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A METHOD FOR FINDING PAIRS OF ANTI-PARALLEL LINEAR FEATURES

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(12) 51

ABSTRACT

A method for finding anti-parallel straight edges is presented and discussed. This method is based on information about the object sides of edges, the similarity and homogeneity of gray level between the edges, the angle difference, the amount of overlap, and also information about the estimated object gray level. Two figures of merit are defined to calculate the mutual support of two antiparallel linear features. Examples are shown of applying the method to high resolution aerial photographs. Results indicate that cultural features such as roads and buildings can be extracted and that a significant reduction in the complexity of the image description can be obtained. This algorithm should be especially useful in a relaxation type scheme for classifying linear feature segments when the degree of anti-parallelism of the segments is needed.

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1. Introduction

A characteristic of cultural features that appear in high resolution aerial photographs is the large number of straight edges. The edges of cultural features usually occur in pairs, as in the sides of roads and of buildings. As a preliminary step towards the recognition of objects, the straight edges can be extracted [1,2], and clustered into anti-parallel pairs (i.e., pairs of facing edges that are parallel but have opposite senses). The clustering process is the subject of this paper. In general, this process must take into account information from the picture in the regions around the edges. For example, a road usually has a uniform gray level and thus it is reasonable to expect the object sides of an anti-parallel pair of edges to have similar gray levels.

Some previous work [1,4] has restricted the choice of pairs to lines that are closest neighbors. A method of pairing anti-parallel lines reported in [5] is based on the distance between the lines, the amount by which they overlap, and whether or not other lines are interposed. Another method, reported in [3], finds the pairs of lines that are anti-parallel up to a certain angle difference when similarity of gray levels between the pair is satisfied. The process to be described here performs a more global analysis and deals with lines extracted from an image together with information about the object side of each line (e.g., bright or dark objects with respect to the background in the scene) and also the region between the lines.

The process accepts as input a set of ordered pairs of line end points and the gray level picture. It attempts to find pairs of lines that are anti-parallel and that obey relations involving similarity and homogeneity of the region between the lines, the angle difference, the amount of overlap, the shortest distance between the lines, and also the estimated or typical gray level of the objects.

The basic procedure is as follows: A strip is moved along the object side of each line. While the strip moves, it hits other line segments. The first figure of merit is defined on the basis of similarity, homogeneity of the region between the lines, the distance, the angle difference, and the amount by which the lines overlap. The second figure of merit uses the information in the first one and also the estimated or typical gray level of the objects. The second figure of merit also has the property of noise cleaning, i.e., suppressing non-object lines. The movement of the strip is stopped by the maximum object size allowed or by the maximum allowable similarity level in the scene.

In what follows the anti-parallel constraints will be derived and then the figures of merit will be explained.

2. Anti-parallel constraints

A pair of lines should satisfy certain constraints in order to be accepted as a candidate anti-parallel pair. In general these constraints depend on:

a) Whether the lines face each other.

b) Whether their object sides are similar and the region between them is homogeneous.

c) The angle difference between the lines.

d) The overlap between the lines.

e) The distance between the lines.

f) The object gray level.

In what follows each of the above measures will be discussed in more detail.

2.1 Sense

Two lines are accepted as anti-parallel candidates if they are parallel but have opposite senses. The sense function can be defined as follows:

$$S(i) = \begin{cases} 1 & \text{if the two lines have opposite sense} \\ 0 & \text{if not} \end{cases}$$

where i is the label of the line being considered as anti-parallel to a given line.

2.2 Similarity and homogeneity

Referring to Figure 1, the measure of similarity between line A and the anti-parallel candidate lines A_1, A_2, etc. is defined as

$$S_{i1} = |g-g_i|$$

where g and g_i are the average gray levels along small strips on the object sides of lines A and A_i, respectively. The measure of similarity between line A and the region between the lines is defined by

$$S_{i2} = (1/n) \sum_{h=1}^{n} |g-s_h|$$

where s_h is the average gray level of each strip and n is the number of strips between the lines. Similarly the measure of similarity between line A_i and the region between the lines is defined by

$$S_{i3} = (1/n) \sum_{h=1}^{n} |g_i-s_h|$$

In the above two measures, since we take the average gray levels of small strips and then take the average of the differences, S_{i2} and S_{i3} are measures of similarity, and to some extent measures of the homogeneity of the region between the lines. If S_{i1},S_{i2}, and S_{i3} are small for a pair of lines, then that pair is more anti-parallel on the basis of similarity and homogeneity.

To define the final measure, a piecewise linear function as shown in Figure 2 is defined for each of the above measures. According to this function, when the above differences are less than $S_{max}/2$ the measure function h_{ik} (k=1,2,3) is 1, and when the difference is greater than the maximum allowable level of similarity h_{ik} is 0. In summary:

$$h_{ik} = \begin{cases} 0 & \text{if } S_{ik} > S_{max} \text{ or } S(i)=0 \\ 1-(2S_{ik}-S_{max})/Smax & \text{if } S_{max}/2 < S_{ik} < S_{max} \\ 1 & \text{if } 0 \leq S_{ik} < S_{max}/2 \end{cases}$$

for k=1,2,3, where S_{max} is the maximum allowable similarity level. The final similarity and homogeneity measure is defined as

$$H(i) = h_{i1}+h_{i2}+h_{i3}$$

The maximum possible value for H(i) is 3 and the minimum value is 0.

2.3 Angle

The difference of slopes (with respect to the x-axis) of two anti-parallel candidates is also an important factor in finding anti-parallel pairs. Referring to Figure 3, the angles of line A and lines A_1, A_2, etc. with respect to the x-axis are θ, θ_1, θ_2, etc. The absolute difference of the angles

$$\varphi_i = |\theta - \theta_i|$$

is a measure of parallelism of the line A with respect to the line A_i. It is obvious that the smaller the angle difference, the better the degree of parallelism. To express this situation, a piecewise linear function is proposed. Figure 4 shows the proposed function. φ_{max} is the maximum allowable difference for selecting anti-parallel candidates (usually 30°). According to this function, up to a certain tolerance level $\varphi_{max}/2$ the angle function is equal to 1. This tolerance is assumed because of possible error in the angles of the lines fitted to the connected components. If the angle difference is greater than $\varphi_{max}/2$ the angle measure function is decreased linearly to zero. In summary, the linear angle function is defined as

$$F(\varphi_i) = \begin{cases} 1 & \text{if } \varphi_i < \varphi_{max}/2 \text{ or } S(i)=0 \\ 1-(2\varphi_i - \varphi_{max})/\varphi_{max} & \text{if } \varphi_{max}/2 < \varphi_i < \varphi_{max} \\ 0 & \text{if } \varphi_i \geq \varphi_{max} \end{cases}$$

2.4 Overlap

A rough method of calculating the overlap between two anti-parallel candidates is demonstrated in Figure 5. In this method perpendicular lines from each end of an anti-parallel candidate are drawn towards the other line. The distance on the line in question between the ends of these perpendiculars is considered as the overlap distance ℓ_i. Another more accurate way of calculating the overlap distance is to calculate the length of the intersection of the projections of the lines onto a line that runs between them and has an angle that is the mean of their angles modulo 180° (see [5]).

For simplicity the first method of calculation of the overlap distance is used in the program. To define the overlap measure, we use the linear function shown in Figure 6. In this figure $\ell_{max} = Max(\ell_i)$, the maximum overlap distance among the candidates. The overlap measure function is normalized with respect to ℓ_{max} and is calculated as

$$O(\ell_i) = \begin{cases} 0 & \text{if } \ell_i > \ell_{max} \text{ or } S(i)=0 \\ \ell_i/\ell_{max} & \text{if } \ell_i \leq \ell_{max} \end{cases}$$

2.5 Distance

The shortest distance between lines A and A_i can be used to define the distance measure. To define the smallest distance between two anti-parallel candidates, at each end of each line perpendiculars are drawn to the other line. If the intersection of the perpendicular with the other line is located outside the given segment, that distance is ignored. Among the remaining distances, the minimum is selected as the distance between the two lines. Figure 7 shows an example of calculating the distance between two lines. As shown in this figure, among the four distances

$$d_{ij} \quad (j=1,2,3,4)$$

d_{i3} and d_{i4} are ignored and

$$d(i)=\min(d_{i1},d_{i2})$$

is selected as the shortest distance between the two lines.

The distance measure can be defined on the basis of the calculation of the smallest distance d(i). The linear function of Figure 8 is used for this purpose. According to this figure, the distance measure function is normalized (equal to 1) with respect to $d_{min}=\min[d(i)]$, that is, the minimum distance among the candidates. The distance measure function decreases linearly to zero at the value ℓ, where ℓ is the maximum allowable size of the objects on the scene. Thus finally, the distance measure is defined as

$$D(i) = \begin{cases} 0 & \text{if } d(i) > \ell \text{ or } S(i)=0 \\ 1-[d(i)-d_{min}]/(1-d_{min}) & \text{if } d(i) \leq \ell \end{cases}$$

2.6 Object gray level

The given or estimated object gray level can also be used in defining the figure of merit. This measure can be incorporated into the figure of merit in such a way as to yield high values for the merit of object lines and low values for non-object lines, or for an object and a non-object anti-parallel candidate. A method of estimating the object gray level is reported in [3].

If the difference between the estimated or given gray levels of the two anti-parallel candidates and the average object side gray level is small, the two lines should reinforce each other to yield a high measure; otherwise, they should punish each other to yield a low measure. A linear function is defined for this purpose, as shown in Figure 9. In this figure g_e is the estimated gray level of the object and g_i the gray level average of a small neighborhood along the object side of the candidate line i. S_{max} is the maximum allowable level of similarity. In summary, the object gray level measure for each line is defined as follows:

$$f(g) = \begin{cases} 1 & \text{if } 0 \le |g_e - g_i| < S_{max} \\ 2 - |g_e - g_i|/S_{max} & \text{if } S_{max} \le |g_e - g_i| \le 2 \cdot S_{max} \\ 0 & \text{if } |g_e - g_i| > 2 \cdot S_{max} \end{cases}$$

In this definition if g_i is within the maximum allowable similarity, the gray level measure is equal to 1; otherwise, it linearly decreases to zero as the absolute difference of

g_i and g_e approaches $2 \cdot S_{max}$. Using the above definition for each line, the mutual gray level strength between line i and line j is defined as

$$F(g_{ij}) = f(g_i) \cdot f(g_j)$$

3. Definition of the figures of merit

Two figures of merit are defined. The first one uses the similarity and homogeneity, angle, overlap, and distance measures. The second one uses the information used in the first one as well as the object mutual gray level strength.

The first figure of merit is defined as

$$FM1=Max(AS)$$

where the anti-parallel strength AS is defined as

$$AS=H(i)\cdot F(\varphi_i)\cdot O(\ell_i)\cdot D(i)$$

where i is the label of the anti-parallel candidate. All the measures in AS are calculated only for those lines with sense function S(i)=1 (anti-parallel candidates).

This definition simply multiplies all the measure functions except the mutual gray level measure function. The maximum value of FM1 is 3, when all of the following conditions are satisfied:

a) The candidate line has its object side gray level within half of the maximum level of similarity S_{max} to the line in question and the space between them.

b) The angle difference is less than or equal to $\varphi_{max}/2$.

c) The candidate line has the maximum overlap relative to the other candidates.

d) The candidate line has the minimum distance relative to the other candidates.

The minimum value for FM1 is 0.

The second figure of merit uses information about the given or estimated object gray level as well. It is defined as

$$FM2 = Max(AS')$$

where the anti-parallel strength AS' is defined as

$$AS' = H(i) \cdot F(\varphi_i) \cdot O(\ell_i) \cdot F(g_{ij})$$

where j is the label of the given line and i is the label of the anti-parallel candidate. Here again the maximum value of the figure of merit is 3, when the conditions stated for the first definition are satisfied together with the condition that the difference between the object side average gray levels of the pair of lines and the estimated object gray level are within the maximum level of similarity.

Finally, one can define the probability of the lines i and j being anti-parallel as

$$P_{ji} = (\text{anti-parallel strength})/3$$

The following is an algorithm for computing these figures of merit for a given image.

1) Read in the data for each line in the form (x_1, y_1, x_2, y_2) where (x_1, y_1) are the coordinates of the first end point and (x_2, y_2) are the coordinates of the second end point of the line. Read in the gray level picture too.
2) Generate a strip along the object side of a line.

3) Move this strip parallel to the segment. While the similarity and the total moving distance are less than the specified levels, note the line hit by the strip, and calculate the various measures and the figure of merit. If no lines are found go to (5).

4) For the candidate lines found in (3) choose the one with maximum anti-parallel strength. Mark the line found in order not to process it again.

5) Continue the process for the remaining lines.

The width of the strip used in calculation of the average gray level is 4 pixels.

In this algorithm a line is not compared with all other lines. When several lines are facing a line, the method allows all of these lines to choose the same line as anti-parallel.

