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Joint-transform correlator architecture for wavelet feature extraction

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ABSTRACT

A version of an image consisting of multiple wavelet scales allows for more flexible feature extraction when compared to the use of one wavelet scale. We proposed an imaging system based on a multiple-input joint-transform correlator, that could be used for multiple wavelet-scale analysis of an input image. Given a single input image and wavelet, for m wavelet scales, m versions of the wavelet and m copies of the input image were generated using conventional optics that are used as inputs to a joint wavelet-transform correlator. The output consisted of $4m$-1 correlation results, one of which is the desired output. The space-bandwidth product of the system is the same as for a conventional two-input joint-transform correlator.

Keywords: feature extraction, joint-transform correlator, optical pattern recognition, wavelet transform

1.0 INTRODUCTION

Wavelet transforms are often useful because they perform a multiresolution analysis of an image. This allows an input image to be viewed in one frequency "band" corresponding to the frequency response of the wavelet. If an object's energy is concentrated in one wavelet scale, then an optical correlator may be an efficient architecture for pattern recognition or feature extraction.[1-4] However, a more versatile optical correlator system would allow images to be viewed in a combination of wavelet scales (multispectral). Such a system may be able to improve performance measures such as signal-to-noise ratio, peak-to-correlation energy, and discrimination. A method is needed that produces a multi-spectral version of an input image so more flexible feature extraction or improved performance is possible.

We described an imaging system based on the joint-transform correlator (JTC) that produces a multispectral version on an input image. In the next section we briefly described the general theory of a conventional JTC, and then extended the discussion to multiple inputs. Next, we described how this multiple-input JTC can be used for multispectral analysis using wavelets. Finally, we showed some simulations and presented our conclusions.

2.0 CONVENTIONAL JOINT-TRANSFORM CORRELATOR

To perform the correlation operation with a JTC, functions are encoded in the input plane. A schematic diagram of a conventional JTC is shown in Fig. 1. To perform the cross-correlation between the images $b(x,y)$ and $d(x,y)$, they are centered at $x = \pm\alpha$ as shown in Fig. 1 and Fig. 2a. A lens produces the Fourier transform when the input plane is illuminated with coherent light. In the Fourier plane, the complex light field is

$$U = B(p,q)\,e^{j\alpha p} + D(p,q)\,e^{-j\alpha p}, \quad (1)$$

where $B(p,q)$ is the Fourier transform of $b(x,y)$, and similarly for $d(x,y)$. A square-law device such as a liquid crystal light valve is placed in the Fourier plane before an additional Fourier transform is performed. The output intensity distribution from a square-law detector can be written as

$$|U|^2 = UU^* = [B(p,q)\,e^{j\alpha p} + D(p,q)\,e^{-j\alpha p}]\,[B(p,q)\,e^{j\alpha p} + D(p,q)\,e^{-j\alpha p}]^*. \quad (2)$$

Multiplying terms, taking the Fourier transform, and grouping terms results in

$$I = b(x,y) \otimes b(x,y) + d(x,y) \otimes d(x,y) + b(x,y) \otimes d(x+2\alpha,y) + d(x,y) \otimes b(x-2\alpha,y), \quad (3)$$

in the output plane, where $\otimes$ indicates the correlation operation. The first two terms are the autocorrelations of the input functions and appear on the optical axis. The third and fourth terms are the cross-correlation between the two input functions and appear at $x = \pm 2\alpha$. This is shown in Fig. 1 and Fig. 2b.

