote sensing, and bio-medical image processing. Several digital methods have been proposed to deal with this problem [see 1, 2, 3 for references]. Optical computing methods, such as the application of Vander Lugt filters provide an alternative. Here

* To whom all correspondence should be addressed.

† Contribution No. 5 from Laboratories for Coherent Optics and Electrooptical Research.

new scheme is described where texture discrimination is effected by the application of deconvolution filters in a coherent optical system. The deconvolution is implemented by Fourier transform division using a complex two element spatial filter. The filter realization is by the holographic method first developed by Stroke and Halioua[4] for image deblurring operations. In addition to the well-known advantages of optical computing such as speed and parallel processing capability, it is shown by experimental results that the performance of the deconvolution filter is far better than the conventional Vander Lugt filters in such applications.

2. Description of the Method

2.1. *Model*

It appears that the subpattern/placement model[5] is the most appropriate model to deal with structural textures. Taking a cue from this widely used model we propose that a two dimensional structural texture $t(x, y)$ may be viewed as a convolution between a subpattern $h(x, y)$ and an array of impulse functions $c(x, y)$, *i.e.*,

$$t(x, y) = h(x, y) * c(x, y) \tag{1}$$

where

$$c(x, y) = \sum_{n,m} \delta\,[(x - x_n), \quad (y - y_m)]$$

and x_n, y_m are the coordinates of the impulse functions constituting the array. $h(x, y)$ can be single unit cell or a proto-sample of the texture which, in general, would encompass several unit cells.

The experimental results of this study bear testimony to the validity of the proposed convolution model for a structural texture.

2.2. *Principle*

Fourier transformation of (1) yields:

$$T(u, v) = H(u, v) \cdot C(u, v) \tag{2}$$

where T, H and C are Fourier transforms of t, h and c respectively. Given a texture in the form of a transparency whose amplitude transmittance is $t(x, y)$ the transform $T(u, v)$ can be obtained as the amplitude distribution in the back focal plane F_1 of a lens L_1; the transparency being placed in the input plane I and illuminated with a plane wavefront derived from a laser (Fig. 1). $H(u, v)$ can be expressed as,

$$H(u, v) = |H(u, v)| \exp(i\phi_H). \tag{3}$$

The deconvolution filter required should have an effective transmittance $[H(u, v)]^{-1}$. This is realised by the combined action of, (*a*) an amplitude filter with transmittance $|H(u, v)|^{-1}$ which is placed in the plane F_1; (*b*) a holographically recorded phase filter with transmittance $\exp(-i\phi_H)$ which is located in the second transform plane F_2 of Fig. 1[4]. The plane F_2 is an image of plane F_1 produced by lens L_2.

The filtering action by the deconvolution filter produces $C(u, v)$, which upon retransformation by lens L_3 yields the required impulse function array in the ouput plane 0 of Fig. 1.

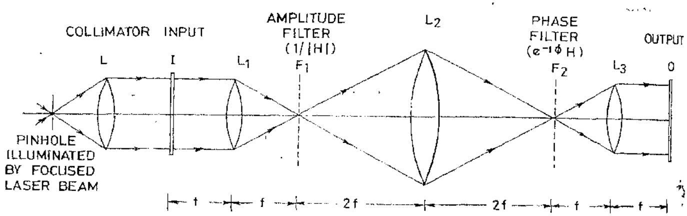


FIG. 1. Schematic of optical computing system.

If a scene containing textures t_1, t_2, t_3, t_4 as shown in Fig. 2*a* is used as input and if the deconvolution filter corresponds to texture t_1, then an impulse function array of the form shown in Fig. 2 *b* will be obtained in the output plane. *This distinctive dot pattern effectively discriminates the region containing the selected texture from others in the given scene.*

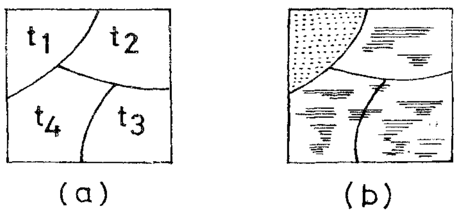


FIG. 2. Schematic representation of texture discrimination using deconvolution filter technique.