4. Examples and discussion

The algorithm presented here performs well on several input data sets. The straight edges in the image were extracted using an iterative enhancement technique [2], and the resulting lines along with the gray level picture were used as input to the pairing program. Figure 10 shows one input image, and the set of lines extracted from it is shown in Figure 11. Figure 12 shows the histogram of the first figure of merit. The maximum level of similarity is set to be 10 in calculation of the measures used in computing the figures of merit; this is quite a tolerant value. Figures 13 to 17 show the results of finding anti-parallel lines with different thresholds (2.3, 2.0, 1.5, 1.0, 0.1) on the value of the figure of merit. In these figures the midpoints of the anti-parallel pairs are connected together by the program for the purpose of displaying the selected pairs. The effect of changing the maximum level of similarity has also been studied. When this level is changed to 12 or 15 the results are shown in Figures 18 to 29. The effect of increasing the maximum level of similarity is to modify the histogram of the figure of merit and also to make the similarity and homogeneity measure less important in the formula for the figure of merit. Comparing the results it is apparent that no major change results when the maximum level of similarity is changed. Figure 30 shows another image, and Figures 31 to 35 show the results of using the process on this image.

Another series of experiments has been performed using the second figure of merit. The results for the first image using different thresholds are shown in Figures 26 to 40. It is seen that the second method of defining the figure of merit also has the property of deleting non-object lines (noise lines). Figures 41 to 46 show the results for the second image. Examination of the outputs obtained for different thresholds on the figure of merit shows that one can choose the lowest nonzero threshold without causing trouble. The effect of increasing S_{max} in the second figure of merit has also been studied. As we increase this level, the probability that non-object lines as anti-parallel lines are found is increased. The results of increasing S_{max} to 12 and 15 are shown in Figures 47 to 57.

These results suggest that one might use this approach to define the degree of anti-parallelism of line segments in a relaxation scheme for classifying the segments.

5. Extensions and conclusions

A possible extension that might improve the results is to stop the movement of the strip when it hits a non-candidate line with a high degree of overlap. This extension is suggested by object model considerations.

This paper has presented an algorithm for finding pairs of anti-parallel linear features. The process is based on the degree of similarity of the object sides of the lines and also the homogeneity of the region between them, their angle difference, their overlap, the minimum distance between them, and also the given or estimated object gray level. Two figures of merit were evaluated using lines extracted from real images for an edge detection and enhancement process. The results were seen to be generally reasonable and the result of applying the process was a new image representation that was more useful for further processing than the initial edge image. This process should be especially useful for defining the degree of anti-parallelsim of lines segments in a relaxation scheme for classifying the segments.

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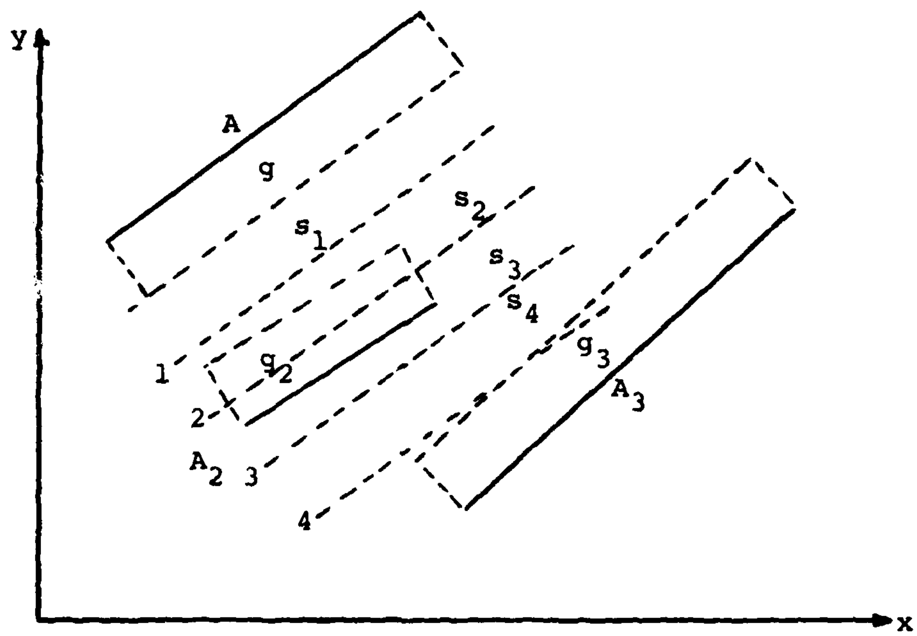

Figure 1. Calculation of degree of similarity and homogeneity.

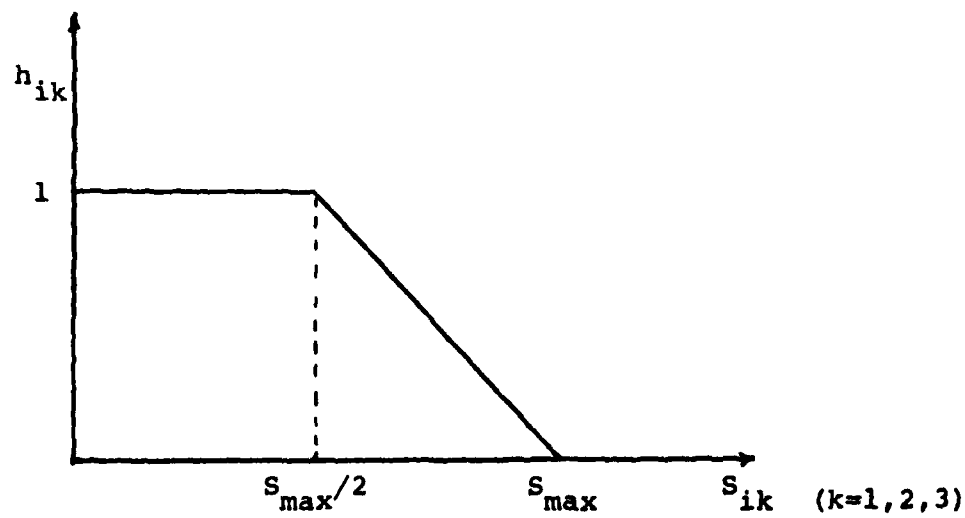

Figure 2. Function for calculation of similarity measures.

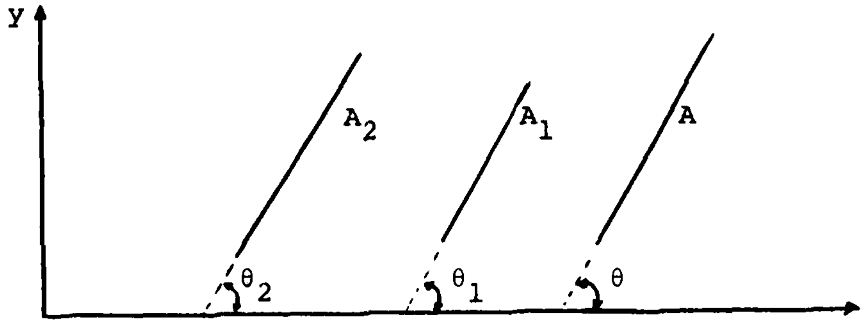

Figure 3. Line A and the anti-parallel candidates A_1, A_2.

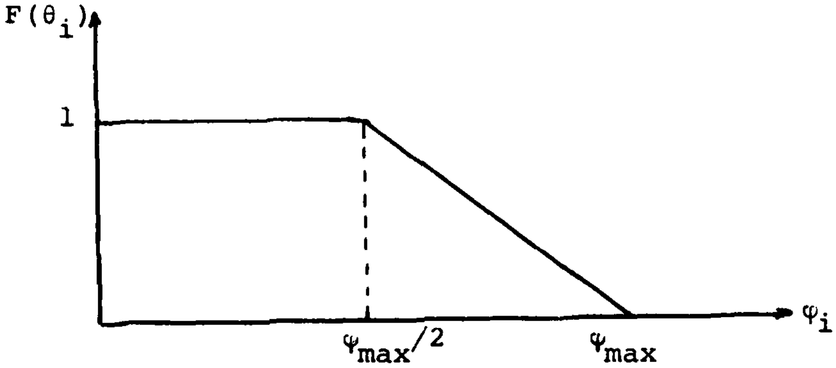

Figure 4. Calculation of the angle measure function.

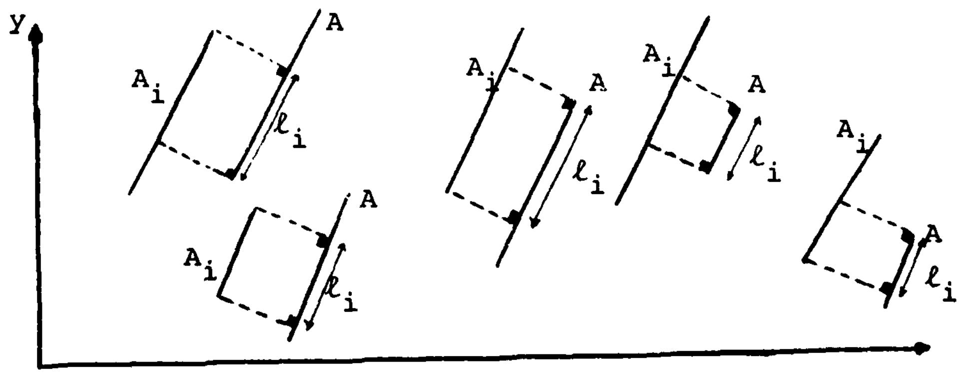

Figure 5. Examples of overlap calculations.

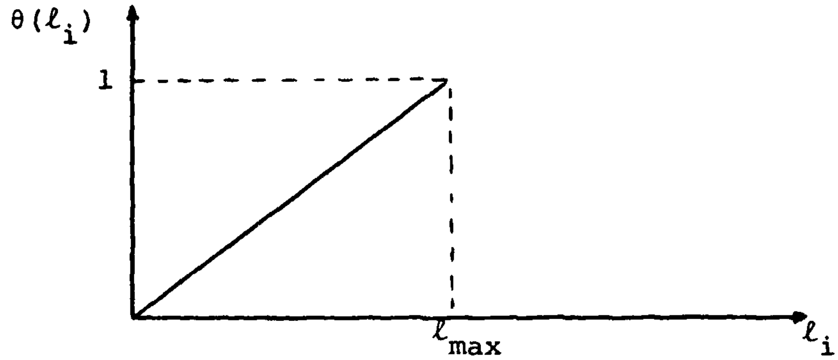

Figure 6. Calculation of the overlap measure function.

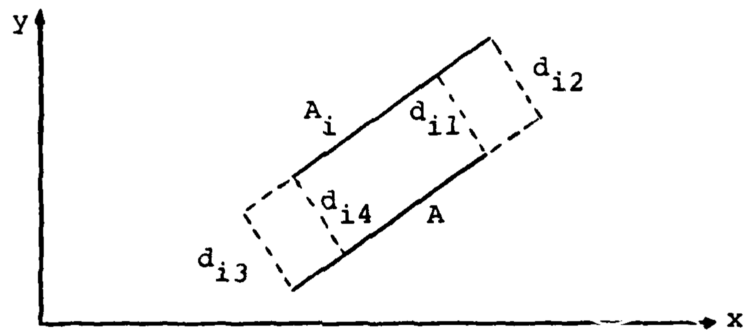

Figure 7. Calculation of the smallest distance between two lines.

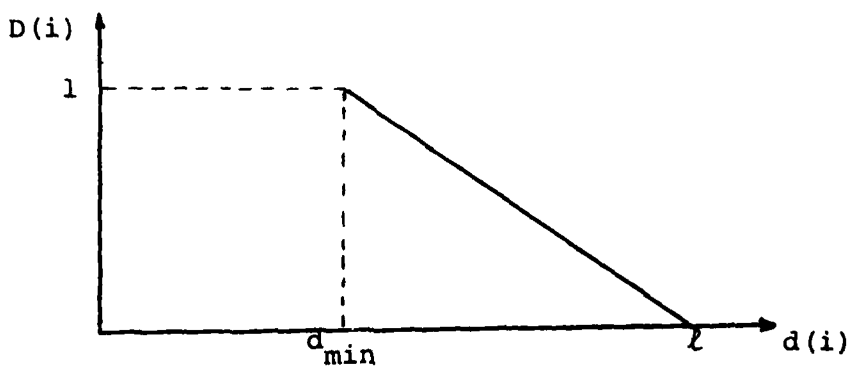

Figure 8. Linear function for calculation of distance measure.