To perform the wavelet transform at one scale using a JTC, one input is the image of interest and the other is the wavelet function. The wavelet transform at a particular scale then appears at the output of the JTC. Because wavelets have zero mean, this may present a difficulty in the implementation. To remove the DC component from the wavelet function, it was experimentally shown that the input functions could be encoded in phase to eliminate the DC component.[3]

3.0 MULTIPLE-INPUT JOINT TRANSFORM CORRELATOR

3.1 Theory

We considered a JTC with the use of any number of inputs arranged along a line as the inputs. We used the JTC as in Fig. 1 but considered n inputs separated by α in the input plane arranged along the x-axis as shown in Fig. 3. The images were labeled $a_1(x,y)$ to $a_n(x,y)$, with the center image labeled as $a_{(n+1)/2}(x,y)$. Using this configuration, the complex light field in the Fourier plane was

$$U = A_1(p,q)\,e^{j\left(\frac{n-1}{2}\right)\alpha p} + A_2(p,q)\,e^{j\left(\frac{n-3}{2}\right)\alpha p} \ldots A_{\frac{n+1}{2}}(p,q) + \ldots A_n(p,q)\,e^{-j\left(\frac{n-1}{2}\right)\alpha p} \quad . \tag{4}$$

The output intensity distribution from a square-law detector was written as $|U|^2 = U \times U^*$. Multiplying $n \times n$ terms, taking the Fourier transform, and grouping terms resulted in $2n - 1$ locations in the output plane where a correlation response would occur. The output plane was described as

$$\begin{aligned} I = {} & \left[\sum_{i=1}^{n} a_i(x,y) \otimes a_i(x,y)\right] \\ & + \left[\sum_{i=1}^{n-1} a_i(x,y) \otimes a_{i+1}(x+\alpha,y) + \sum_{i=1}^{n-2} a_i(x,y) \otimes a_{i+2}(x+2\alpha,y) \right. \\ & \qquad \left. + \ldots \sum_{i=1}^{n-(n-1)} a_i(x,y) \otimes a_{n-1}(x+(n-1)\alpha,y)\right] \\ & + \left[\sum_{i=1}^{n-1} a_{i+1}(x,y) \otimes a_i(x-\alpha,y) + \sum_{i=1}^{n-2} a_{i+2}(x,y) \otimes a_i(x-2\alpha,y) \right. \\ & \qquad \left. \ldots \sum_{i=1}^{n-(n-1)} a_{n-1}(x,y) \otimes a_i(x-(n-1)\alpha,y)\right] . \end{aligned} \tag{5}$$

The first term in brackets in Eq. (5) contains the DC terms which is the sum of the autocorrelations of all the input images. The second term in brackets correspond to n - 1 terms to the left of the DC term which are shown in Fig. 4; each one of these terms is separated by a distance α. The third term is similar to the second but corresponds to the right of the DC term in Fig. 4. In addition, the terms on each side of the DC term are the same but rotated by π radians as in a conventional JTC.

3.2 Multispectral example using wavelets

Under certain conditions the input arrangement in Fig. 3 may produce a multispectral version of the input image corresponding to multiple wavelet scales. We considered an example that produced a version of an input image that corresponded to two wavelet scales. In other words, the output image corresponded to the sum of the correlations of the input image and two different wavelets. To perform this type of operation we referred to Fig. 3 and set $n = 5$, and $a_3(x,y) = 0$. We considered the input image $f(x,y)$ at locations $a_1(x,y)$ and $a_2(x,y)$, so $f(x,y) = a_1(x,y) = a_2(x,y)$. Finally, we set a wavelet corresponding to one scale $w_1(x,y) = a_4(x,y)$, and the wavelet of another scale $w_2(x,y) = a_5(x,y)$. The configuration in the input plane is shown in Fig. 5.

The response in the output plane was obtained by substituting the appropriate variables in Eq. (5), and the output plane was represented schematically as shown in Fig. 6. The third term from the DC is the term of interest here. It was the sum of correlations of the input image and two different wavelets.

3.3 Implementation

To implement the multiple-input JTC optically a few points must be considered. One is the removal of the DC from the wavelet image. Wavelets have zero mean, so the wavelet image cannot be used directly. One solution is to display the wavelet in phase;[3] however, we proposed to use a DC block arrangement.

Because more than one scale of a wavelet is used in our arrangement, multiple wavelet images are needed; one for each scale of the wavelet used. Displaying multiple images on an SLM would increase the space-bandwidth product of the system, so we proposed to use conventional optics to produce different versions of the wavelet at different scales. Similarly for copying the input image.