(*a*) A composite texture scene.

(*b*) Output expected after deconvolution operation.

2.3. *Experiment*

2.3.1. *Amplitude filter* : A proto-sample $h(x, y)$ of the texture to be discriminated is placed in the input plane I (Fig. 1). The intensity of the Fourier transform $|H(u, v)|^2$ is recorded on a photographic plate in the plane F_1. Adjusting the exposure for maximum linear recording and controlling the development process to obtain a contrast factor $\gamma = 1$, a filter can be made with transmittance in amplitude $T_A(u, v)$ given by

$$T_A(u, v) = 10^{-D_n}(u, v)/2 \tag{4}$$

where $D_n(u, v)$, the density distribution in the developed plate, is given as $\gamma \log_{10} |H(u, v)|^2$. It can be clearly seen from eqn. (4) that $T_A(u, v) = |H(u, v)|^{-1}$, if $\gamma = 1$. This plate acts as the amplitude filter which will be placed in plane F_1 of the optical computer set up shown in Fig. 1.

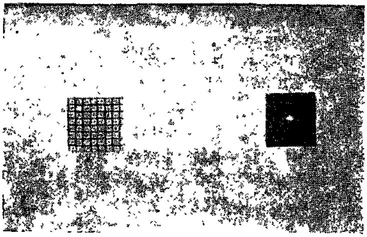
2.3.2. *Phase filter* : To record the holographic phase filter, the sample $h(x, y)$ is placed in input plane I and the amplitude filter is placed in its original recording position (*i.e.*, in plane F_1 of Fig. 1). This set up generates a pure phase function $\exp(i\phi_H)$ out of plane F_1, which is imaged on to plane F_2 with a magnification of approximately unity. Using a strong inclined plane wavefront, $A \exp(iu\theta/\lambda)$, a hologram is recorded in plane F_2, where A is the amplitude, λ is the wavelength of the laser source and θ is the inclination of the reference beam with respect to optical axis.

The intensity distribution incident on the hologram plane is given by

$$I(u, v) = A^2 + 1 + A \exp\left[i\left(\frac{u\theta}{\lambda} - \phi_H\right)\right] + A \exp\left[i\left(-\frac{u\theta}{\lambda} + \phi_H\right)\right] \tag{5}$$

The desired phase component of the deconvolution, which is represented by the third term in eqn. (5) can be obtained as a result of the process of reconstruction of wavefronts from the hologram located in plane F_2 of Fig. 1. The overall deconvolution output appears off-axis at an inclination of θ.

Using the sample $h(x, y)$ as the input, the alignment of the amplitude and phase filters is carried out so as to produce a bright spot in the output plane 0. Figure 3 *a* shows a sample of the texture used as input and the corresponding output is shown in Fig. 3 *b*. A reproduction of the amplitude filter recorded for this texture sample is shown in Fig. 3 *c*.

The synthesis of the deconvolution filter is complete after the proper alignment of both amplitude and phase filters and the system is now ready (*a*)  (*b*)

 (*c*)

FIG. 3. Components for the synthesis of deconvolution filter.
(*a*) Proto-sample of a texture used for filter synthesis.
(*b*) Output for Fig. 3 *a*.
(*c*) Reproduction of the amplitude filter.

for use. A composite texture scene shown in Fig. 4*a* is now used as input to this system. The output is shown in Fig. 4 *b* and it consists of a characteristic dot pattern in the region containing the selected texture. The appearance of the dot pattern is taken, for reasons aleady mentioned, to indicate that the desired discrimination of texture is achieved.

