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Multispectral image feature extraction by the joint wavelet-transform correlator

Samuel Peter Kozaitis
Mark A. Getbehead
Wesley E. Foor

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S. P. Kozaitis

Florida Institute of Technology
Division of Electrical, Computer Science and Engineering
150 W. University Blvd.
Melbourne, FL 32901

M. Getbehead, W. E. Foor

Rome Laboratory
Photonics Center
25 Electronics Pkwy.
Rome, NY 13441

ABSTRACT

A multispectral version of an image consisting of multiple wavelet components allows for more flexible feature extraction when compared to the use of one wavelet component. We showed how a multiple-input joint wavelet-transform correlator could be used for multispectral analysis of an input image. 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, pattern recognition, wavelet transform

1.0 INTRODUCTION

Optical correlators that implement the wavelet transform often do so using one scale of the wavelet.[1-3] This allows an input image to be viewed in one frequency band corresponding to the frequency response of the wavelet. Multiple images, one corresponding to a different frequency band may also be generated.[3,4] Such a configuration is useful because an input image's energy may be concentrated in one scale. However, a more versatile system would allow an image that consists of multiple frequency bands (multispectral) to be generated. A method is needed that produces a multispectral version of an input image so that various wavelet components of an image can be combined or removed for more flexible feature extraction.

We described an imaging system based on the joint wavelet-transform correlator (JTWC) 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 functions $b(x,y)$ and $d(x,y)$, they are centered at $x = \pm\alpha$ as shown in Fig. 1 and Fig. 2a. A lens performs 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. 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 more detail in Fig. 1 and Fig. 2b.

To perform the wavelet transform 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 JTWC. 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 used the same 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 label $a_1(x,y)$ 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 x 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

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

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 functions. We considered an example that produced a version on 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 of $a_1(x,y)$ 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). 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 JTWC 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 JTWC configuration for the multispectral example is shown in Fig. 7. It used an input SLM to display an input image and wavelet image. Images used for inputs to the JTC could be made using conventional optics. 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 JTWC must capture all images, and 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. We used the input image of an airplane, and a Haar wavelet both shown in Fig. 8. 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. The Haar wavelet was used for both $w_1(x,y)$ and $w_2(x,y)$ and consisted of 4 x 4, and 8 x 8 pixels respectively; the value of α was set to 50 pixels. 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. Of the three remaining responses on each side of the output plane, the center response is the multispectral response. It is the coherent sum of the other two responses. These two responses are the wavelet coefficients for one scale each.

5.0 CONCLUSION

We showed how a multiple-input JTWC 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

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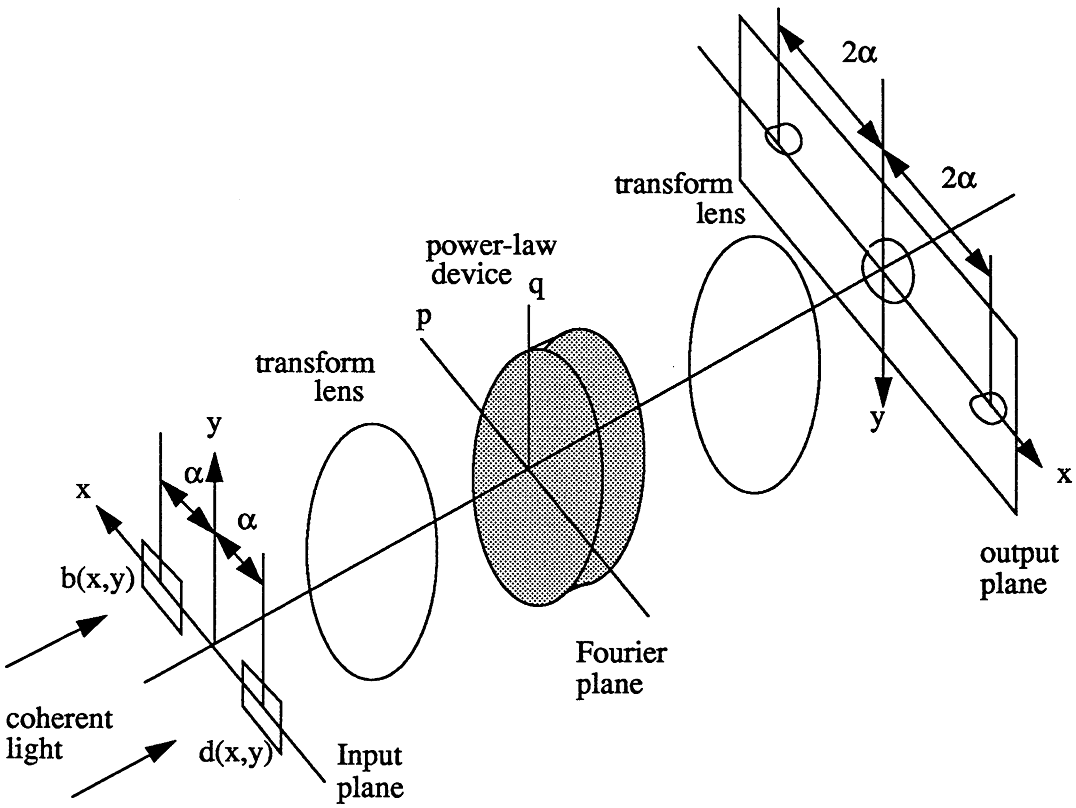

