THE AUTOMATIC ANALYSIS OF AERIAL PHOTOGRAPHIC DATA

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Summary. As the volume of aerial photographic data increases in various applications, there is increasing demand for automated data analysis. Faster and larger computer alone is not the solution. In this paper effective and computationally efficient techniques for computer processing of the aerial photographic data are presented. They include: (1) picture data compression, (2) feature exttraction using the histograms of the original and sharpened pictures, (3) sequential target and classification, (4) threshold selection, and (5) Walsh power spectrum analysis. All of these techniques may be incorporated in a fully automated data analysis system to meet certain real-time on-line system requirement.

Introduction. In spite of the advance of a number of remote sensing techniques, taking aerial photographs remains to be an effective way to collect information on the ground. Processing of the aerial photographic data is presently performed almost exclusively manually, although there is an obvious need for atuomatic analysis of such data. There are two major areas of automation in data analysis. The first involves A/D and D/A interfaces, displays, coordinate transformation and correction, etc. The second is the digital processing to extract useful information from the data. Only the second area is considered in this paper. To derive useful information may require picture enhancement by digital means or decision making to detect or classify the objects, etc. Although a large number of digital filtering, pattern recognition, and picture bandwidth compression techniques have been developed, they are generally not cost-effective. Cost or computation time should be a major consideration on automated image data analysis. The following simple and efficient procedures are presented in this paper for computer processing of aerial photographic data: (1) picture data reduction and smoothing, (2) feature extraction from grayscale histograms, (3) sequential target acquisition, (4) threshold selection, and (5) Walsh power spectrum analysis. It is felt that these axe useful techniques for automatic aerial photographic data analysis in realtime on-line digital processing systems.

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Picture Data Reduction. Image data usually contain too much information to be handled effectively by the computer. The area of data reduction for picture bandwidth compression has been well studied in recent years. Its objective is to reconstruct the transmitted image at the receiving site as accurately as possible. For the purpose of pattern recognition, data reduction is to remove the irrelevant details and to retain only the discrimination information. Thus the objective is to reduce the amount of computation for classification with minimal loss of recognition accuracy.

Figures 1 and 2 are examples of aerial photographs considered. The pictures are digitized and then quantized into 256 possible gray levels. In this case each digitized picture is a 1024 x 1024 array of points. The data at each point can be further quantized into two levels, 0 and 1. The picture is now represented by strings of 1's and 0's which are particularly convenient for computer storage, processing and data transmission.. For data reduction, every 3 x 3 matrix of binary points can be reduced to one point by thresholding. If the total number of 1's exceeds 4 then the 9 points are replaced by a single point 1, otherwise the point 0 is used. The 9 to 1 compressed (reduced) picture will again be represented by strings of 1's and 0's. This kind of operation can easily be performed by using APL (a programming language). A sample APL program for picture reduction is shown in Figure 3. Figures 4 and 5 are 9 to 1 compressed pictures corresponding to Figures 1 and 2 respectively. Figure 6 is a 25 to 1 compressed picture for Figure 2. Only the target (object) areas are shown for compressed pictures. The simple decision operation removes low-level noises and thus provides data smoothing. The isolated data points are also considerably eliminated by data reduction. High-level noise, however, causes errors in decision and picture reduction must then be preceded by filtering to remove the noise. The maximum allowable picture reduction depends on target size and the objective of data analysis. If the objective is to detect or classify the target, then a considerable amount of reduction (i.e. greater than 25 to 1) is allowed. If image enhancement is desired, the amount of reduction should be small (say 9 to 1 or less).

Feature Extraction Using Histograms. Since gray-scale histogram contains essential statistical information of a picture, useful features may be derived from histograms. Variance of the histogram is a useful but not necessarily effective feature. For aerial photographic data, the histogram is normally a bimodal or unimodal distribution. If the target and the background are well separated, the histogram is bimodal, otherwise it is unimodal. The degree of bimodality of the gray-scale histogram provides a good indication of the existence of a target. An empirical measure of bimodality is defined as

$$\delta = \frac{\text{the valley height}}{\text{minimum of two peaks}}$$

The degree of bimodality can be improved by sharpening the picture when the noise level is low. Unimodal may become bimodal by sharpening. Figures 7 and 8 are the two-level gradient pictures of the target area corresponding to Figures 1 and 2 respectively. The targets are much more clear in the gradient picture than in the original picture. Thus the degree of bimodality of the original or sharpened picture is a useful feature which can be derived from histograms.