3. DISCUSSION OF RESULTS

It is evident from Fig. 4 *b* that good discrimination of the selected texture results from the deconvolution operation. Corresponding to every identifiable segment in the input plane which matches with the chosen sample, a bright spot is obtained in the ouput plane. The weaker spots observed around the boundaries arise as a result of partial matching. By selecting a proper threshold, the actual boundary can be detected. It is possible to detect a sharper boundary by choosing a smaller sample. Best results can be obtained if, ideally, a unit cell is chosen as sample,

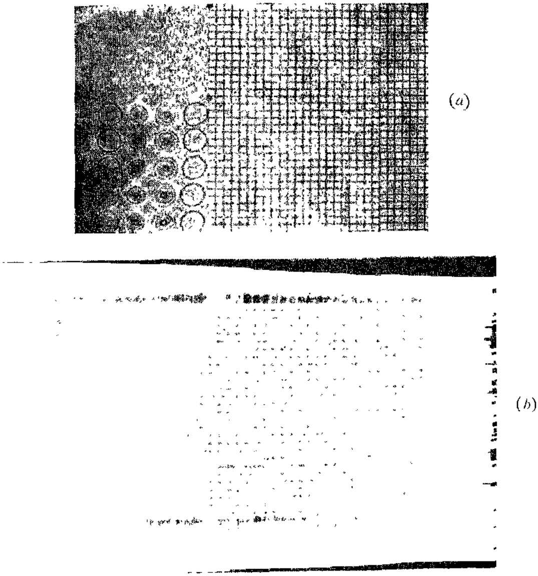


FIG. 4. Results of the operation of a deconvolution filter on a composite texture scene.
(*a*) A composite texture scene.
(*b*) Output for the scene of Fig. 4 *a*.

In Fig. 4 *b* cloud-like patches of light are observed in the background across the entire filtered scene. This corresponds to the filtered DC and low spatial frequency components of the complete input scene that are allowed to pass through the filter. Though these effects can be reduced further by the proper choice of maximum density of the amplitude filter, they cannot be totally eliminated; the use of a DC stop filter would cause dark field imaging and the output image would be corrupted by excessive impulse like noise.

3.1. *Comparison with Matched Filtering*

Vander Lugt type matched filtering[6] performed on the scene in Fig. 4 *a* yields an output shown in Fig. 5 *a*. An initial sample from the selected texture is used in the synthesis of the matched filter. The autocorrelation function of this sample produced by the matched filter is shown in Fig. 5 *b*,

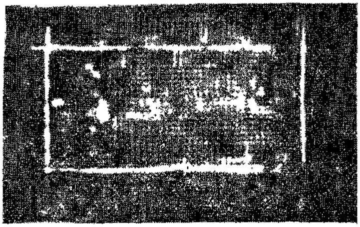
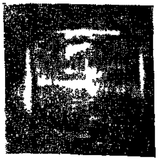
(a)   (b)

FIG. 5. Results of the operation of a conventional matched filter on the same composite scene of Fig. 4 *a*.

(*a*) Matched filter output for Fig. 4 *a*.

(*b*) Matched filter output for a sample of the texture.

It has, besides, a central maximum, several secondary maxima. The sharp impulses produced by a deconvolution filter, as opposed to the damped periodic nature of the output generated by matched filter for texture samples, is the main reason for the superior discrimination effected by the new method. An added advantage is the higher dynamic range obtainable with two element deconvolution filters in comparison with single element matched filters[4, 5].

3·2. *Placement Rules*

The array of impulse functions (bright spots) indicates the placement of the unit cells. It may be noted that this array could be obtained by using an arbitrarily chosen sample that would in general encompass several unit cells. This array essentially reveals the rules of placement.