FIGURE 1. Schematic diagram of a conventional joint-transform correlator

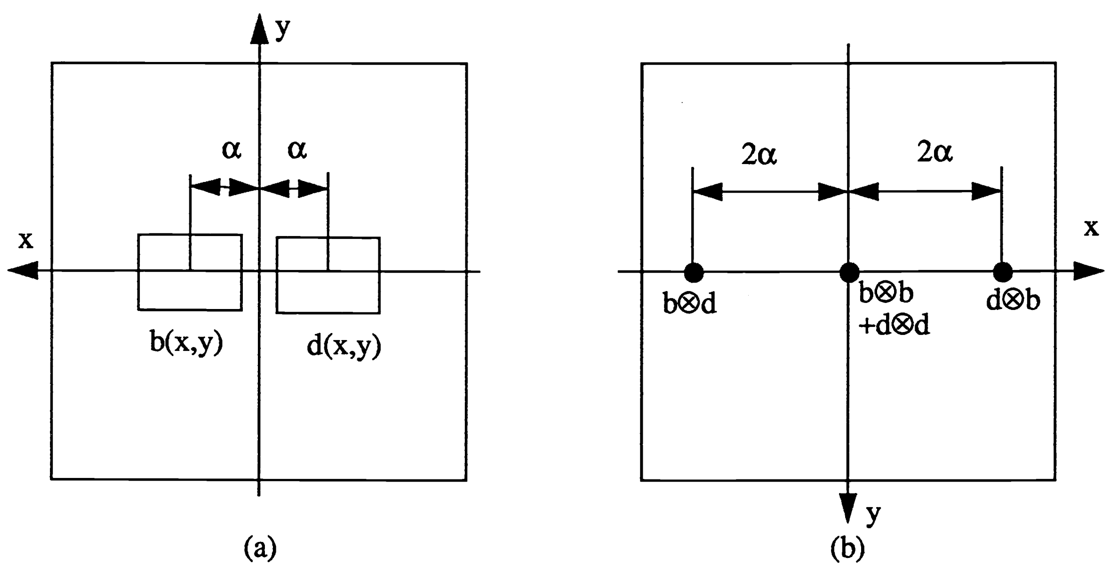

FIGURE 2. Input and output planes of a JTC showing locations of inputs and outputs (a) input plane (b) output plane