Sequential Target Acquisition. For the 13 aerial photographs available, computer experiment on sequential target acquisition has been performed. For each picture, five 100 x 100 subpictures are selected and one of the five contains the real target. The histogram of each subpicture is determined and recognition proceeds as follows.

Step 1. Check the existence of bimodal distribution.

Step 2. Measure the quantity δ. The smaller the δ, the more likely the target is located. If none of the subpicture has bimodal distribution, the decision is to reject. Among the 13 pictures, two are rejected, one is decided incorrectly; the remaining pictures are decided correctly. The sequential method appears to be quite effective in detecting the existence of a target. Although the bimodality is measured manually here, the process can be automated by additional software. For the pictures rejected, the gray-scale histogram of the gradient pictures can provide better recognition results. It is noted that the hardware for computing histogram is commerciallyavailable.

Threshold Selection. To generate a binary, i.e. two-level picture, it is necessary to determine a good threshold. When the target and the background are well separated, the valley is a good place for locating the threshold if the two peaks are nearly equal in height., This, however, is not the case for the 13 pictures available. Threshold selection may be considered as an unsupervised signal detection problem which requires evaluating the mean and variance of each component Gaussian density. Some a priori knowledge is available about the background making it easier to determine the threshold. Our experience indicates that the threshold should be located closer to the target side on the valley. To automate the selection, computational algorithm must be developed. For unimodal histogram, gray-scale normalization and gradient operation are needed to obtain a bimodal histogram.

Walsh Power Spectrum. Among all orthogonal transforms, Walsh transform requires the least amount of computation. Its performance is close to other transforms where fast algorithms are available. For a given subpicture, the Walsh power spectrum is obtained by first taking the Walsh transform and then computing the power at each sequency component which is the sum of squares of the Walsh transforms at the same sequency. It is noted that the Walsh matrix must be arranged in sequency order. For a 16 x 16 subpicture, the Walsh matrix W is given by

$$
W = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} \\
1 & 1 & 1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & \bar{1} & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & 1 & 1 & 1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} \\
1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & 1 & 1 & 1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & 1 & 1 \\
1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & 1 & 1 & \bar{1} & \bar{1} \\
1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 \\
1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} \\
1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 \\
1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} \\
1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & 1 & \bar{1} & \bar{1} & 1 & 1 & \bar{1} & 1 & \bar{1} & \bar{1} & 1 \\
1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & 1 & \bar{1} & 1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & 1 & \bar{1} \\
1 & \bar{1} & 1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & 1 & \bar{1} & 1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 \\
1 & \bar{1} & 1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & 1 & \bar{1} & 1 & \bar{1} \\
1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 \\
1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1} & 1 & \bar{1}
\end{bmatrix}
$$

The Walsh transform is obtained by pre-multiplying and post-multiplying the picture function (an array of numbers representing the gray levels) by the matrix W. The ratio of a.c. power to the total power has been shown experimentally to be an effective measure for detecting and classifying a target. The a.c. power is an indication of the variation of object boundary in the subpicture.

Conclusion. We have presented several effective and conputationally efficient techniques for automatic analysis of aerial photographic data. All of these techniques may be incorporated in a fully automated data analysis system to meet certain real-time on-line system requirements.