A proposed multiple-input JTC configuration for the multispectral example was shown in Fig. 7. It used an input SLM to display an input image and wavelet image as in a conventional JTC. The DC of the wavelet could be eliminated using a DC block in the Fourier transform plane of a telescope arrangement. The scale of a wavelet could be adjusted by varying the focal length of lenses in another telescope arrangement. Neutral density filters may be used to adjust the amplitude of the wavelet. The input lens in the JTC must capture all images, but a detector is required for only a portion of the output plane.

4.0 SIMULATION EXPERIMENTS

We simulated the operation of a JTC used for multispectral analysis using two scales. We used the input image shown in Fig. 8, and a Bessel-Gaussian wavelet.[3] The Bessel-Gaussian wavelet was considered because it would be useful for rotation-invariant pattern recognition because it is circularly symmetric. It was described as

$$\frac{1}{\sqrt{a}}w\left(\frac{r}{a}\right) = \frac{1}{\sqrt{a}}J_0\left(\frac{r}{a}\right)exp\left[-\left(\frac{r}{2a\sigma}\right)^2\right] \quad (6)$$

where σ is related to the width of the bandpass response, a is the scale factor, and r is the distance form the origin.

We performed the simulation with an input image corresponding to the configuration of Fig. 5 using a total of 512 x 512 pixels. The image of the plane was used for $f(x,y)$ and contained 50 x 50 pixels and α was set to 50 pixels. The wavelet was used for both $w_1(x,y)$ and $w_2(x,y)$, both with $s = 0.6$, and $a_1 = 0.7$ and $a_2 = 1.2$. The output plane of the correlator is shown in Fig. 9 with the grayscale inverted for display purposes. The output consisted of nine responses; the three in the center were clipped because of their large value due to the autocorrelation responses and overlapped each other so one large spot appeared. The autocorrelation responses also overlapped the responses immediately next to the autocorrelation responses. The two remaining responses on the right hand side of Fig. 9 were expanded and shown in Fig. 10. The response on the right corresponded to $a_2 = 1.2$ and the one on the left corresponded to the sum of a_1 and a_2. Changing a_1 to $a_1 = 1.0$ changed the response on the left but not on the right as shown in Fig. 11. A small part of the correlation between the image and the wavelet with associated with a_1 can be seen in the left side of the image. Rotating the input image simply rotated the output image because of the circular symmetric nature of the wavelet as shown in Fig. 12.

5.0 CONCLUSION

We showed how a multiple-input JTC can be used for multispectral analysis of an input image. An input image and wavelet image are required as inputs. For m wavelet scales, m versions of the wavelet and m copies of the input image generated using conventional optics are used as inputs to a JTC. The output consists $4m$-1 correlation results, one of which is the desired output. The space-bandwidth product of the system is the same as for a conventional JTC.

6.0 REFERENCES

[1] W. Wang, G. Jin, Y. Yan, and M. Wu, "Joint wavelet-transform correlator for image feature extraction," *Applied Optics* vol. 34(2), 370-376 (1995)

[2] X. Yang, N. P. Caviris, and M. Wen, "Optical wavelet correlators for cluttered target identification," in *Optical Pattern Recognition V,* SPIE 2237, 402-418 (1994)

[3] P. S. Erbach, D. A. Gregory, and X. Yang, "Optical wavelet transform by the phase-only joint-transform correlator," *Applied Optics* vol. 35(17), 3117-3126 (1996)

[4] D. Mendlovic, I. Ouzieli, I. Kiryuschev, and E. Marom, "Two-dimensional wavelet transform achieved by computer-generated multireference matched filter and Dammann grating," *Applied Optics* vol. 34(35), 8213-8219 (1995)