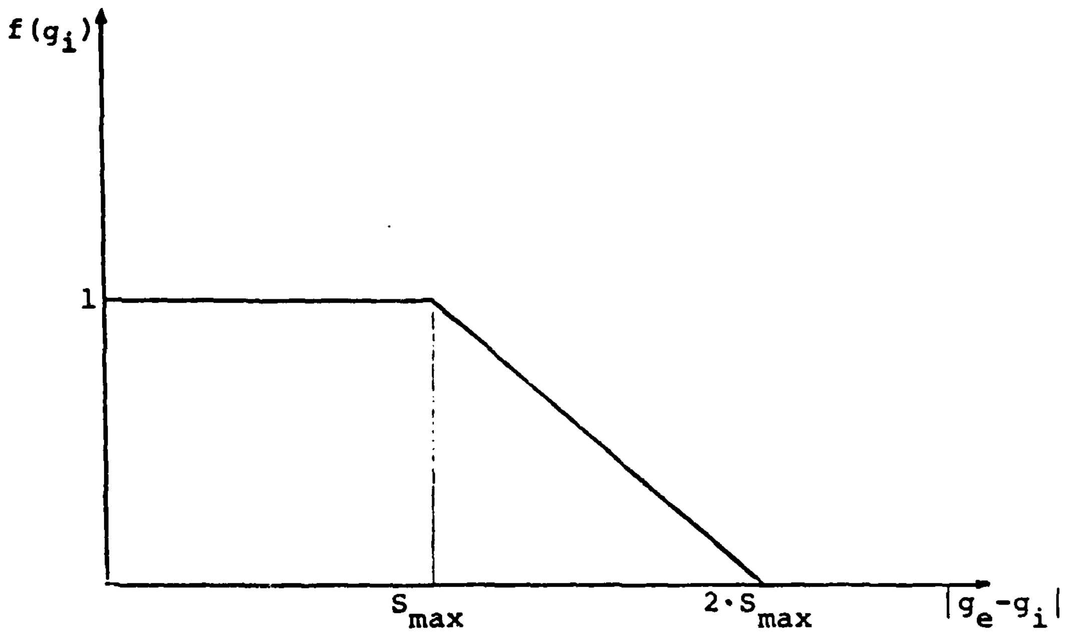

Figure 9. The function used for calculation of the gray level measure.

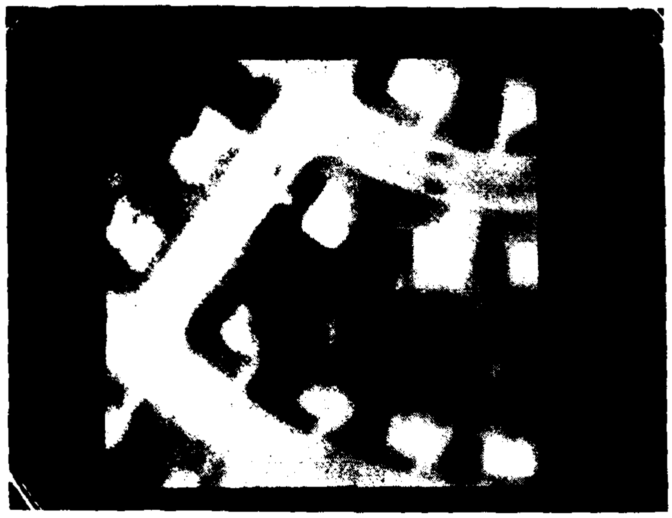

Figure 10. A suburban scene.

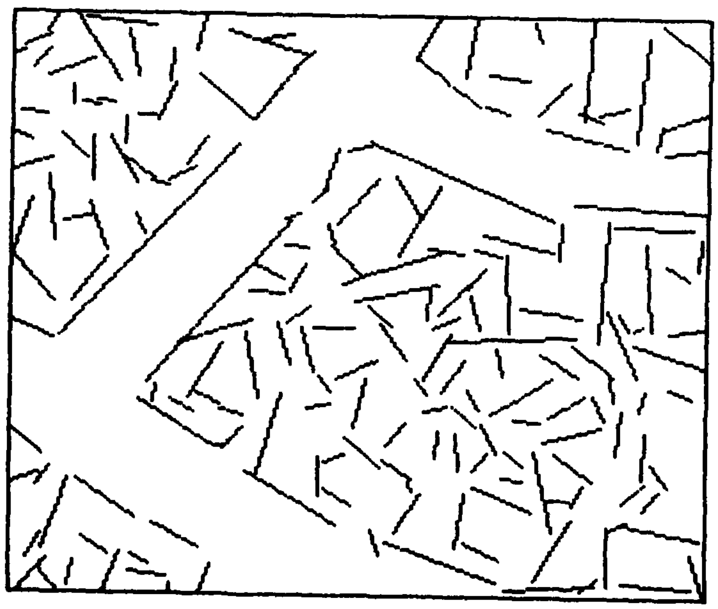

Figure 11. The extracted lines.

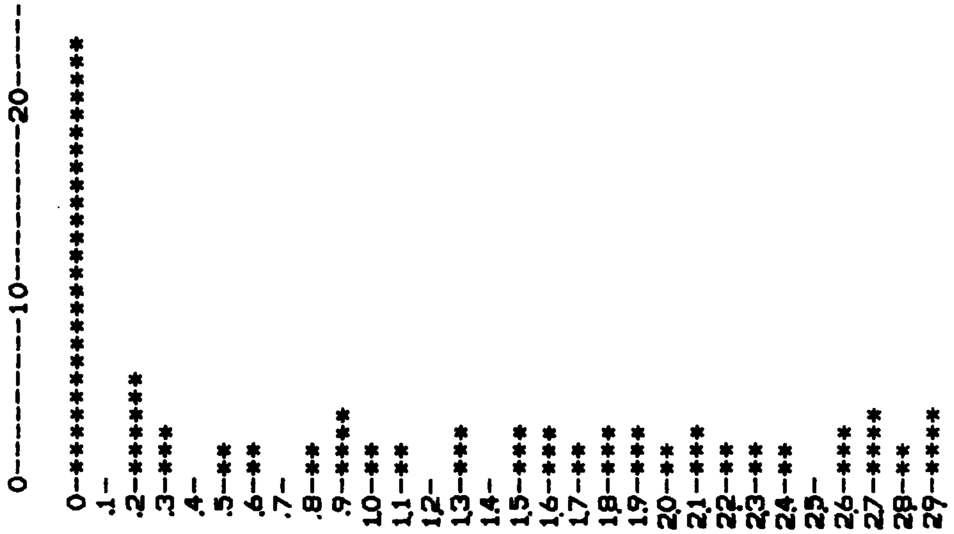

Figure 12. The histogram of the first figure of merit, S_{max}=10, suburban scene.

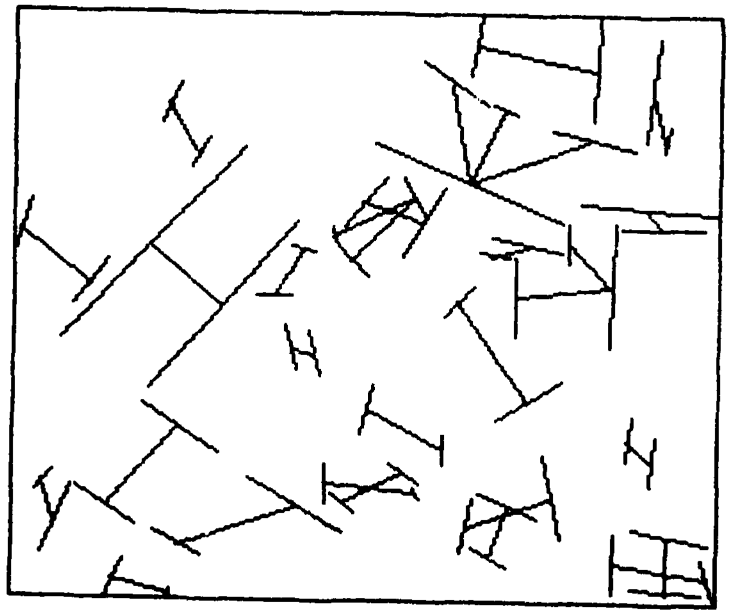

Figure 13. Anti-parallel lines: FM1=2.3, S_{max}=10.

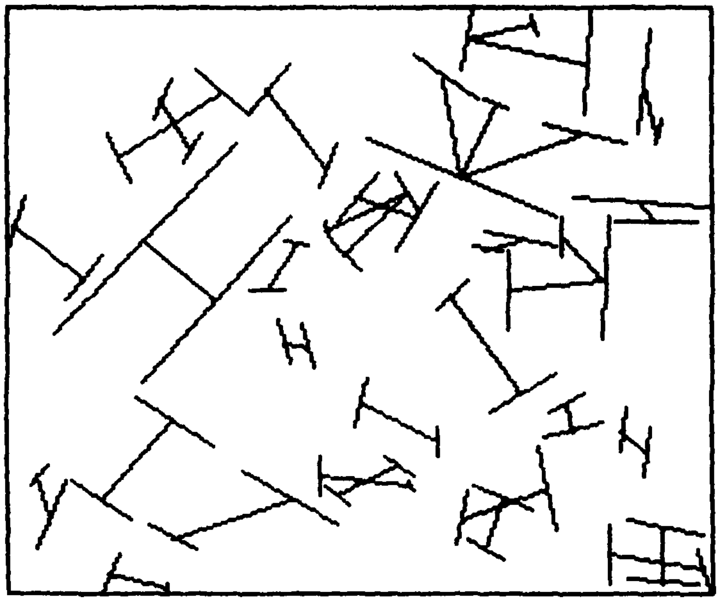

Figure 14. Anti-parallel lines: FM1=2.0, S_{max}=10.

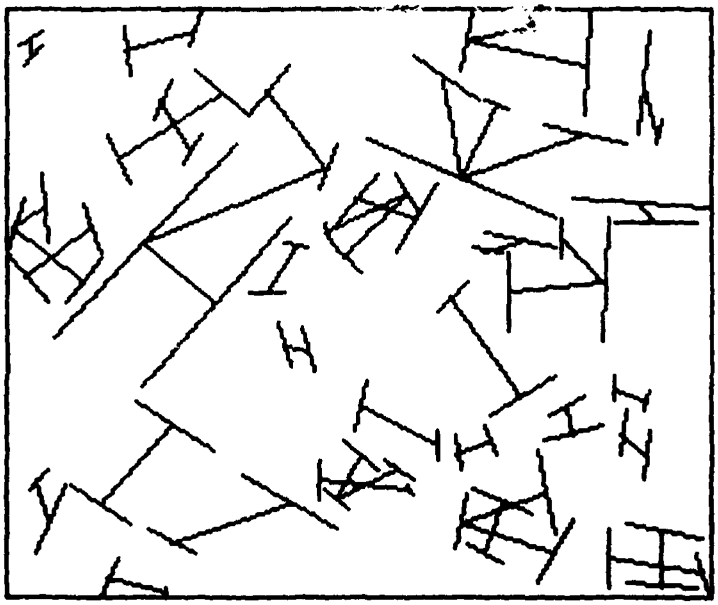

Figure 15. Anti-parallel lines: FM1=1.5, S_{max}=10.

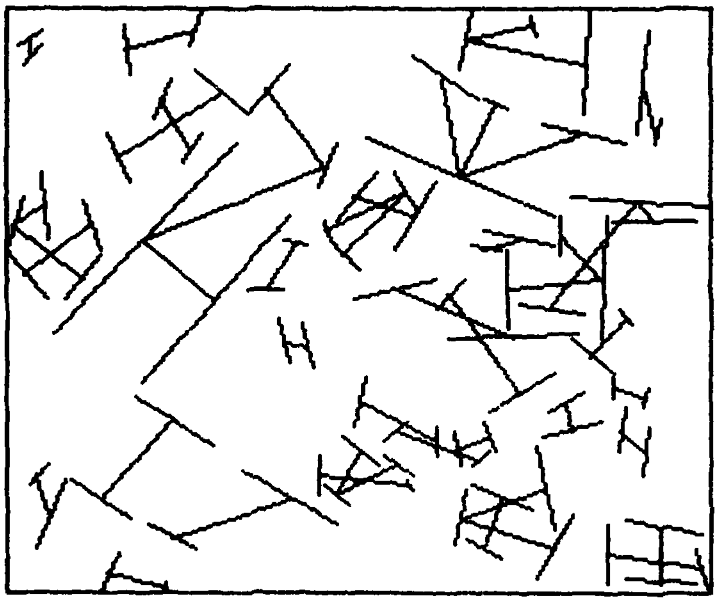

Figure 16. Anti-parallel lines. FM1=1.0, S_{max}=10.

