

DISCONTINUITY MAPPING WITH AUTOMATIC LINEAMENT EXTRACTION FROM HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT

In this study, automatic lineament analysis is performed by using high resolution satellite imagery for identification of rock discontinuities. A case study area is selected as an Andesite mine area in Gölbaşı, Ankara, Turkey. For the high resolution data 8-bit Ikonos Precision Plus with 1 meter resolution orthorectified image is used. The image data contain three bands as blue, green, red as band 1, band 2 and band 3, respectively. Then an additional band (fourth band) for the image is assigned by obtaining the average of the three bands. The automatic lineament extraction process is carried out with LINE module of PCI Geomatica v8.2. In order to determine the most accurate parameters of LINE, an accuracy assessment is carried out. To be the reference of the output, manual lineament extraction with directional filtering in four principal directions (N-S, E-W, NE-SW, NW-SE) is found to be the most suitable method. For the comparison of automatic lineament extraction and manual lineament extraction processes, total length and number of lineaments and directional analyses are carried out by constructing the rose diagrams. Besides these, field studies and previous studies carried out in the study area are also taken into consideration. After the accuracy assessment, final parameters of automatically extracted lineaments are determined. The lineament map produced in this study is found to be a very efficient in mapping the discontinuities for mining applications in terms of cost and time effectiveness.

1. INTRODUCTION

In mining engineering, determination of discontinuities plays an important role both in design and development stages, which requires systematic field studies to update the mining plans for future. It is obvious that these field studies are time and money consuming operations. Therefore it is important to minimize the cost and maximize the incomes and also to take into account the time spent for the field studies.

The term lineament is any linear features that can be picked out as lines (appearing as such or evident because of contrasts in terrain or ground cover on either side) in aerial or space imagery (NASA Remote Sensing Tutorial web page). In geological point of view, the lineaments are usually faults, joints, or boundaries between stratigraphic formations. Other types of lineaments include roads and railroads, contrast-emphasized contacts between natural or man-made geographic features (e.g., fence lines). (NASA Remote Sensing Tutorial web page).

Since both Remote Sensing (RS) and Geographic Information Systems (GIS) have recently started to be used intensively in many earth science applications, it is believed that such a study will be useful in terms of following innovative techniques used in the world for improving nominal mining industry. This study makes use of RS technology in detecting discontinuities and their patterns in Gölbaşı andesite mines area.

2. DATA AND AREA OF RESEARCH

Discontinuities have important role in mining industry. In order to evaluate them for mine design purposes, they have to be determined in large scale maps. Therefore using a high resolution satellite imagery for the lineament extraction is preferred in this study. For that reason, 8-bit Ikonos Precision Plus with 1 meter resolution orthorectified image of the andesite mine area is used. This image combines the details of 1 meter

panchromatic data and color content of 4 meter multi-band data. The RGB image of the area is given in Figure 1.

The study area covers approximately 15 km² with coordinates of 488235 E 4405642 N for the northwest corner and 492338 E 4401956 N for the southeast corner.

It is located 7 km to the east of Gölbaşı, Ankara, Turkey. There are plenty of working and abandoned andesite mines in the region. The location map of the study area is given in Figure 2.



Figure 1. RGB Image of the Study Area

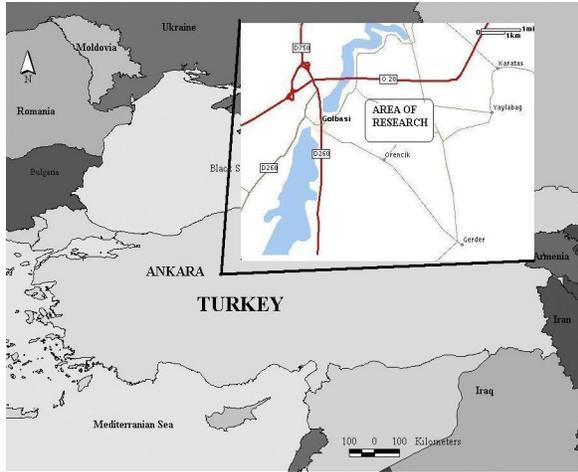


Figure 2. Location Map

3. METHODOLOGY

For lineament extraction, PCI Geomatica Version 8.2 is used. The most important factor for using Geomatica is the ability to extract lineaments from images automatically with the LINE option. For testing the reliability of the software, the lineaments are extracted manually by directional filtering. Furthermore, the lineaments detected is compared with those appear in the slope face of the mines in the area. The face discontinuities are determined again by directional filtering and followed by manual extraction.