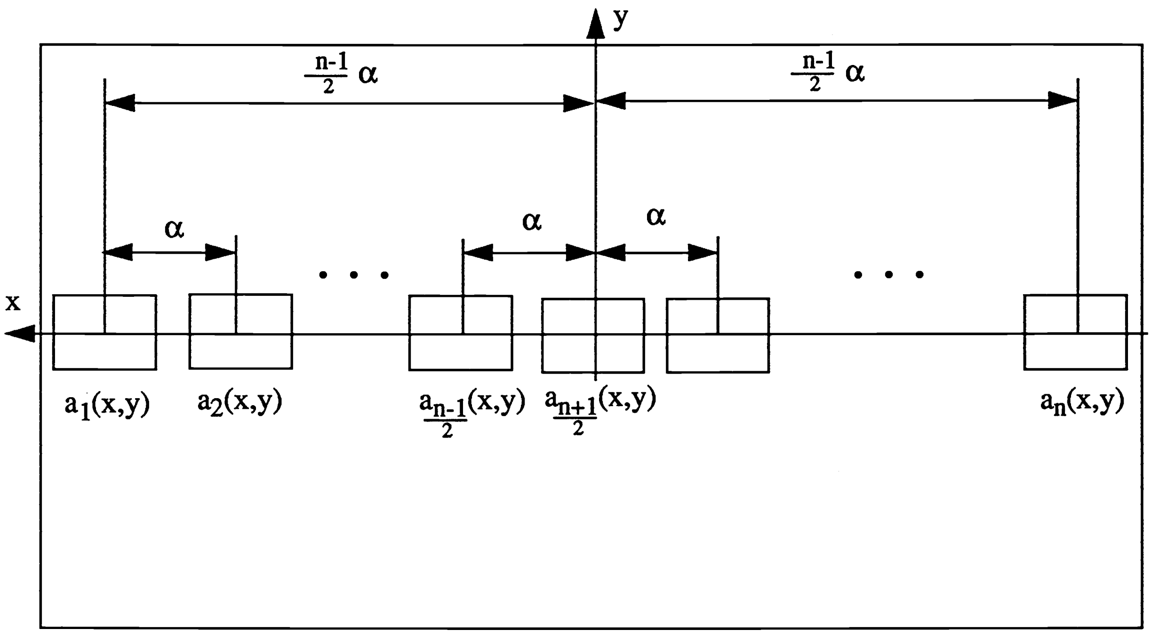

FIGURE 3. Input plane of multiple-input JTC

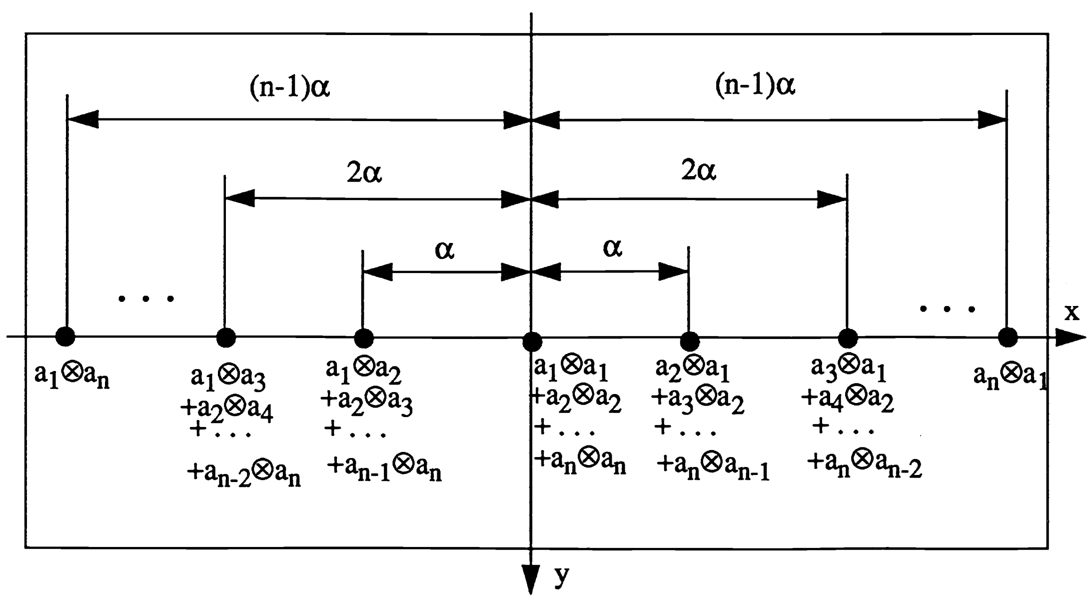

FIGURE 4. Output plane of multiple-input JTC

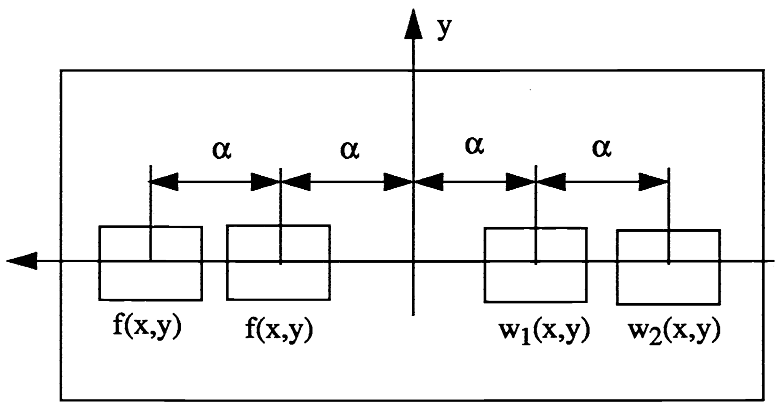

FIGURE 5. Input plane of multispectral example