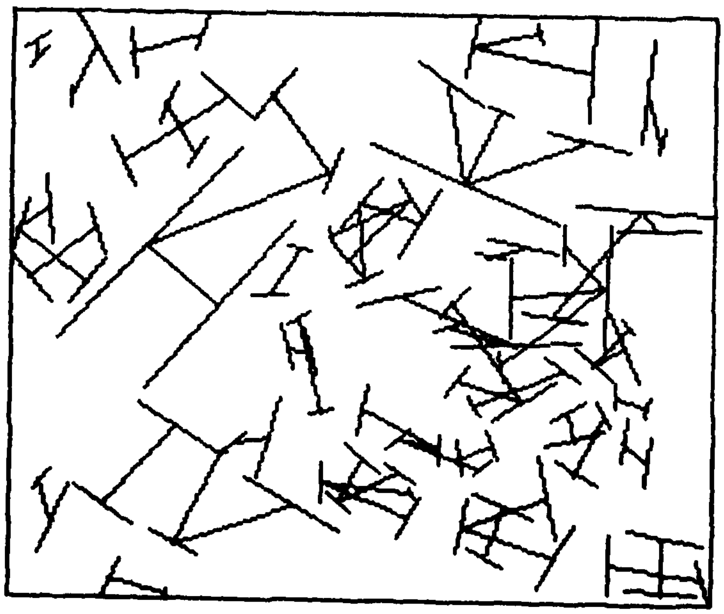

Figure 17. Anti-parallel lines. FM1=0.1, S_{max}=10.

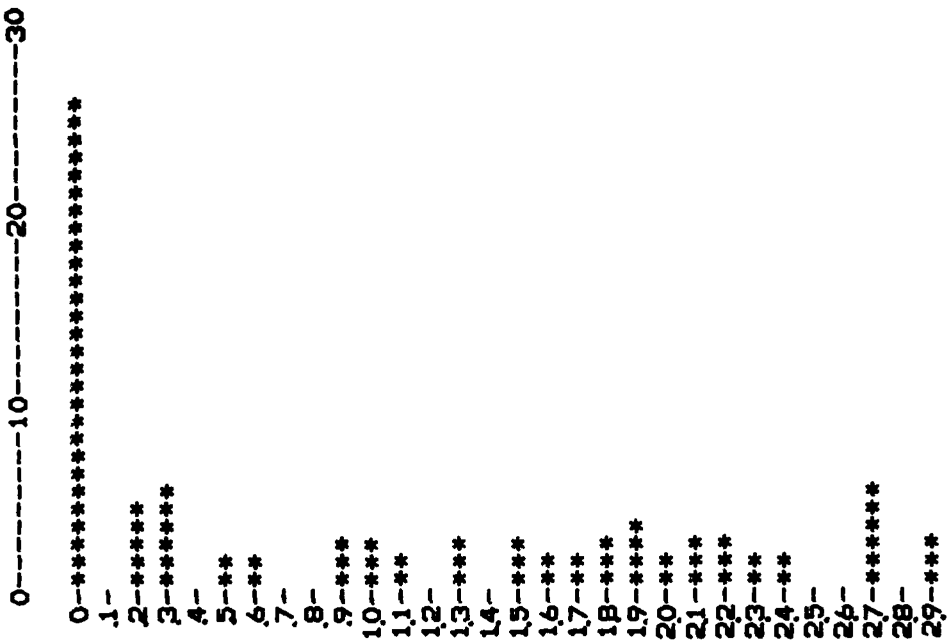

Figure 18. The histogram of the first figure of merit: S_{max}=12, suburban scene.

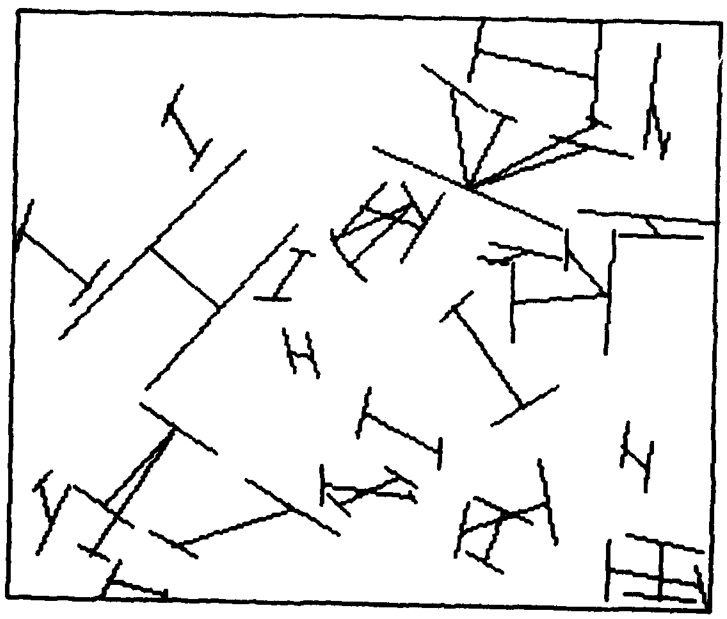

Figure 19. Anti-parallel lines: FM1=2.3, S_{max}=12.

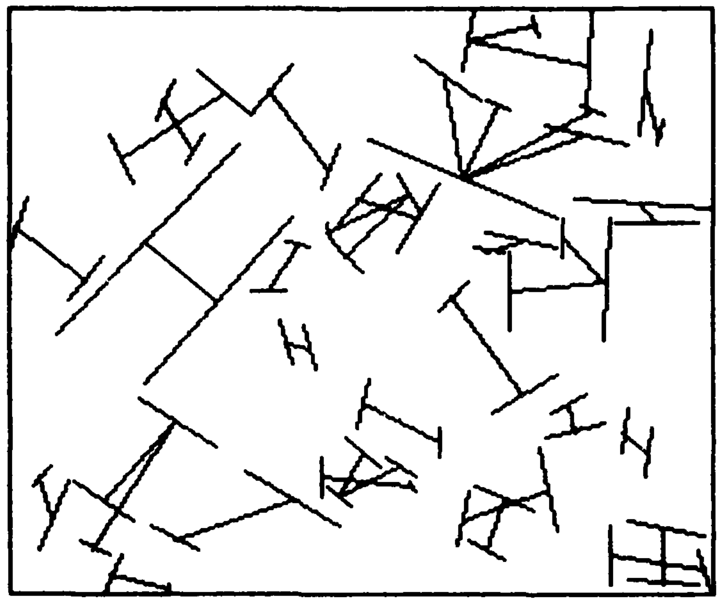

Figure 20. Anti-parallel lines: FM1=2.0, S_{max}=12.

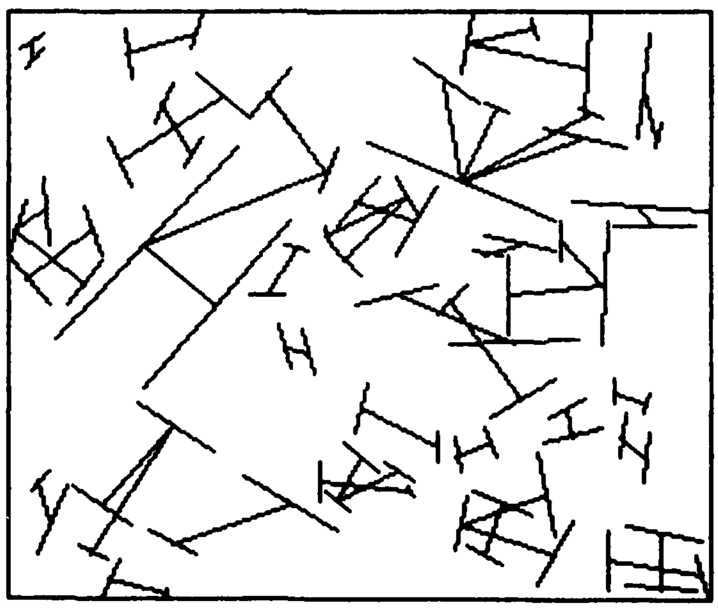

Figure 21. Anti-parallel lines: FM1=1.5, S_{max}=12.

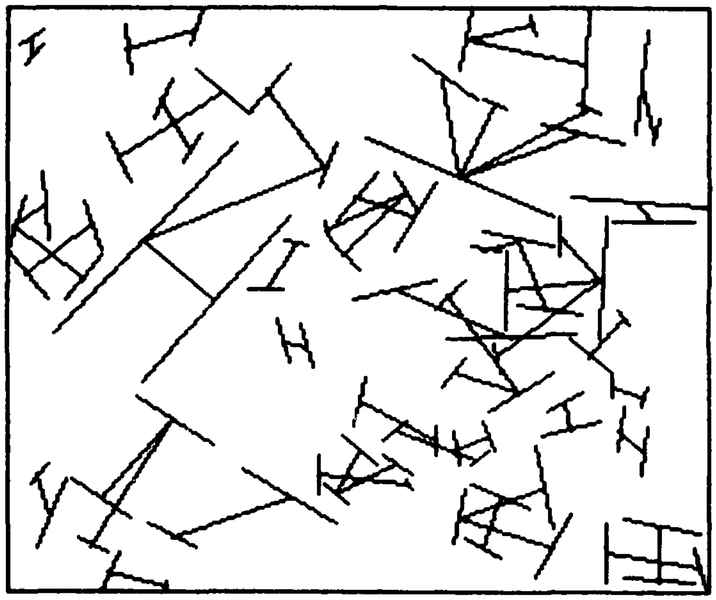

Figure 22. Anti-parallel lines: FM1=1.0, S_{max}=12.

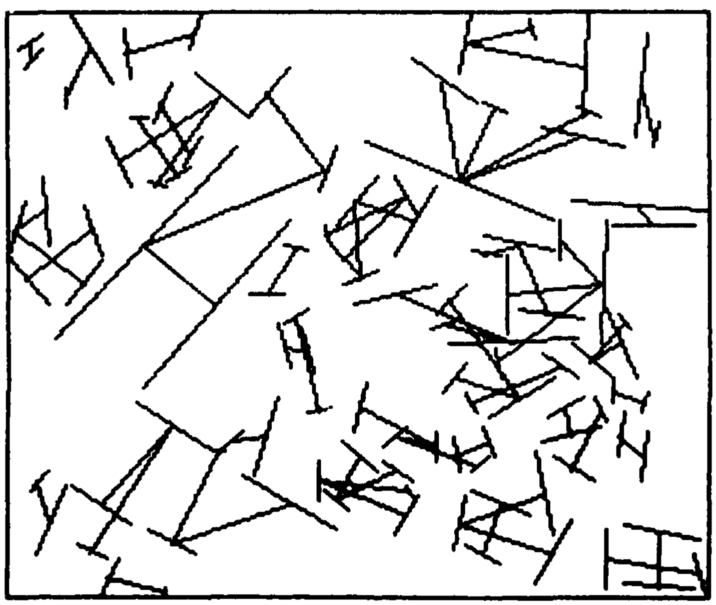

Figure 23. Anti-parallel lines: FM1=0.1, S_{max}=12.

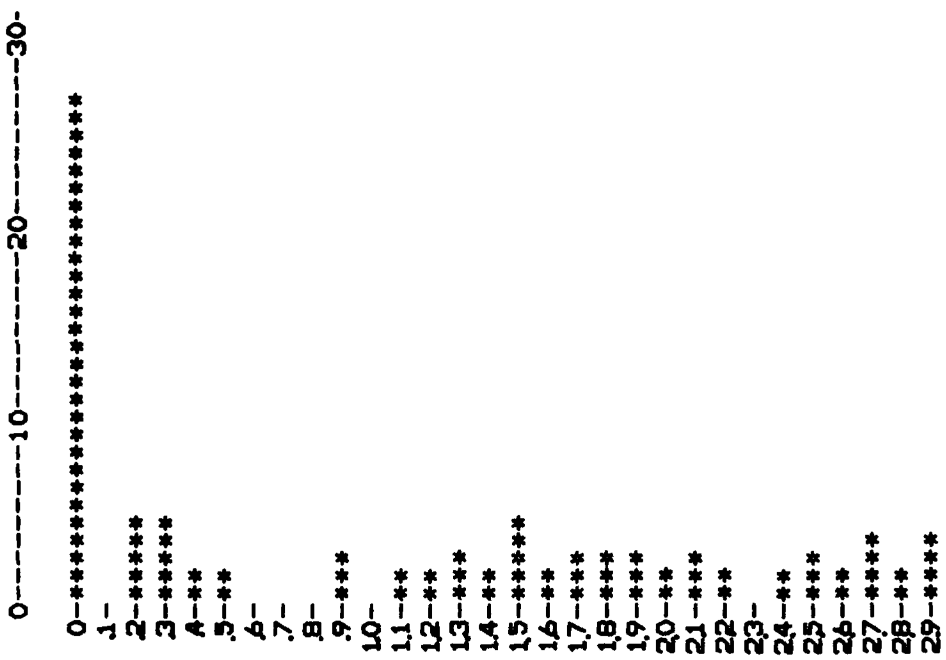

Figure 24. The histogram of the first figure or merit: S_{max}=15, suburban scene.