3.1 Automatic Lineament Extraction

LINE **option** of Geomatica extracts linear features from an image and records the polylines in a vector segment.

LINE is controlled by the following global parameters:

Name	Description
RADI	Radius of filter in pixels
GTHR	Threshold for edge gradient
LTHR	Threshold for curve length
FTHR	Threshold for line fitting error
ATHR	Threshold for angular difference
DTHR	Threshold for linking distance

The LINE module takes a single image channel as input. If it is 16-bit or 32-bit, the image is first scaled to 8 bit using a nonlinear scaling routine. The output of the program is a vector segment which contains linear features as extracted from the image. If database output channel is specified, a binary edge image (which is the result of thresholding the gradient) will be saved in the specified channel.

RADI specifies the size of Gaussian kernel which is used as a filter during edge detection. The larger the RADI value, the less noise and less details in the edge detection result.

The thresholding value of the gradient image is given by the parameter GTHR. This value should be in the range 0 to 255. The user can experiment with different GTHR values and choose one which produces a suitable binary image. If the ON pixels in the image appear to be too sparse, the GTHR value should be decreased. On the other hand, if the ON pixels are

dense and noisy, the GTHR value should be increased. Note that it is important to have sufficient information in the edge image as the subsequent lineament extraction process is based on this input edge image.

Various other parameters control the line extraction process. FTHR is the tolerance for fitting line segments to a (curved) lineament. It is specified in number of pixels. LTHR is the minimum length of a curve (in pixels) to be considered as lineament for further consideration. ATHR is the maximum angle (in degrees) between two vectors for them to be linked. DTHR is the maximum distance (in pixels) between two vectors for them to be linked. (PCI Geomatica Manual, 2001)

In this study, the suitable parameter of LINE for rock discontinuity extraction are determined.

3.1.2. Algorithm of LINE

The algorithm of LINE consists of three stages: edge detection, thresholding, and curve extraction.

In the first stage, the Canny edge detection algorithm is applied to produce an edge strength image. The Canny edge detection algorithm has three substeps. First, the input image is filtered with a Gaussian function whose radius is given by the RADI parameter. Then gradient is computed from the filtered image. Finally, those pixels whose gradient are not local maximum are suppressed (by setting the edge strength to 0).

In the second stage, the edge strength image is thresholded to obtain a binary image. Each ON pixel of the binary image represents an edge element. The threshold value is given by the GTHR parameter.

In the third stage, curves are extracted from the binary edge image. This step consists of several substeps. First, a thinning algorithm is applied to the binary edge image to produce pixel-wide skeleton curves. Then a sequence of pixels for each curve is extracted from the image. Any curve with the number of pixels less than the parameter value LTHR is discarded from further processing. An extracted pixel curve is converted to vector form by fitting piecewise line segments to it. The resulting polyline is an approximation to the original pixel curve where the maximum fitting error (distance between the two) is specified by the FTHR parameter. Finally, the algorithm links pairs of polylines which satisfy the following criteria:

- (1) two end-segments of the two polylines face each other and have similar orientation (the angle between the two segment is less than the parameter ATHR);
- (2) the two end-segments are close to each other (the distance between the end points is less than the parameter DTHR). (PCI Geomatica Manual, 2001)

3.1. Manual Lineament Extraction

In order to evaluate the performance of discontinuity map produced by line module, a reference map is required. The reference map for performance evaluation is determined based on manual extraction of lineaments, as suggested in the literature (Suzen et al., 1998, Koike et al., 1995, Novak et al., Mah et al., 1995). The main advantage of manual extraction is that it is easy to detect the non-geological lineaments such as roads, fences, field boundaries with human eye.

For manual lineament extraction the image is first smoothed with an average low pass filter in order to eliminate the noise. Following the smoothing process, directional filtering method is selected for the lineament extraction because the directional nature of Sobel kernels generate an effective and faster way to evaluate lineaments in four principal directions (Süzen et al.,1998).

The Sobel kernels in four principal directions are given in Table 1.

N-S			NE-SW			E-W			NW-SE		
-1	0	1	-2	-1	0	-1	-2	-1	0	1	2
-2	0	2	-1	0	1	0	0	0	-1	0	1
-1	0	1	0	1	2	1	2	1	-2	-1	0

Table 1. Sobel kernels in four principle directions

A lineament in an aerial photo or a space image can show up either darker pixels in the middle and lighter on both sides; or, is lighter on one side and darker on the other side. When directional filtering is applied to the image the lineaments show up in light color which is surrounded by dark colored pixels.