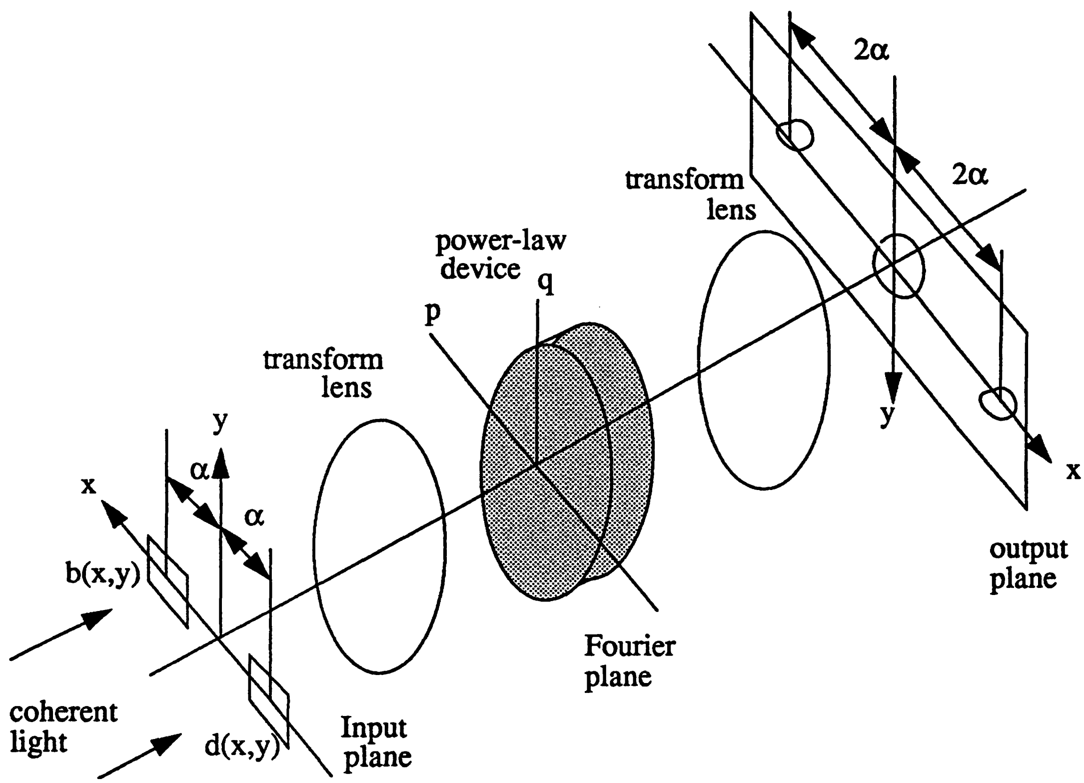

FIGURE 1. Schematic diagram of a conventional joint-transform correlator

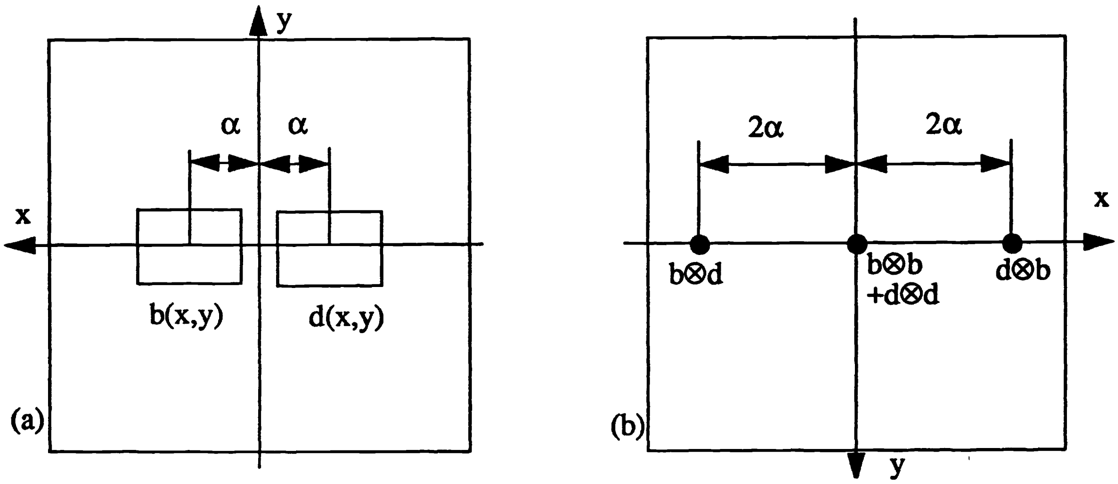

FIGURE 2. Input and output planes of a JTC showing locations of inputs and outputs (a) input plane (b) output plane