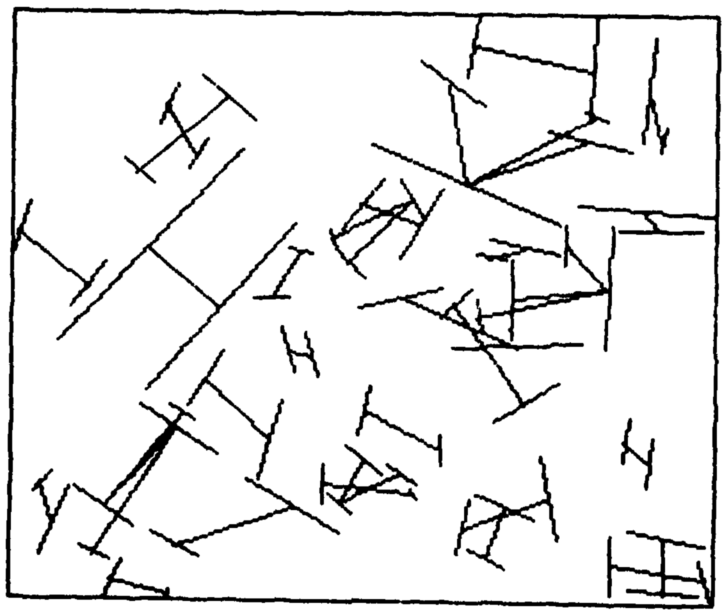

Figure 25. Anti-parallel lines: FM1=2.3, S_{max}=15.

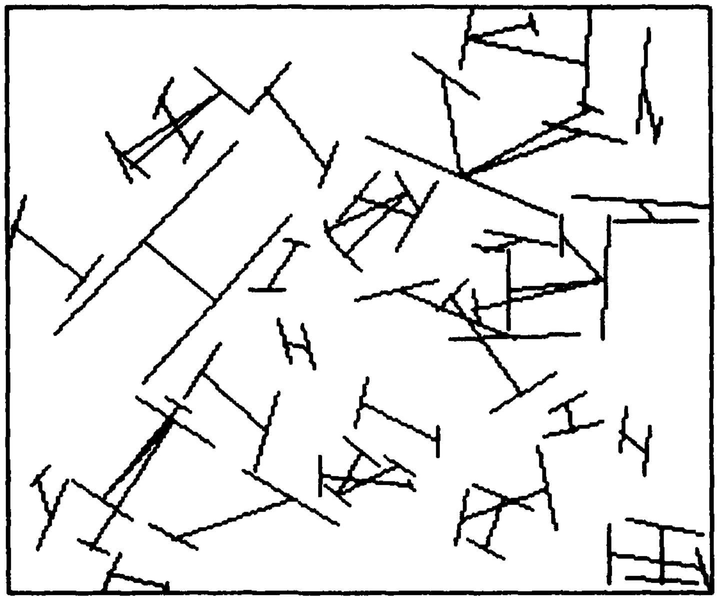

Figure 26. Anti-parallel lines: FM1=2.0, S_{max}=15.

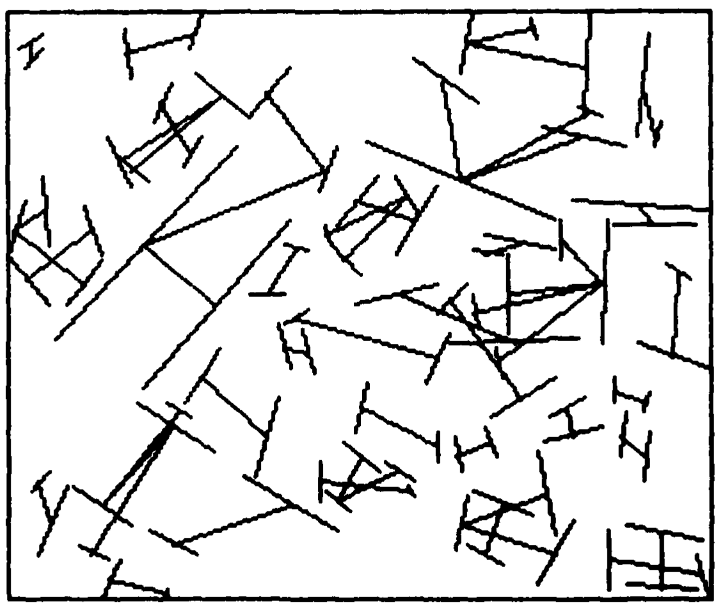

Figure 27. Anti-parallel lines: FM1=1.5, S_{max}=15.

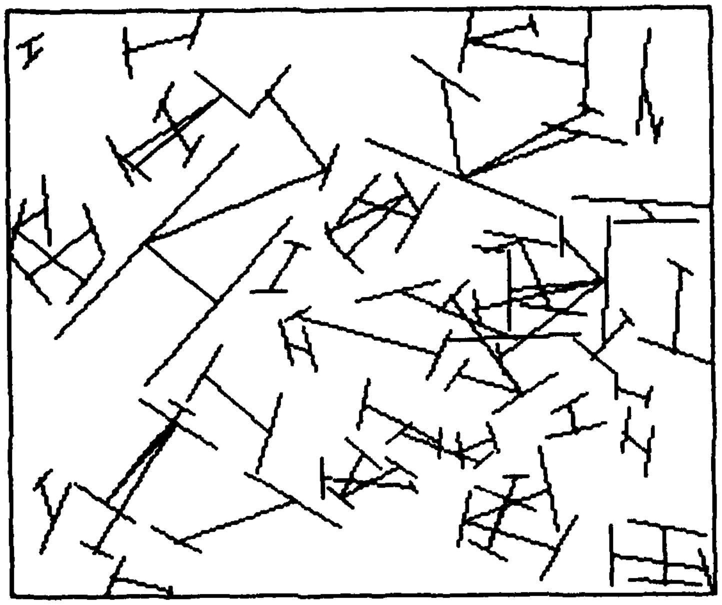

Figure 28. Anti-parallel lines: FM1=1.0, S_{max}=15.

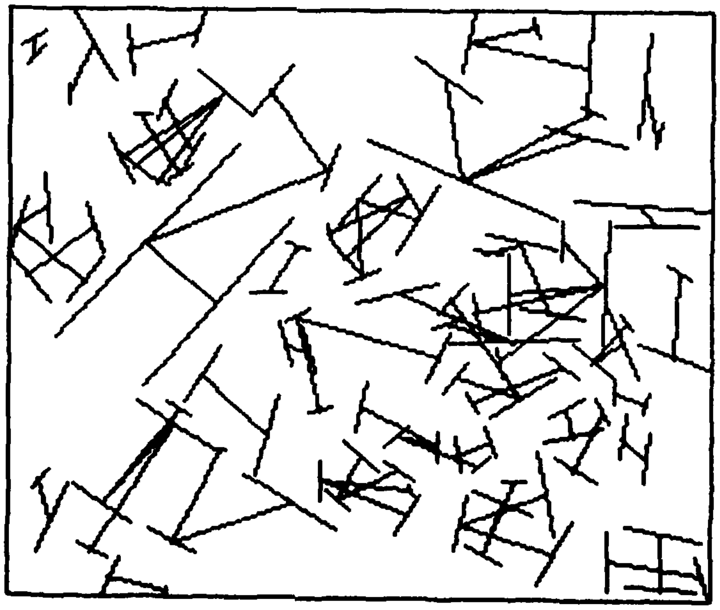

Figure 29. Anti-parallel lines: FM1=0.1, S_{max}=15.

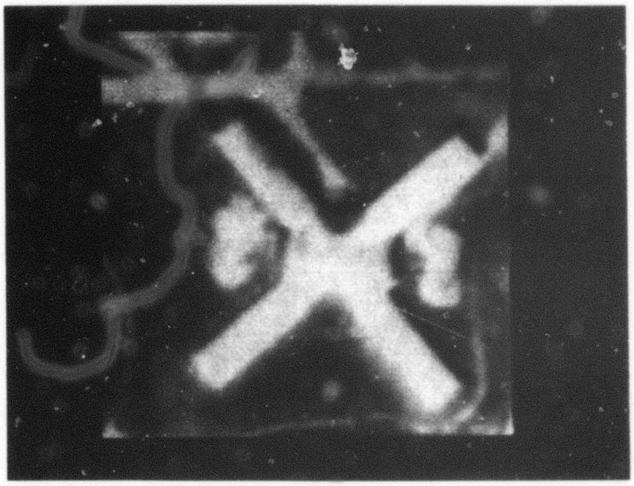

Figure 30. A portion of Lorton Reformatory.

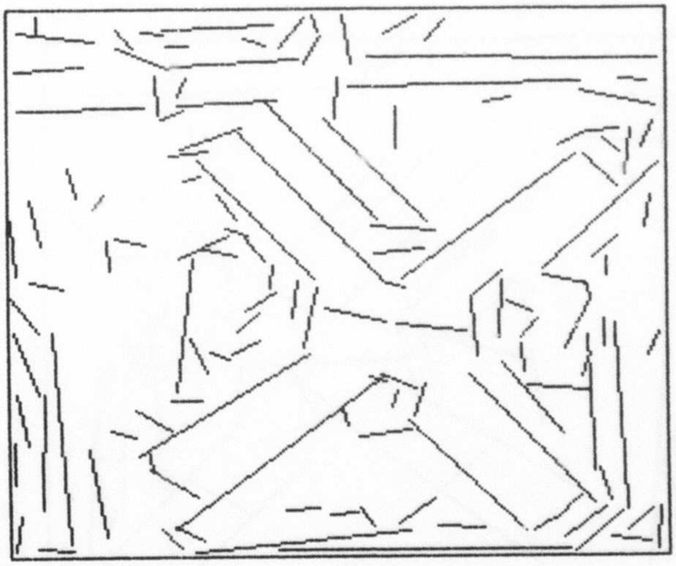

Figure 31. The extracted lines.

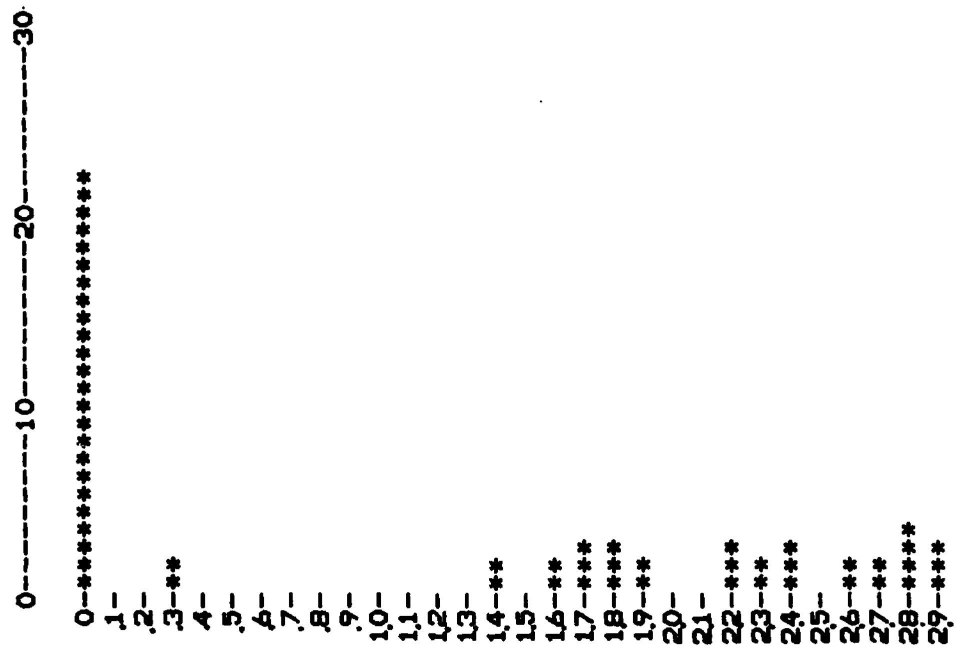

Figure 32. The histogram of the first figure of merit, S_{max}=10, Lorton scene.

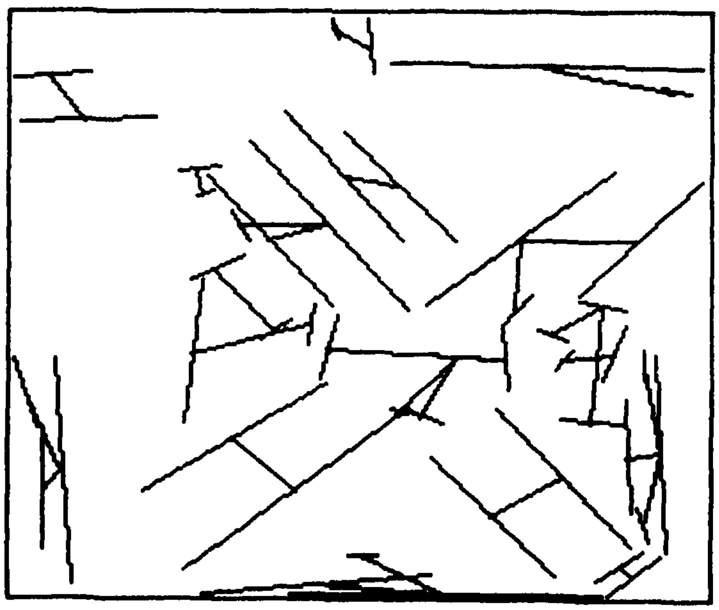

Figure 33. Anti-parallel lines: FM1=2.3 or 2.0, S_{max}=10.