After the filtering operation, the lineaments are digitized manually with a scale of 1:1500. There are 3357 lineaments with total length of 130040 meters in the study area.

4. RESULTS

For the comparison of the manually digitized and automatically extracted lineaments more effectively, the manually extracted lineament map is subjected to further.

The raw image contains agricultural fields in the north western part and village houses in the south western part. Because of this an area of interest is produced by excluding these areas by digitizing. In the reference lineament map, that is produced by manually, a boundary for the area of interest is formed. The automatically extracted lineaments are overlaid by the reference data and the lineaments in the restricted areas are deleted.

Not only the field boundaries and village but also the mine roads are seen as a lineament in the automatic extraction process. Hence the vectors that corresponds to the roads of the mines are also deleted. The resultant lineament map produced by manual digitizing is given in figure 3.

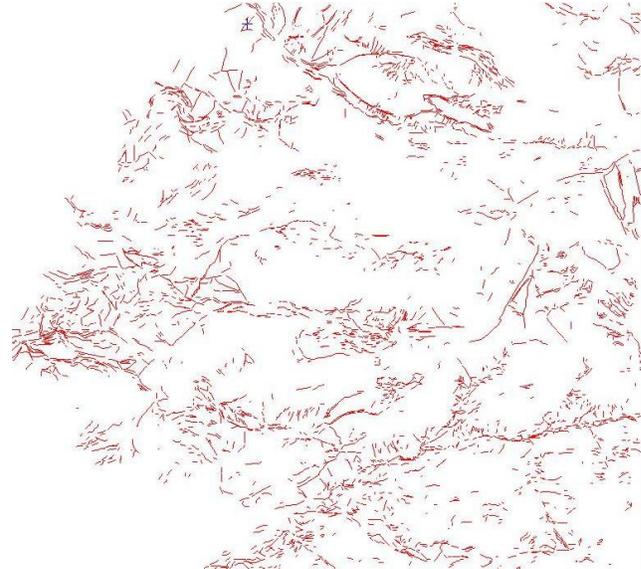


Figure 3. Manual Digitized Lineament Map

The automatically extracted lineament maps are overlaid with the area of interest and the lineaments outside this area are deleted. The andesite mine roads are easy to detect so the roads are also deleted. After these processes the length and number of the automatically extracted maps are found.

The parameters for the LINE process are given Table 2.

LINE ID	RADI	GTHR	LTHR	FTHR	ATHR	DTHR
VEC 1	5	20	10	2	20	1
VEC 2	5	20	20	2	20	1
VEC 3	5	20	15	2	20	1
VEC 4	5	20	25	2	20	1
VEC 5	5	30	15	2	20	1
VEC 6	5	30	20	2	20	1
VEC 7	5	40	15	2	20	1
VEC 8	12	40	25	2	20	1
VEC 9	12	20	25	3	20	1
VEC 10	12	20	25	3	30	1
VEC 11	12	20	25	3	40	1
VEC 12	12	30	20	3	30	1
VEC 13	12	30	30	3	20	1
VEC 14	12	30	25	3	20	1
VEC 15	12	30	20	3	20	1
VEC 16	12	40	25	3	20	1
VEC 17	12	50	25	3	20	1
VEC 18	12	40	20	3	20	1
VEC 19	12	50	20	3	20	1
VEC 20	12	40	15	3	20	1
VEC 21	12	50	15	3	20	1
VEC 22	12	60	15	3	20	1
VEC 23	12	60	20	3	20	1
VEC 24	12	60	25	3	20	1
VEC 25	12	100	15	3	20	1

Table 2. Parameters of LINE Process

Also the number of lineaments are given in Table 3.

LINE ID	LENGTH	NUMBER
LINE 1	112195	2883
LINE 2	122827	3056
LINE 3	165649	5404
LINE 4	89641	1901
LINE 5	104321	3312
LINE 6	74361	1887
LINE 7	69366	2265
LINE 8	117572	2368
LINE 9	210940	4418
LINE 10	252699	4846
LINE 11	298381	5468
LINE 12	245697	5235
LINE 13	135713	2415
LINE 14	172840	3520
LINE 15	225425	5213
LINE 16	139668	2776
LINE 17	115504	2256
LINE 18	181198	4101
LINE 19	147397	3271
LINE 20	235470	5986
LINE 21	189130	4692
LINE 22	153974	3752
LINE 23	120410	2589
LINE 24	95778	1833
LINE 25	78245	1807

Table 3. Results of LINE

5. ACCURACY ASSESSMENT

In order to verify the methodology's applicability, the results obtained from automatic lineament detection need to be checked. To test the accuracy, two different approaches are followed.