Fig. 1 Aerial Photograph Considered (Target: truck)

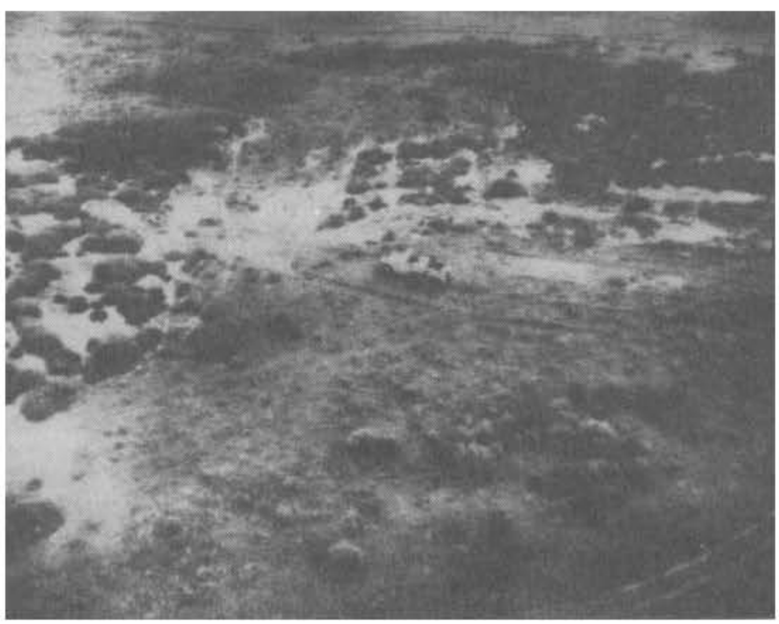

Fig. 2 Aerial Photograph Considered (Target: car)