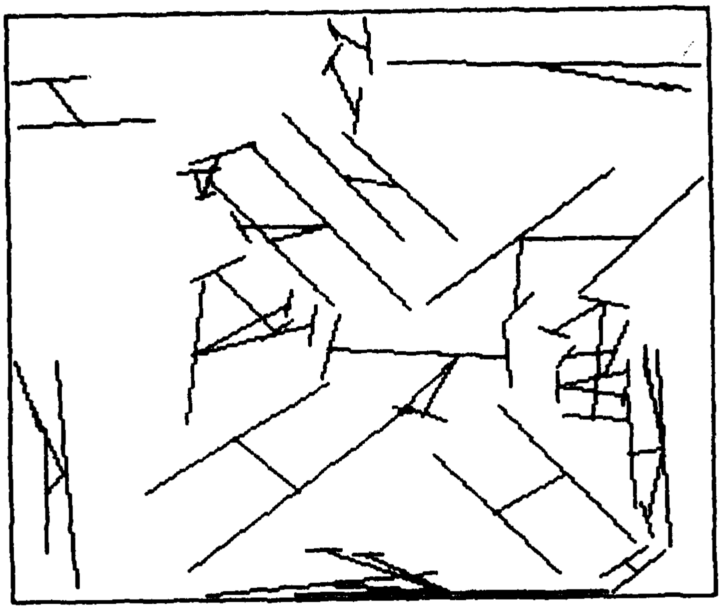

Figure 34. Anti-parallel lines: FM1=1.5, S_{max}=10.

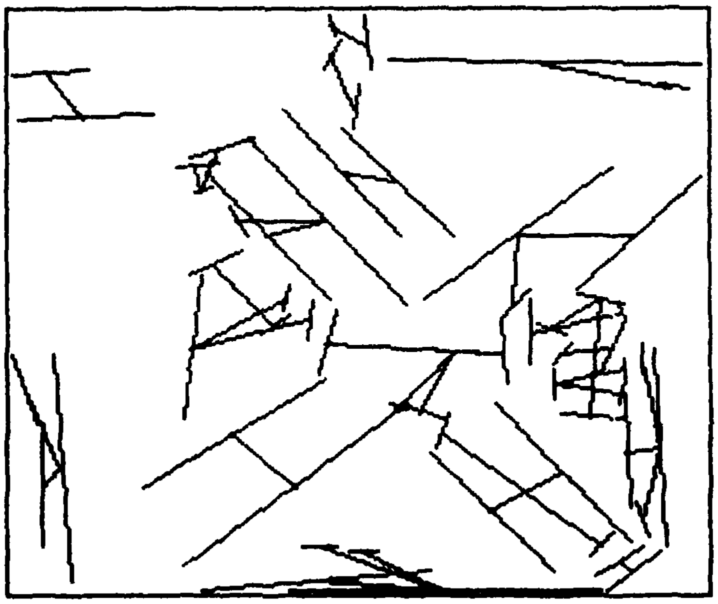

Figure 35. Anti-parallel lines: FM1=0.1, S_{max}=10.

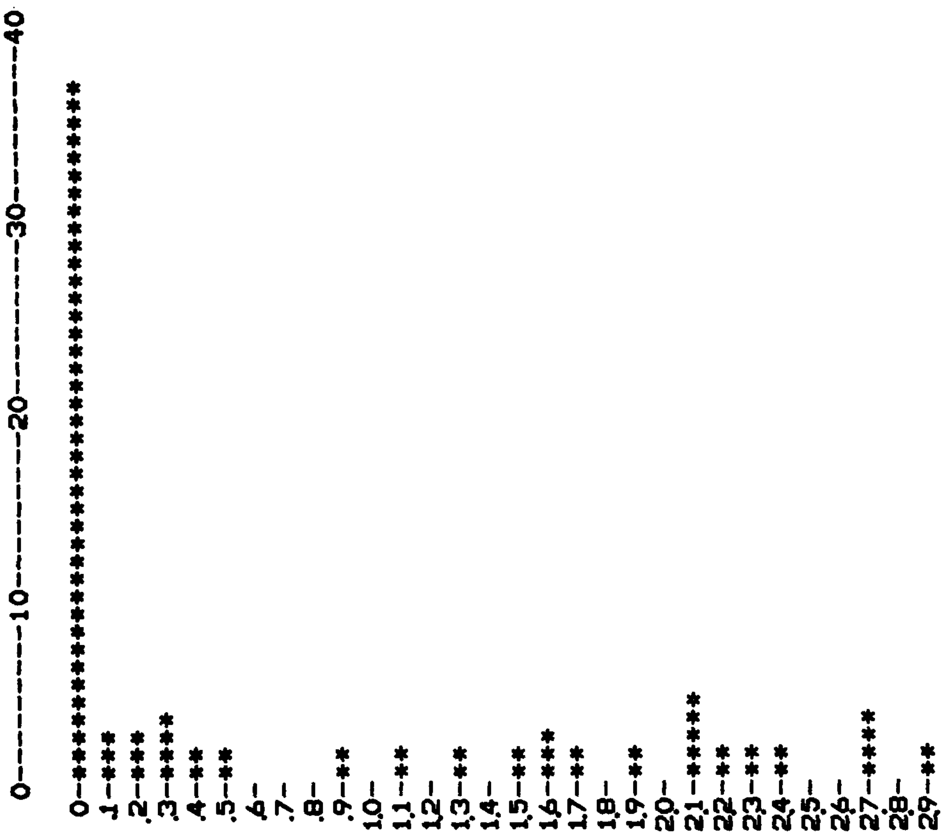

Figure 36. Histogram of the second figure of merit: S_{max}=10, suburban scene.

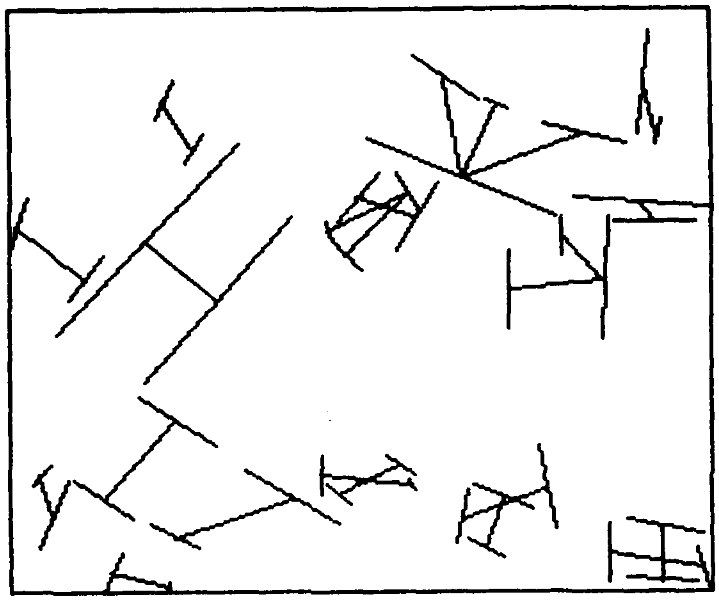

Figure 37. Anti-parallel lines: FM2=2.3, S_{max}=10.

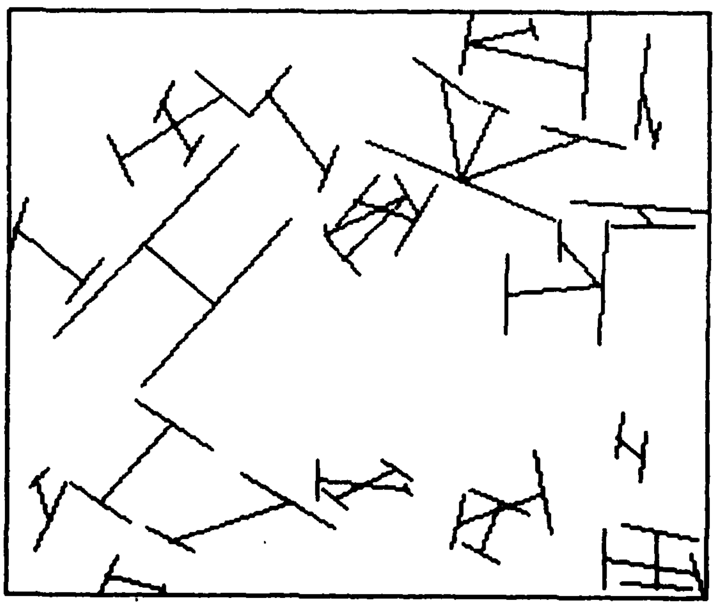

Figure 38. Anti-parallel lines: SM2=2.0, S_{max}=10.

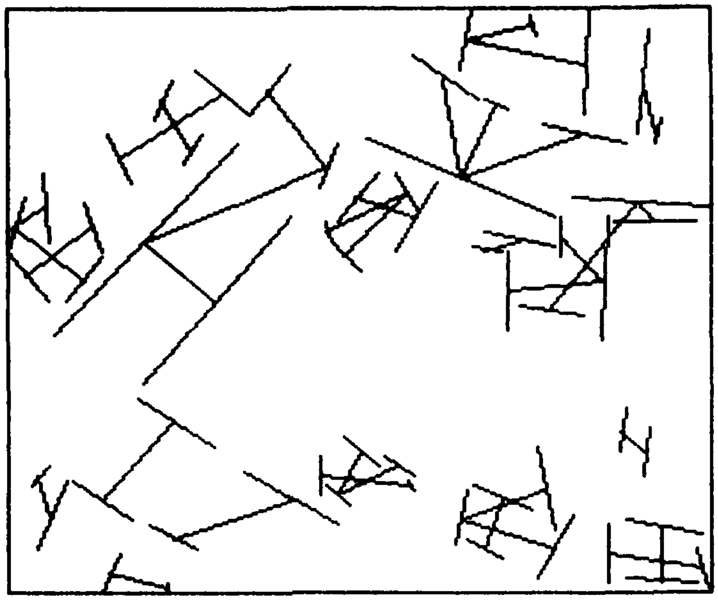

Figure 39. Anti-parallel lines: FM2=1.0, S_{max}=10.

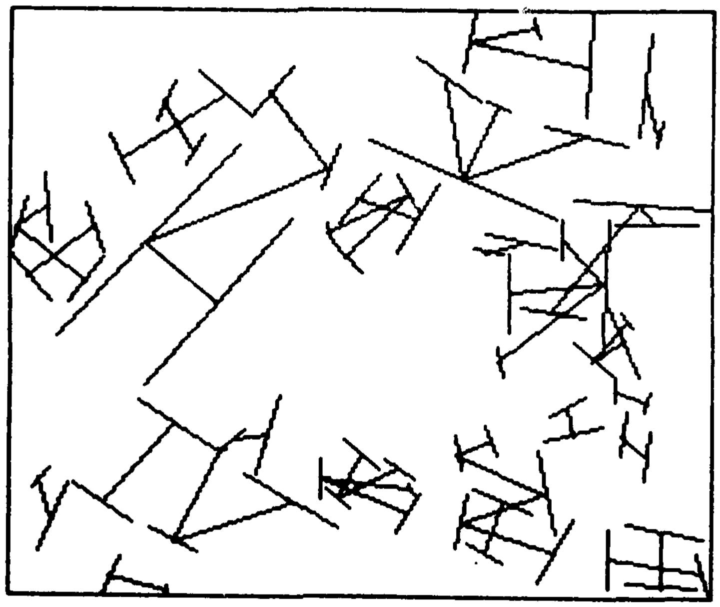

Figure 40. Anti-parallel lines: FM2=1.0, S_{max}=0.1

Figure 41. The histogram of the second figure of merit: S_{max}=10, Lorton scene.