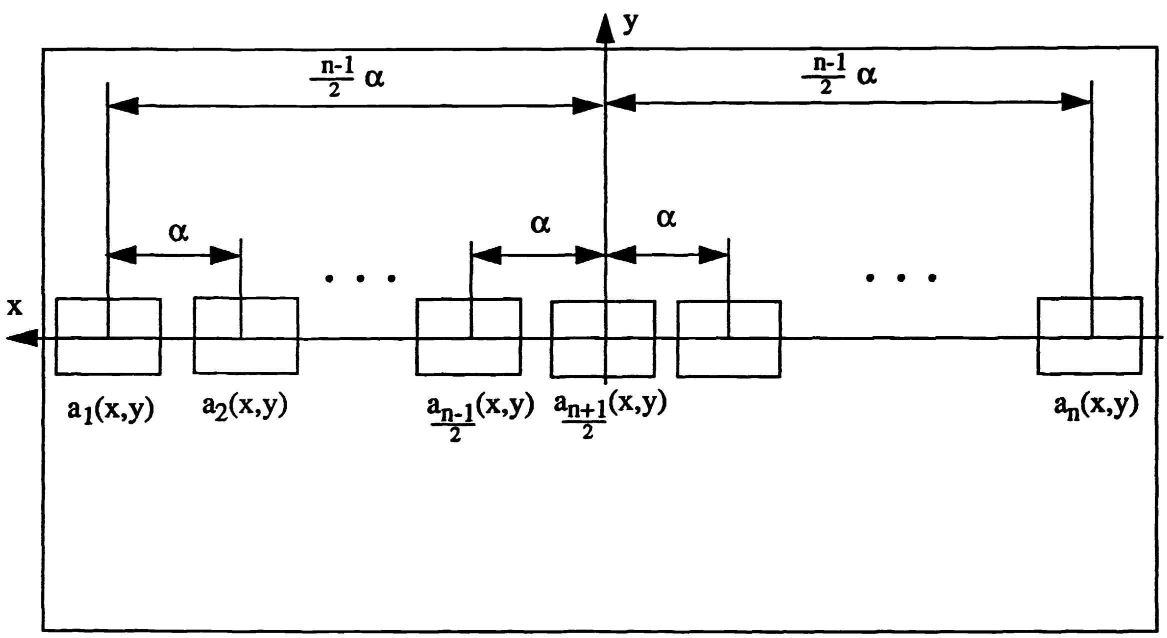

FIGURE 3. Input plane of multiple-input JTC

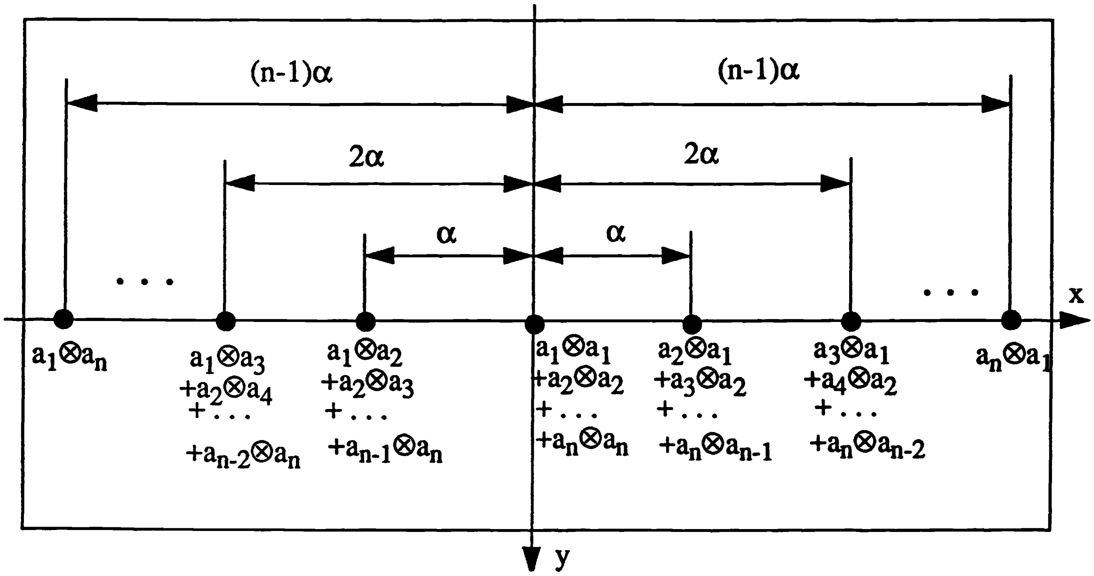

FIGURE 4. Output plane of multiple-input JTC

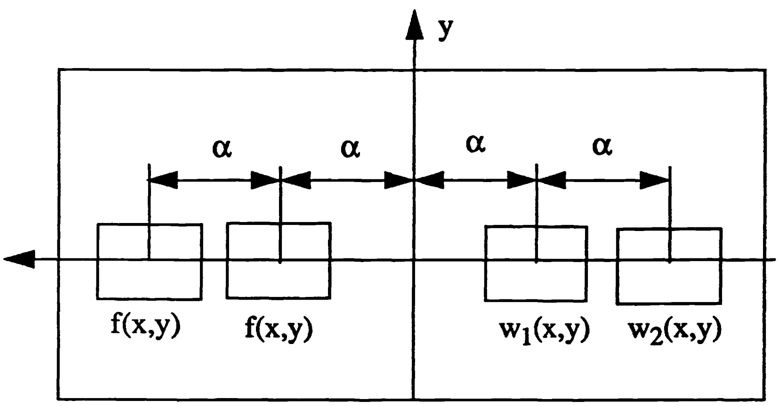