3·3. *Overlapping*

When two textured regions overlap, many a time an entirely different texture seems to emerge. Recognition of the presence of either texture in the overlapped region is, sometimes, a difficult task even for a human observer. Many of the earlier methods have not even considered this problem. The deconvolution method is capable of detecting the presence of the selected texture even in the overlapped region. Figure 6 *a* shows the texture created by translation and superposition of the texture in Fig. 3 *a*, for which a deconvolution filter was synthesized earlier. The filtered output for this scene is shown in Fig. 6 *b*. The presence of the original texture (Fig. 3 *a*) in the input scene is clearly revealed by the dot pattern in the output.

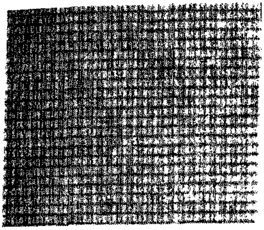
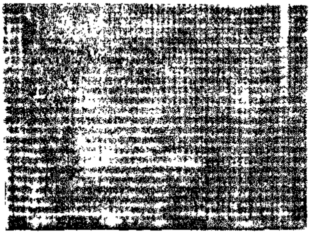
(a)   (b)

Fig. 6. Effect of overlapping.
(a) Texture synthesized by translation and superposition of texture in Fig. 3 a.
(b) Output for Fig. 6 a.

3.4. *Effects of Illumination*

The output in this optical method is, to a considerable extent, independent of the background gray level variations that are produced by external lighting conditions within the scene. This is evident from the input-output pair shown in Fig. 7.

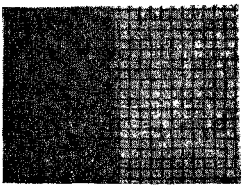
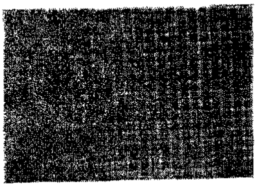
(a)   (b)

Fig. 7. Effect of illumination.
(a) Input scene.
(b) Ouput for Fig. 7 a.

3.5. *Limitations*

The synthesis of deconvolution filters is slow as it requires controlled photographic processing and accurate mechanical alignment. Real time synthesis is not possible using presently available recording materials. The input scene has to be presented in such a manner as to have the texture to be discriminated in the same orientation as the original sample from which the filter was made. Synchronous rotation of the input scene and output recording medium can overcome this difficulty. At present it appears that this method is more suited to deal with regular textures.

Further, like in any other conventional matched filter technique, here also an *a priori* knowledge of proto-sample of texture is necessary.

4. SUMMARY

The feasibility of using an optical deconvolution method for texture discrimination is demonstrated. It is shown that this method is superior to the conventional matched filtering technique. Further it is demonstrated that good discrimination of parent texture is achieved by the use of the method proposed here even in cases where seemingly different textures are generated by conditions such as overlapping and differences in background illumination.

ACKNOWLEDGEMENTS

The authors wish to acknowledge with thanks interest taken by Prof. B. S. Ramakrishna in this project.

REFERENCES

1. Jayaramamurthy S. N. — Computer methods for analysis and synthesis of visual texture, 1973, Ph.D. Dissertation, DCS 601, Department of Computer Sciences, University of Illinois, Urbana-Champaign.
2. Lipkin, B. S. and Rosenfeld, A. (Eds.) — *Picture Processing and Psychopictorics*, Academic Press, New York, 1970.
3. McCormick, B. H. and Jayaramamurthy, S. N. — *Intl. J. Comp. and Inform. Sciences*, 1975, **4**, 1.
4. Stroke, G. W. and Halioua, M. — *Phys. Letters*, 1970, **33A**, 3.
5. Rosenfeld, A. and Lipkin, B. S. — Texture synthesis, in Lipkin B. S. and Rosefeld, A. (Eds.) *Picture Processing and Psychopictorics*, Academic Press, New York, 1970.
6. Vander Lugt, A. B. — *IEEE Trans. Inform. Th.*, 1964, **IT-10**, 139.
7. Stroke, G. W. Halioua, M., Srinivasan, V. and Shinoda, M. — *Science*, 1975, **189**, 261.