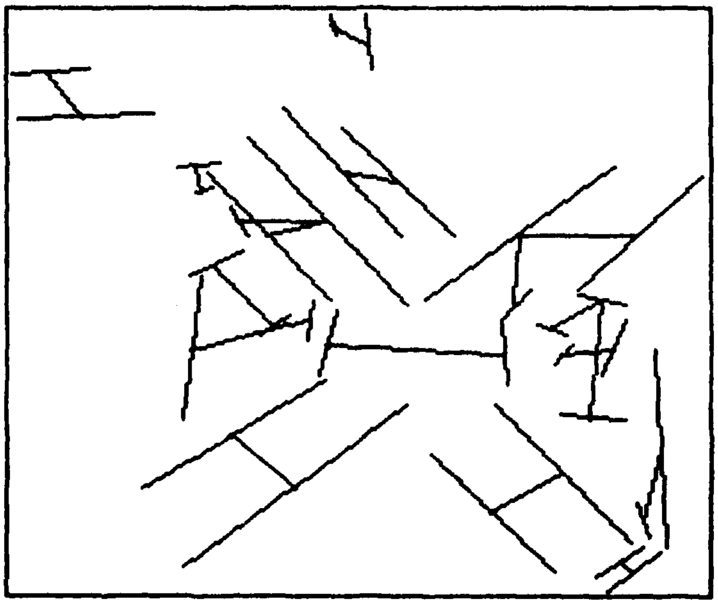

Figure 42. Anti-parallel lines: FM2=2.3, S_{max}=10.

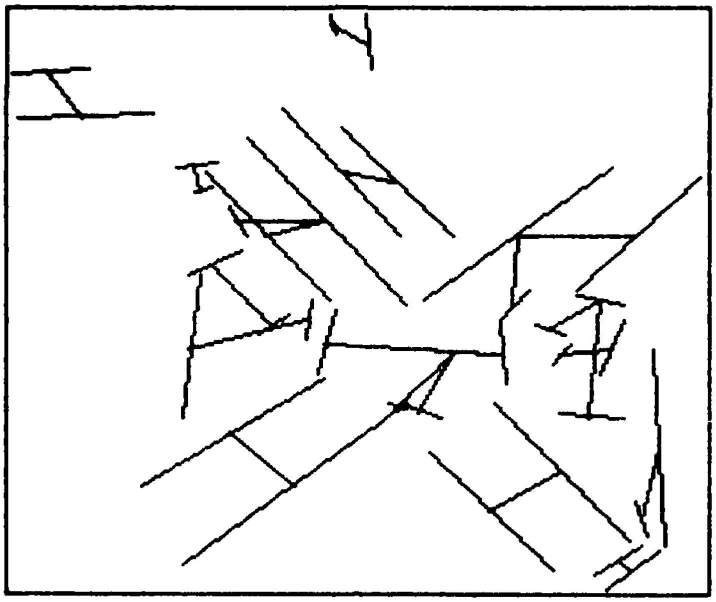

Figure 43. Anti-parallel lines: FM2=2.0, S_{max}=10.

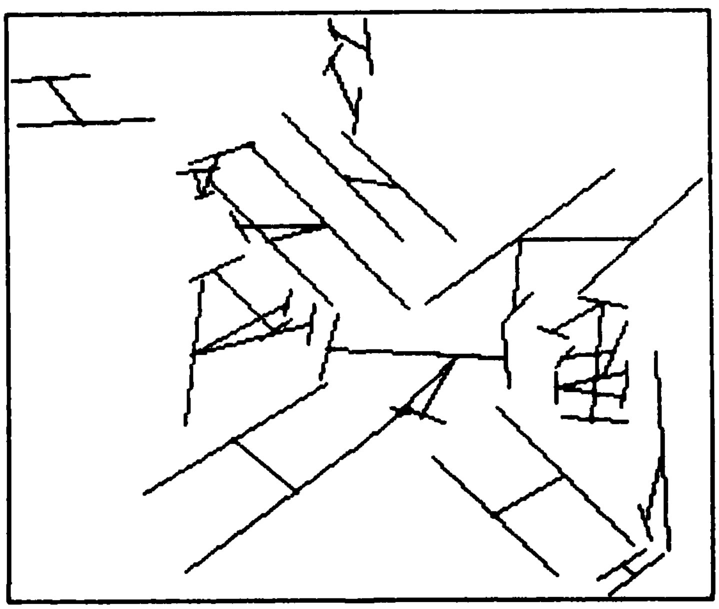

Figure 44. Anti-parallel lines: FM2=1.5, S_{max}=10.

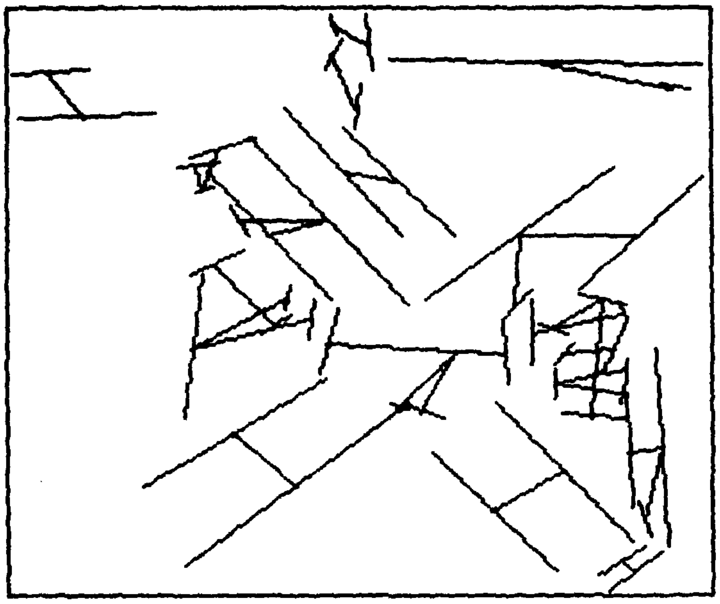

Figure 45. Anti-parallel lines: FM2=1.0, S_{max}=10.

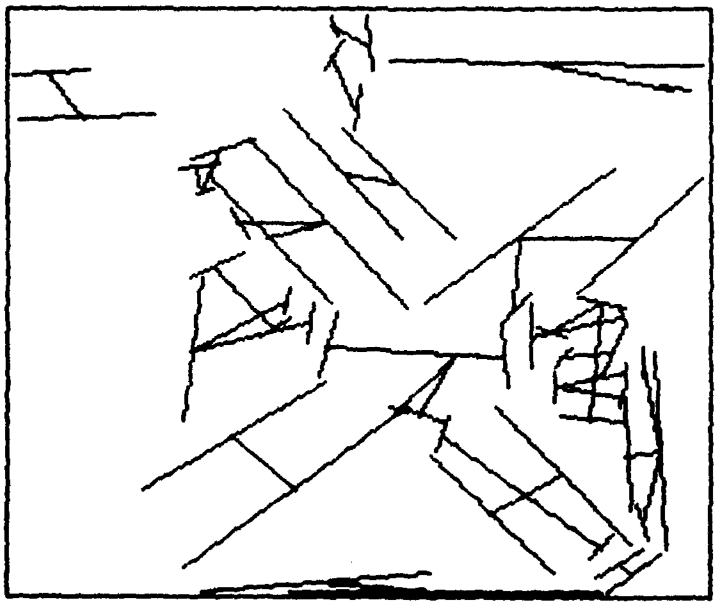

Figure 46. Anti-parallel lines: FM2=0.1, S_{max}=10.

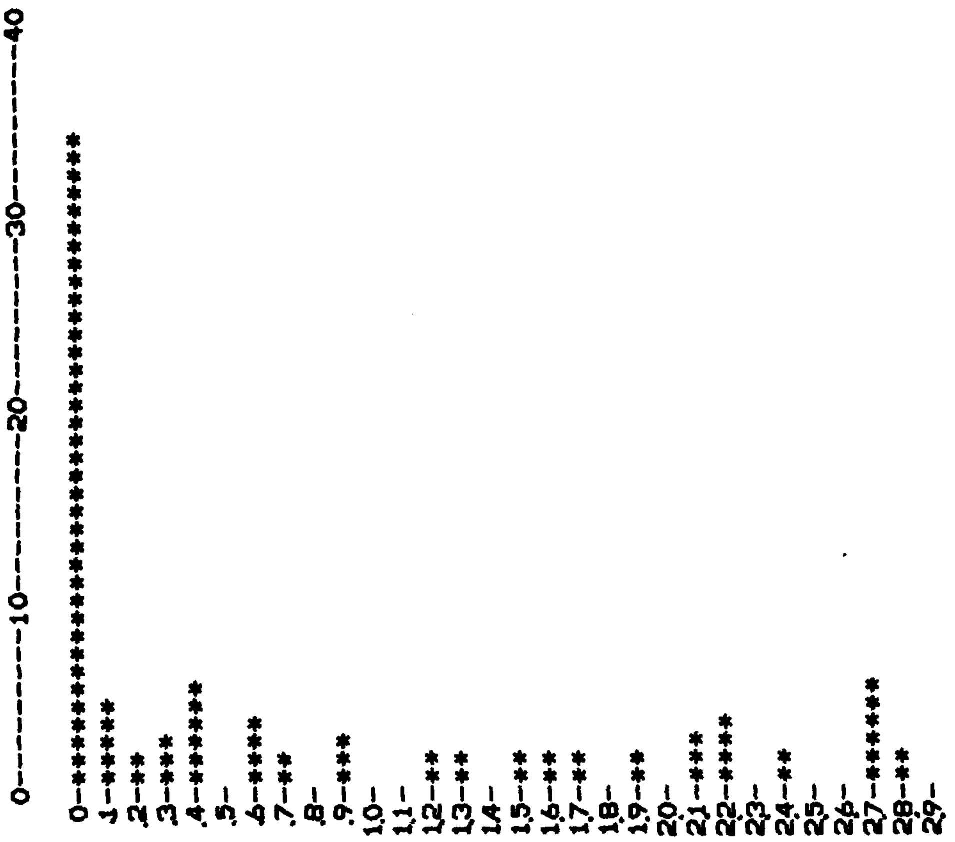

Figure 47. The histogram of the second figure of merit: S_{max}=12, suburban scene.

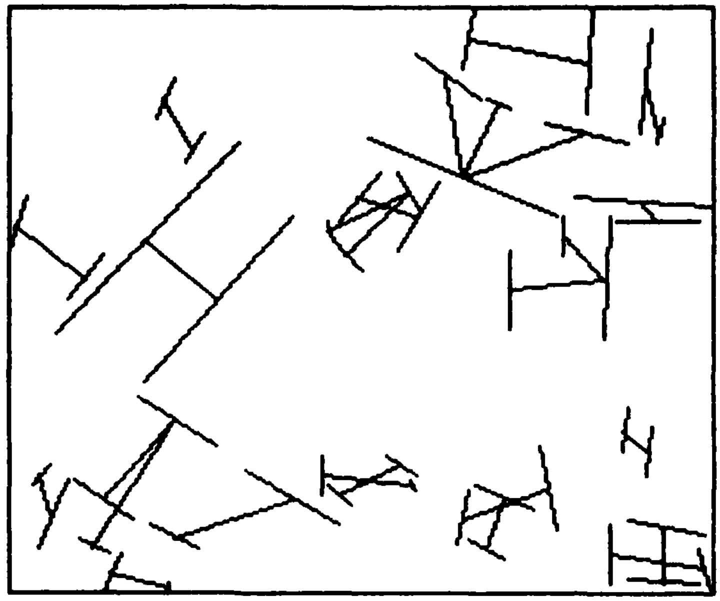

Figure 48. Anti-parallel lines: FM2=2.3, S_{max}=12.

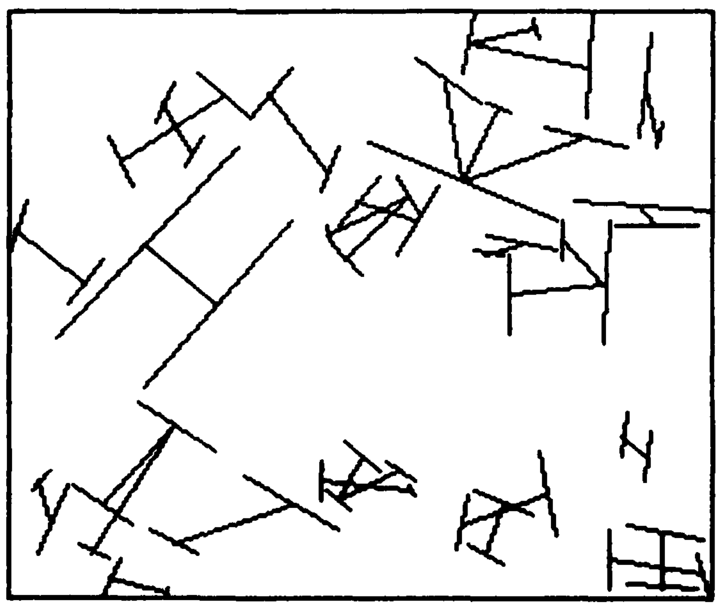

Figure 49. Anti-parallel lines: FM2=2.0, S_{max}=12.