FIGURE 5. Input plane of multispectral example

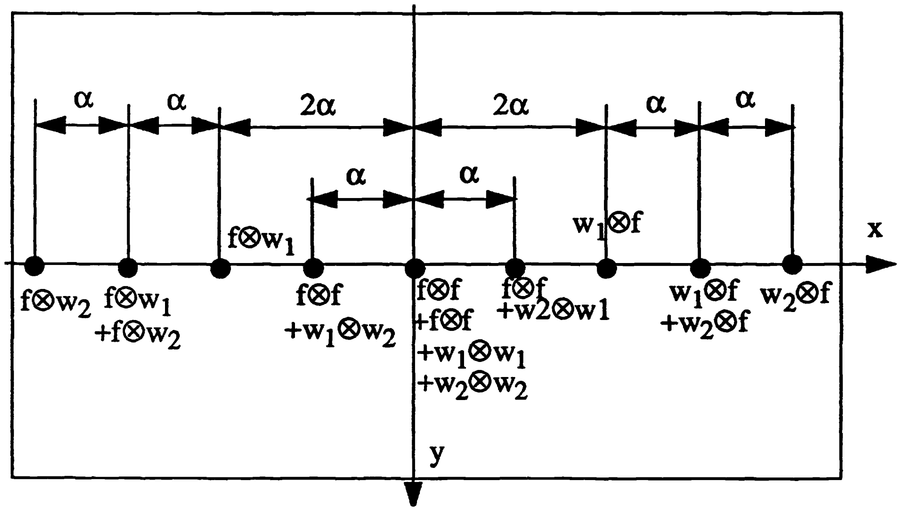

FIGURE 6. Output plane of multispectral example

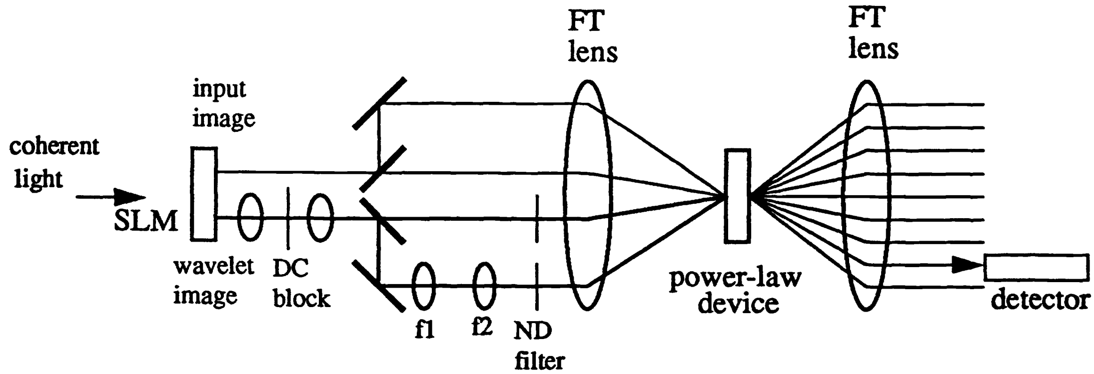

FIGURE 7. Schematic diagram of multiple-input JTC used for multispectral