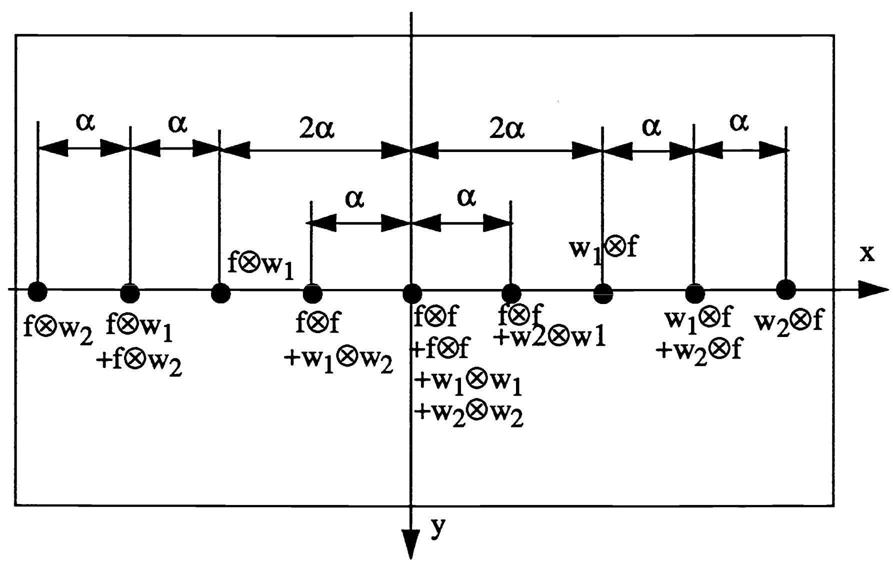

FIGURE 6. Output plane of multispectral example

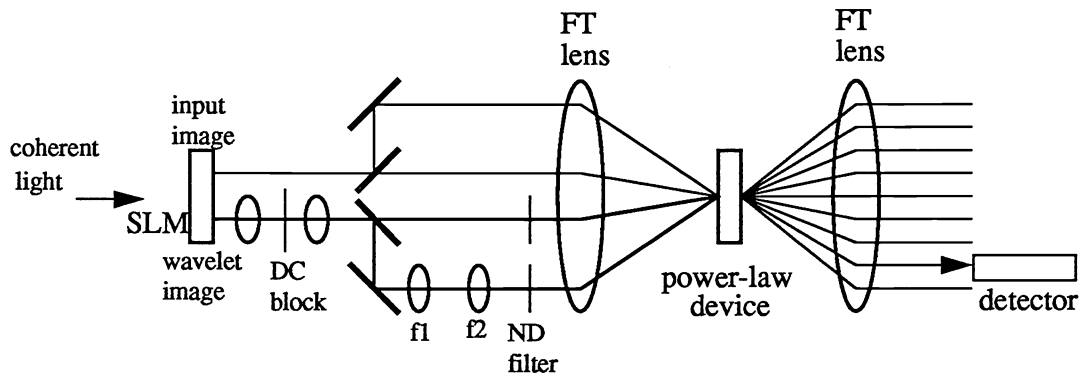

FIGURE 7. Schematic diagram of multiple-input JTC used for multispectral analysis using two wavelet scales