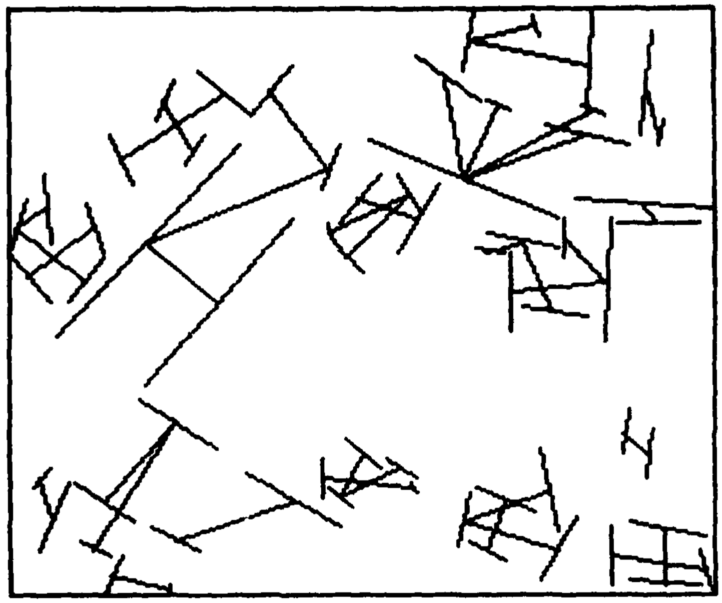

Figure 50. Anti-parallel lines: FM2=1.0, S_{max}=12.

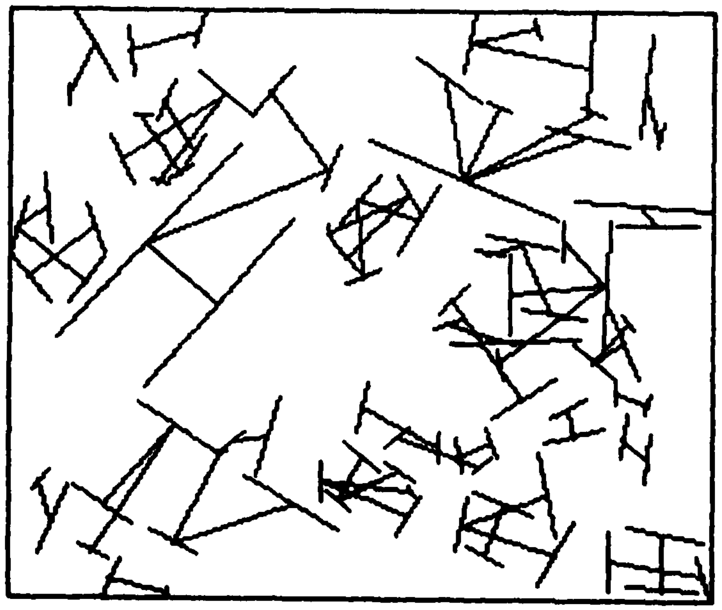

Figure 51. Anti-parallel lines: FM2=0.1, S_{max}=12.

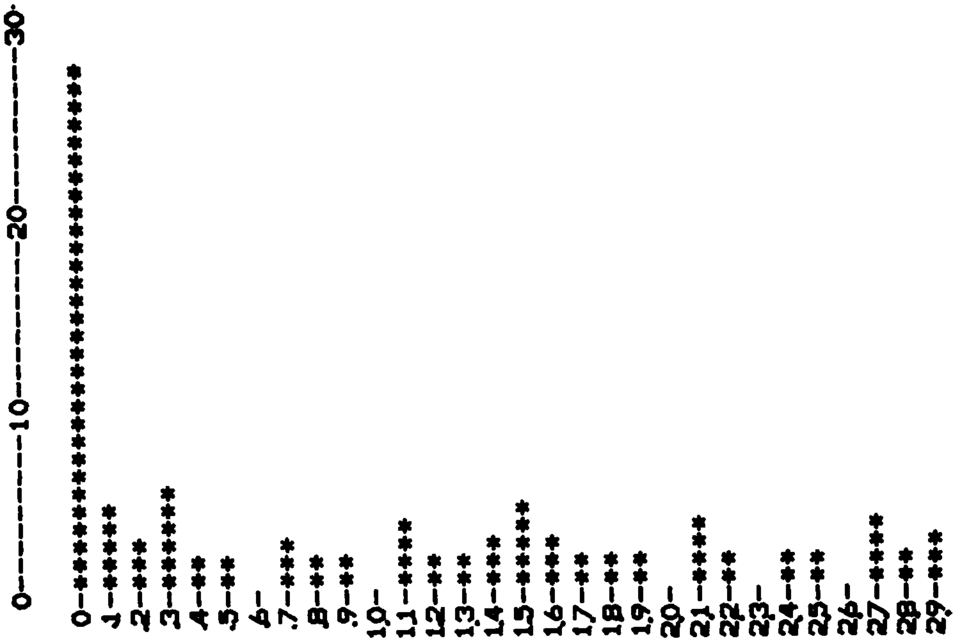

Figure 52. The histogram for the second figure of merit: S_{max}=15, suburban scene.

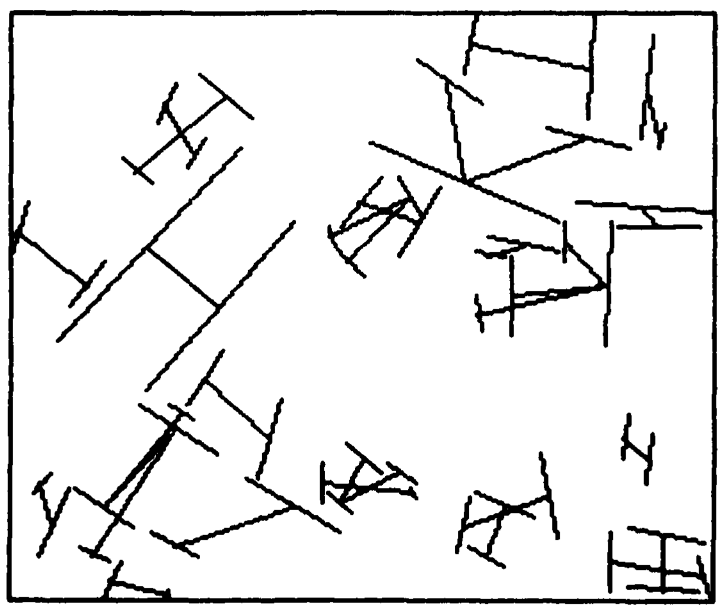

Figure 53. Anti-parallel lines: FM2=2.3, S_{max}=15.

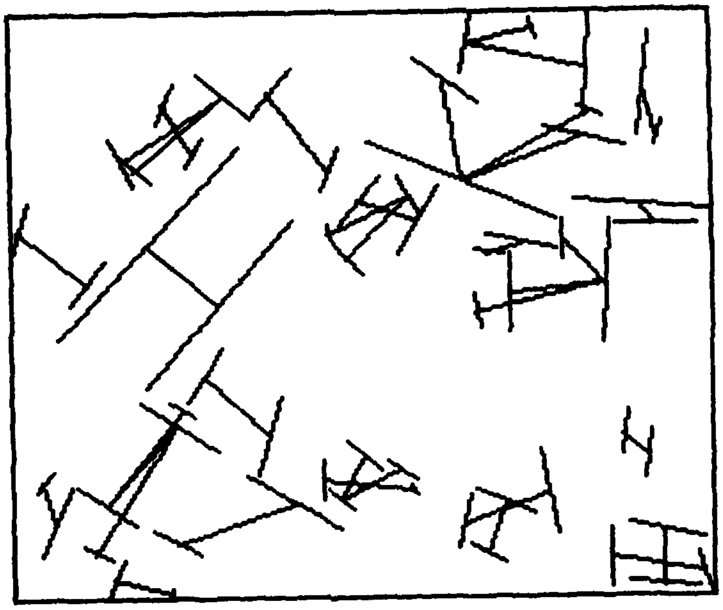

Figure 54. Anti-parallel lines: FM2=2.0, S_{max}=15.

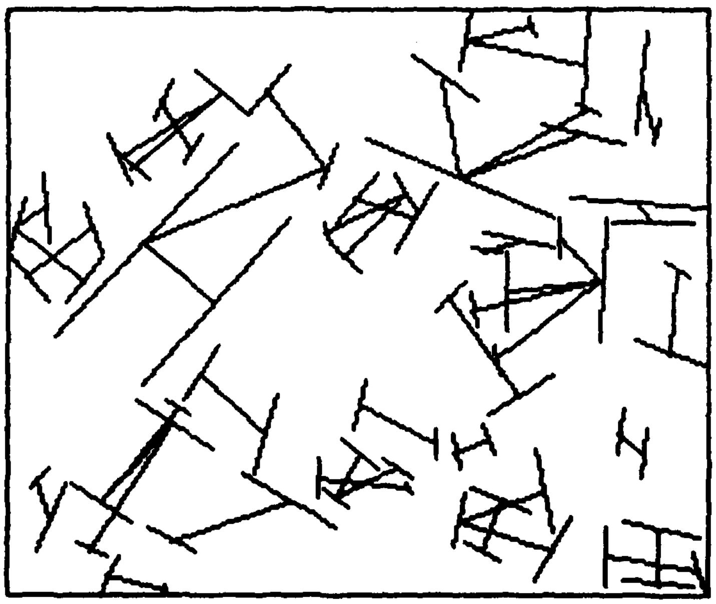

Figure 55. Anti-parallel lines: FM2=1.5, S_{max}=15.

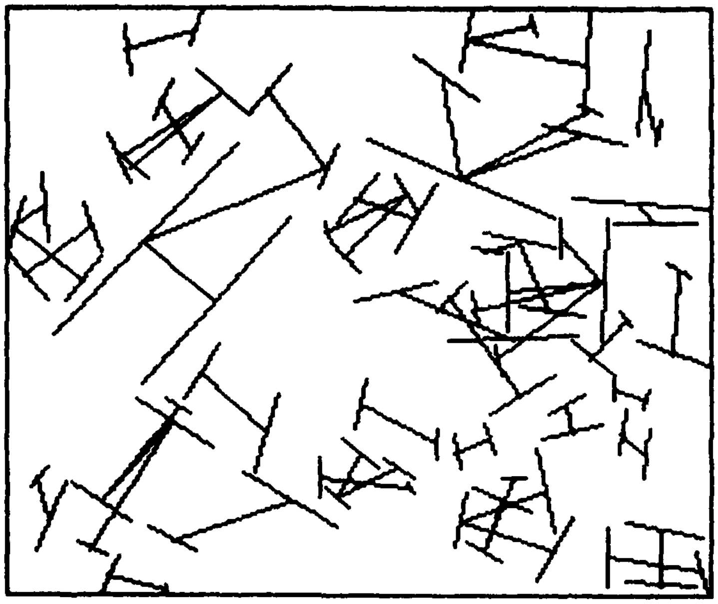

Figure 56. Anti-parallel lines: FM2=1.0, S_{max}=15.

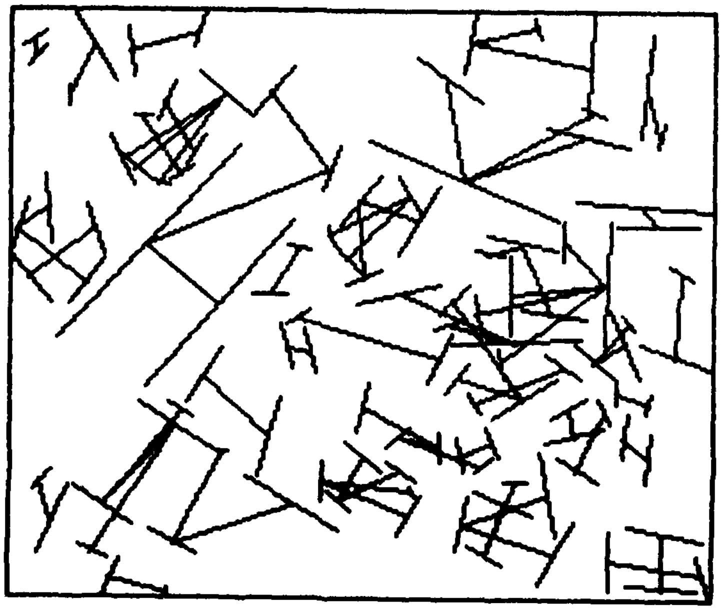

Figure 57. Anti-parallel lines: FM2=0.1, S_{max}=15.

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Pattern recognition
Linear features
Parallels

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method for finding anti-parallel straight edges is presented and discussed. This method is based on information about the object sides of edges, the similarity and homogeneity of gray level between the edges, the angle difference, the amount of overlap, and also information about the estimated object gray level. Two figures of merit are defined to calculate the mutual support of two antiparallel linear features. Examples are shown of applying the method to high resolution aerial photographs. Results indicate that cultural

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) features such as roads and buldings can be extracted and that a significant reduction in the complexity of the image description can be obtained. This algorithm should be especially useful in a relaxation type scheme for classifying linear feature segments when the degree of anti-parallelism of the segments is needed.