In the first approach rose diagrams for both automatically and manually extracted maps are created and major orientation of the lineaments are compared.

In order to check the reliability of the results, previous studies in the region by Karpuz (1982) and field investigations of Gölbaşı andesite mines are taken into account.

In the second approach, the near-face lineaments with the face discontinuities are compared. The face discontinuities are determined with the same method that is applied to the Ikonos imagery.

For the accuracy assessment, number and the total length of lineaments are considered.

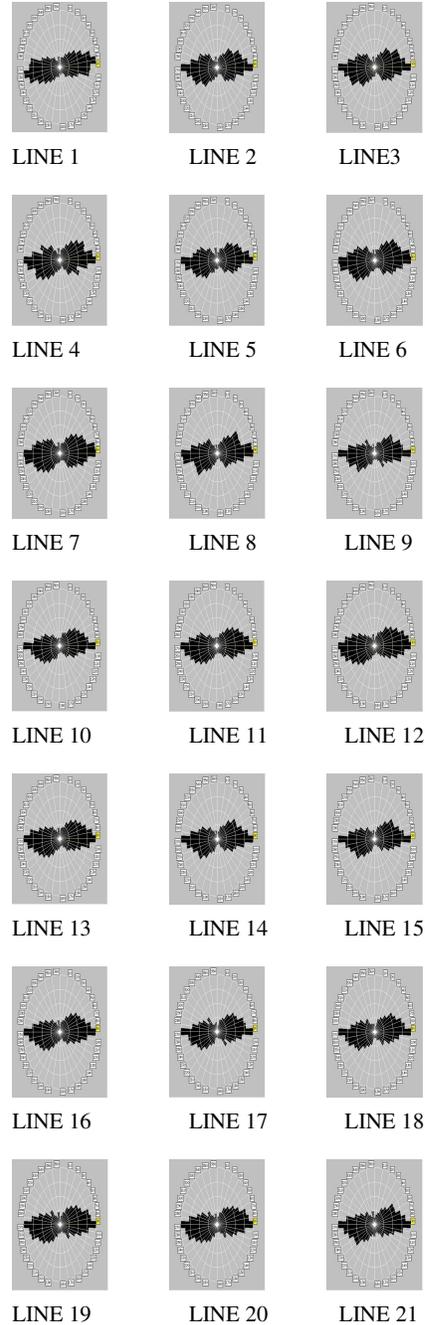
5.1. Directional Analysis

For the rose diagram applications, the 'Line Best Fit' method is used. This method uses the direction of a straight line that is computed with a least squares approximation of a line element. Simple illustration of the method is given in Figure 4.



Figure 4. Simple illustration of Line Best Fit Method

The rose diagrams of the automatically extracted lineaments are given in Figure 5.



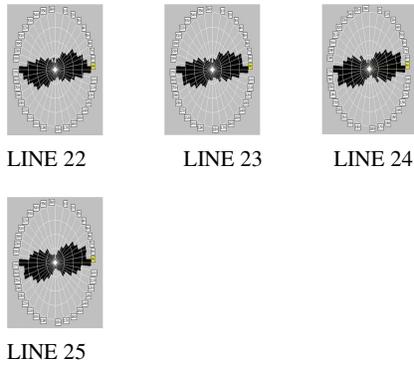


Figure 5. Rose Diagrams of Automatically Extracted Lineaments

Rose diagram for manual extraction is given in Figure 6.

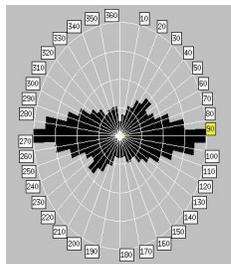


Figure 6. Rose Diagram of Manually Extracted Lineaments

Rose diagrams generally indicate the similarity in major discontinuity orientations. The reference lineament map, which is drawn manually has the major orientation of E-W. Similarly the automatically extracted lineament maps has the same major orientation.

Besides the similarities of the rose diagrams, a reliable site investigation is necessary for more accurate analysis. A detailed investigation by Karpuz (1982) is considered for the major discontinuity orientations. The orientations are found from the pole distribution data defined by Karpuz (1982). The pole distribution is shown in Figure 7.