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      ∇S←D1 [illegible] D2
[1]   G←(D2[1]-D1[1])+1
[2]   F←(D2[0]-D1[0])+1
[3]   H←(1024×D1[0])+D1[1]
[4]   S←' □'[PICTURE[(H+(1024×ιF))∘.+ιG]]
[5]   ∇
      ∇COMPRESS
[1]   M←(ρS)[0]
[2]   N←(ρS)[1]
[3]   MP←⌊M÷3
[4]   NP←⌊N÷3
[5]   V←(3×N×ιMP)∘.+(3×ιNP)∘.+(N×ι3)∘.+0 1 2
[6]   S1←4<+/+/(,S='□')[V]
[7]   ' □'[S1]
[8]   ∇
```

Fig. 3 Sample APL Program for Data Compression

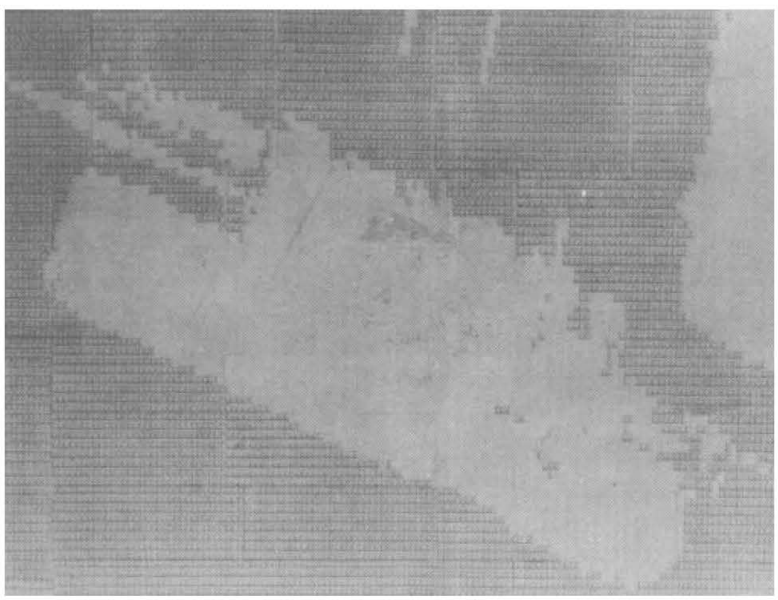

Fig. 4 9-to-l Compressed Picture of Target Area in Fig. 1

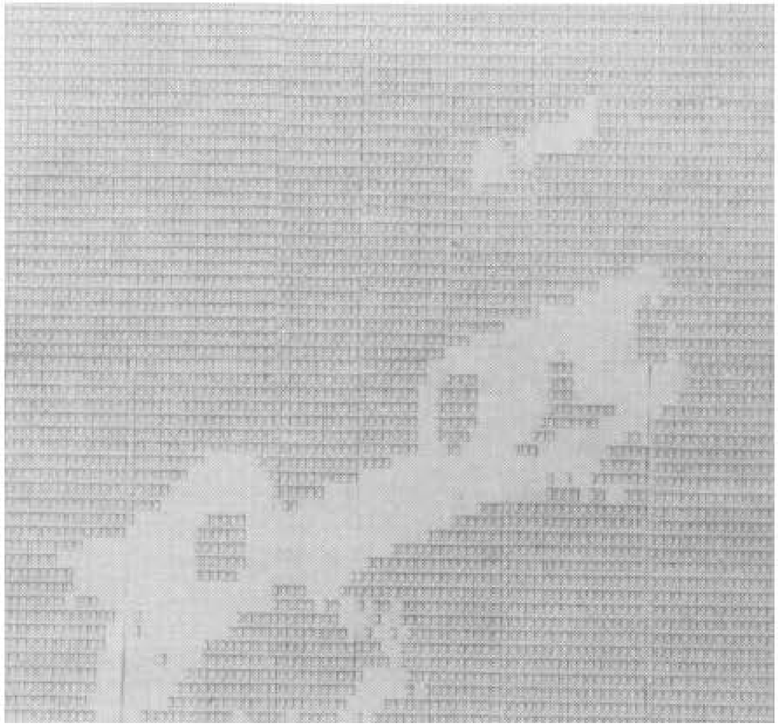

Fig. 5 9-to-1 Compressed Picture of Target Area in Fig. 2

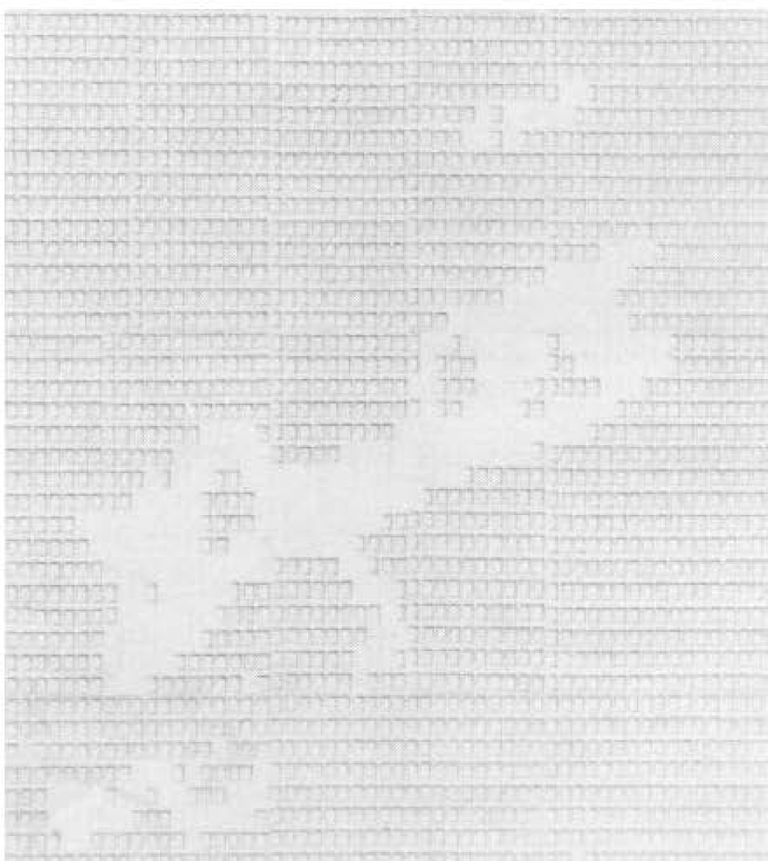

Fig. 6 25-to-1 Compressed Pictures of Target Area in Fig. 2

Fig. 7 Two-level Gradient Picture of Target Area in Fig. 1

Fig. 8 Two-level Gradient Picture of Target Area in Fig. 2