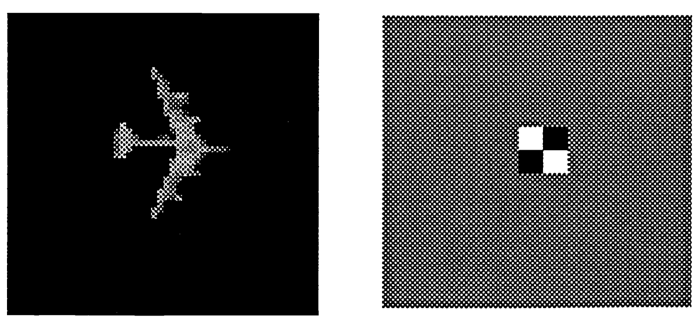

FIGURE 8. Images used in simulation experiment: airplane and Haar wavelet

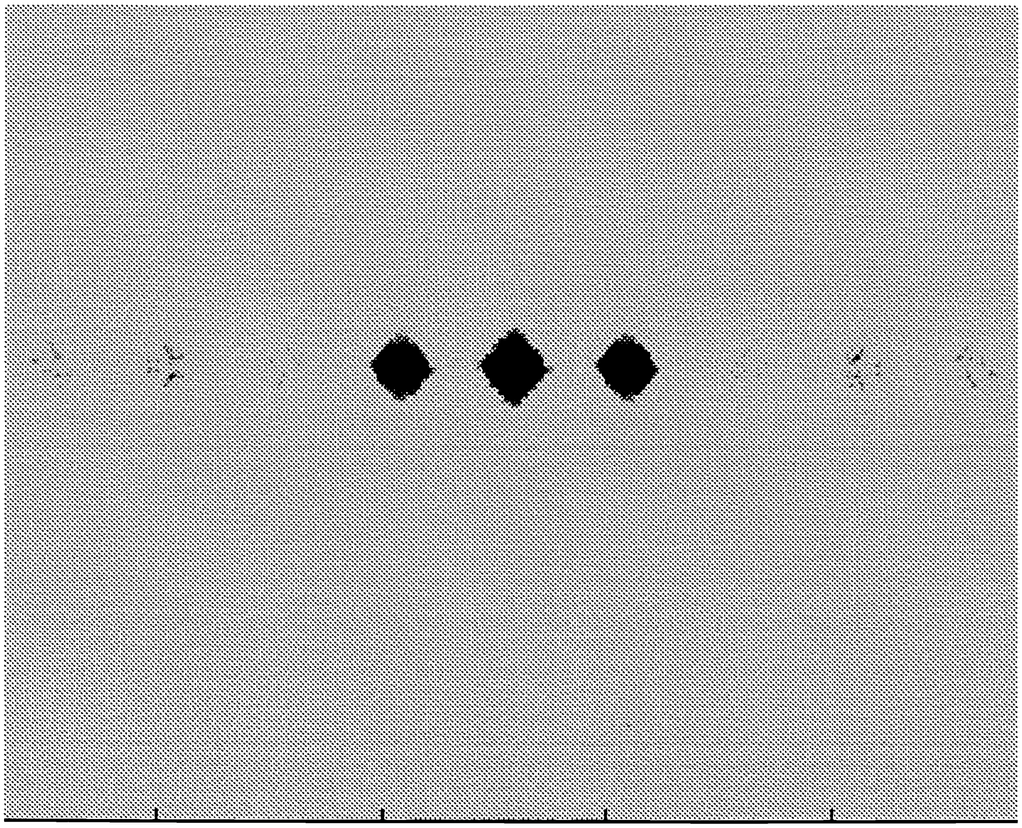

FIGURE 9. Output plane of multispectral simulation experiment