analysis using two wavelet scales

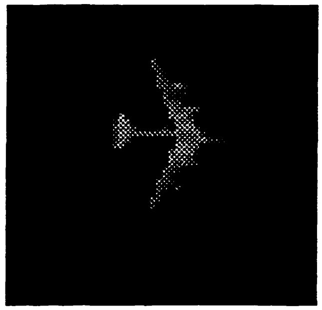

FIGURE 8. Image used in simulation experiments.

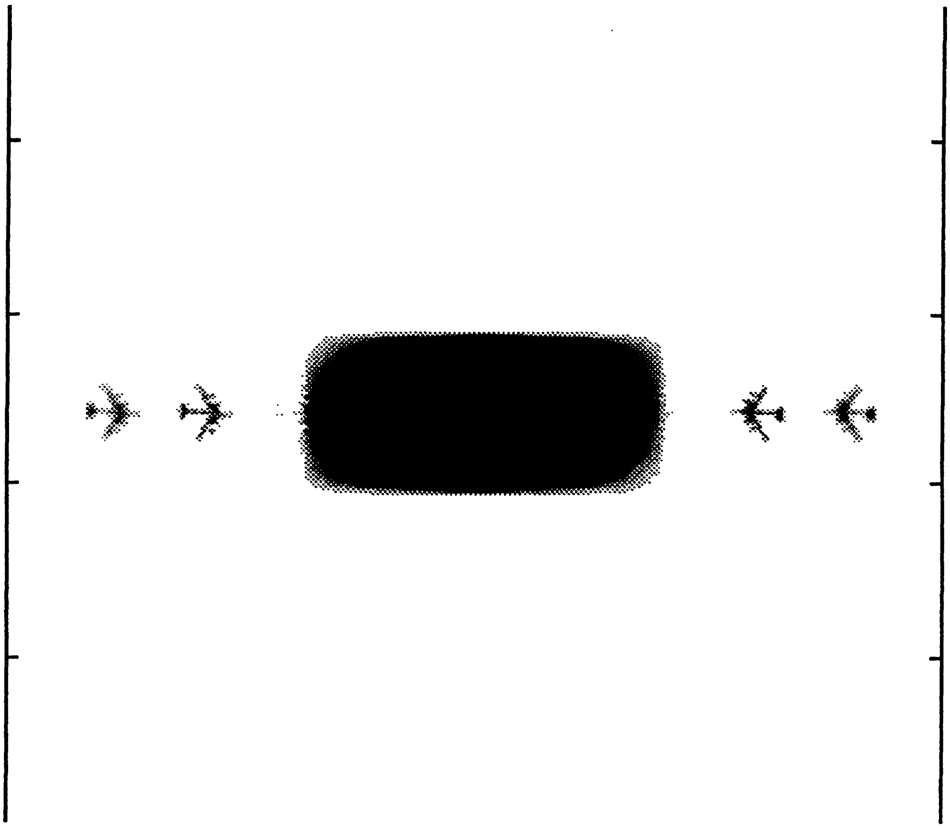

FIGURE 9. Output plane of multispectral simulation experiment.