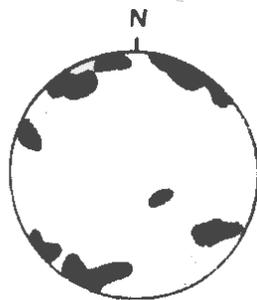


Figure 7. Pole Distribution of the Gölbaşı District

From the pole distribution of the discontinuity sets, three major discontinuity orientation is determined as N 50° E, E-W, N 70° W. From these results, it can be easily seen that the results of Karpuz (1982) and the extracted lineaments have the same orientation. Except one set that is accepted as the minor discontinuity set in the field.

From the field studies carried out, the most suitable mine for detecting lineaments is used for further analysis. As the Ikonos image from year the 2002 a mine that is abandoned would be more suitable. Besides this also surface lineaments must be nearby.

In order to see the applicability of the methodology in mining sites, face discontinuity sets are extracted. For the face lineament extraction, again directional filters are used with the digital images of the face of the quarry. Except the E-W direction, all three directions (N-S, NW-SE, NE-SW) are considered. Because of the reason that nearly horizontal lineaments are difficult to match with the surrounding lineaments, those with E-W direction are eliminated.

The face lineaments are determined by the same method, which is Sobel filtering. The images were taken with a 2 megapixel digital camera. In order to match the face lineaments with the surrounding ones filtering the face images in three directions (N-S, NW-SE, NE-SW) is found to be suitable. Finding a nearly horizontal lineament in the face can give nothing about the nearby detected lineaments.

The strikes of the face discontinuity sets determined from face images, which are supposed to be the lineament orientations found from Ikonos image, are compared with the orientations of the lineament map obtained from the Line module. From the field studies carried out, it is seen that strike directions of face discontinuity sets matches with the orientation of the lineaments detected from nearby the faces.

For the accuracy assessment, the length and the number of the lineaments are considered. A 15 % of tolerance is accepted for the matching process. After examining the tolerance values the final parameters are found.

As the total length of the manually extracted lineaments is 130040 meters. The tolerance value is ± 19506 meters. The lineament maps in this interval are 1 VEC, 2 VEC, 8 VEC, 13 VEC, 16 VEC, 17 VEC, 19 VEC and 23 VEC.

Another parameter is the number of the lineaments. The total number 3357. similarly a 15 % tolerance is accepted. The lineament maps in this interval are 1 VEC, 2 VEC, 5 VEC, 14 VEC, 16 VEC, 18 VEC, 19 VEC, 22 VEC, 23 VEC.

From the analyses, an elimination is made according to the tolerance limits and final parameters are determined according to the rest of the lineament maps. The final parameters of LINE are as follows.

- RADI: 12
- GTHR: 25 - 60
- LTHR: 20 - 30
- FTHR: 3
- ATHR: 20
- DTHR: 1

For the RADI parameter, also 5 or 7 value gives good results. Higher values of RADI results in loss of data and joining of lines.

For the GTHR parameter lower than the determined region gives plenty of lineaments that appear to be non-geologic. Also values higher than the region yields to poor results with respect to the output number and total length.

The LTHR value must not be higher than the region in order not to obtain circular shapes. Below the lower value curvilinear lineaments are eliminated.

FTHR parameter is recommended as 2 or 3 in order to get shorter line segments that better approximate the lineament.

The most suitable value for ATHR is found to be 20. The ATHR value less than 20 brings about disconnected lines while ATHR value higher than 20 results in polygon shaped lines.

The DTHR value determines the maximum distance of two lineaments to be linked. As the aim of this study is to detect discontinuity sets with high resolution data, it is better to detect lineaments separately. Because of that reason minimum value of 1 is selected.

6. CONCLUSION

In this study, decreasing the cost and increasing the efficiency of detecting discontinuity sets is aimed. Also automatic lineament extraction yields more effective results. In order to check the reliability of the automatic lineament extraction, manual lineament extraction is referred as a reference. From the results obtained, an elimination is done within the 15 % tolerance limit. As a result, final operating parameters for automatic lineament extraction process of LINE is determined.

Not only the manual extraction of lineaments but also field studies and previously detected discontinuity sets verify the results.

As a future application of this study, the accuracy assessment of the process may be studied detailly in the way that matching the lineament map according to the location (pixel numbers) of the lineaments detected.

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