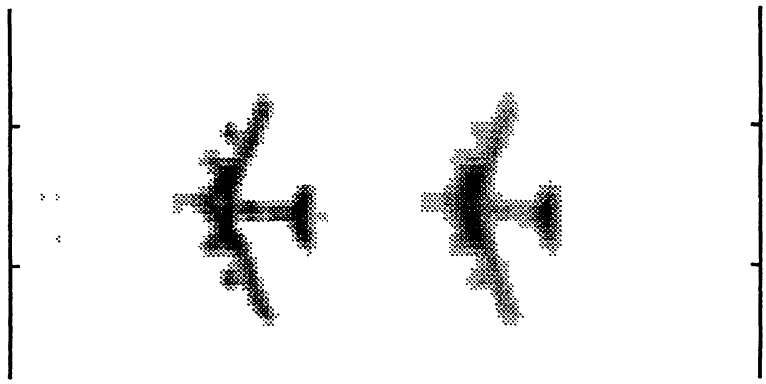

FIGURE 10. Close-up view of right hand side of Fig. 9. Response on right is for a_2=1.2, response of left is for $a_1 + a_2$, where $a_1 = 0.7$.

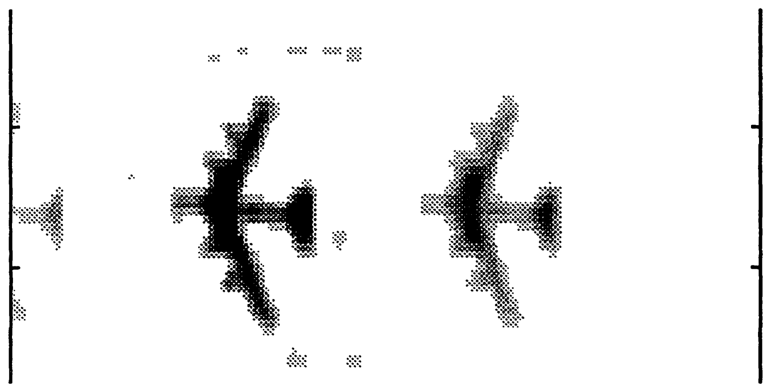

FIGURE 11. Response on right is for a_2=1.2, response of left is for $a_1 + a_2$, where $a_1 = 1.0$.

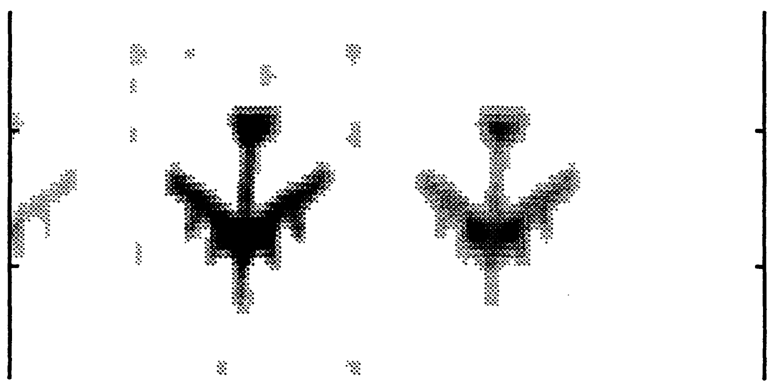

FIGURE 12. Response when input image was rotated by 90 degrees. Response on right is for a_2=1.2, response of left is for $a_1 + a_2$, where $a_1 = 1.0$.