Rock discontinuities mapping with computer-based lineament extraction from satellite imagery

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Abstract. This study presents an approach for automatic lineaments analysis by using high-resolution digital images for mapping and delineating rock discontinuities. As a case study, we combine Landsat 8 images with 15 m resolution and shuttle radar topographic mission (SRTM) of a discovered gold mine in Nuba Mountains, Sudan. The satellite image contains band 7, band 4, and band 1 in red, blue, and green. In addition, band 5 is assigned to obtain the average of the three bands. The automatic extraction of lineaments approach was initially carried out with PCI Geomatica software, and then an accuracy assessment is performed to determine the most accurate parameters of extracted features. On the excellent reference of the output, the extracted lineaments are transferred to the Arc map software, and the coordinates of lines have been fixed. Finally, the attribute table of lineaments was imported to Rockware software to draw the rose diagram. Moreover, a manual lineament extraction process is carried out. For comparing automatic lineament extraction and manual lineament extraction, total length and number of lineaments and directional analyses are done by constructing the rose diagrams. Besides these two processes, field investigation in the study area is also applied to verify digitally extracted lineaments that the features represent true discontinuities. The final parameters of automatically extracted lineaments are determined. The produced lineament map in this study is proved to be very efficient in the discontinuities mapping for mining applications in terms of cost and time effectiveness.

KEYWORDS: Remote Sensing, accuracy assessment, Rose diagram, High-resolution Imagery, lineament map.

1. Introduction
The strength of a rock mass is often controlled by discontinuities within the entire body of the rock. The rock’s discontinuities exist within almost all near-surface rock masses (Huang and Speck 1988). The most critical effects of discontinuities are to reduce the tensile strength of the rock. Excavation and construction in a jointed rock mass without adequately understanding the discontinuous rock mass may lead to unexpected strata deformation. Additionally, the existence of joints induces anisotropy of strength and many other properties in the rock mass (Huang and Speck 1988). Determining discontinuities plays an essential role in mining engineering design and development stages (Kocal et al., 2004). This role requires systematic field investigations to bring up to date the
mining plans for the future. These fieldworks are time and money consuming tasks. Thus, it is a good value job to minimize the cost and consider the time spent on the ground investigations. Lineament refers to any linear features traced as lines in satellite imagery (NASA Remote Sensing Tutorial web page). These features appear as such or evident because of contrasts in terrain or ground cover on either side. The lineaments are usually interpreted as joints, faults, or boundaries between stratigraphic formations in rock engineering. In addition, lineaments also include artificial geographic features such as roads and railways (NASA Remote Sensing Tutorial web page).

Lineament mapping is considered an essential issue in mechanical rock engineering to solve specific problems in the area. For example, for mineral exploration (Rowan and Lathram, 1980), the lineaments' nature and pattern should be identified. Aerial and Satellite images are extensively used to extract lineaments for different purposes (Casas et al., 2000).

Since both Geographic Information Systems (GIS) and Remote Sensing (RS) have recently been used widely in numerous earth science applications, since the initiation of digital image technology, it became obvious that many tasks which require data extraction from images by manual interpretation can be performed with the aid of a computer (O'Leary et al., 1976). The digital computer and modern image sensors have recently helped the image interpretation process in many ways, such as lineament extraction (Qari, 1991). Image processing methods have been widely used to study geological and terrain features (Qari, 1991; Kumar and Reddy, 1991; Mah et al., 1995; Sützen and Toprak, 1998; Arlegui and Soriano, 1998; Nama, 2004). In this regard, it is believed that such a study will be useful in following innovative techniques used in the world to improve the nominal mining industry. This work uses RS technology in tracing discontinuities and their patterns in the Nuba Mountains mines area, Sudan.

2. Study area and data

The study area covers approximately 67 km² and is bounded by coordinates of 11° 24' 0" to 11° 48' 0" N, and 31° 15' 0" to 31° 28' 0" E. The area is located 70 km to the east of Al Obaid, Sudan. Figure 1 shows the location map of the study area. There are plenty of working and gold mines in the region.

![Figure 1. Location Map](image)

Discontinuities have an essential role in mining engineering. To assess them for mine design purposes, they have to be determined in large-scale maps. Therefore using high-resolution satellite imagery for the lineament extraction is preferred in this study. Occasionally, 8-bit Ikonos Precision Plus is used with a 1-meter resolution orthorectified image of the andesite mine area. This image combines the details of 1-meter panchromatic data and the color content of 4-meter multi-band data.
The Greyscale image of the area is given in Figure 2.

![Greyscale Image of the Study Area](image)

**Figure 2. Greyscale Image of the Study Area**

### 3. Methodology

For lineament delineation, PCI Geomatica Version 8.2 is used. The most crucial factor for using Geomatica is extracting lineaments from satellite images automatically through the LINE option. For software reliability testing, the features are extracted manually by directional filtering. Furthermore, the lineaments detected are compared with those that appear in the slope face of the quarry in the area. The face discontinuities are retraced by directional filtering and followed by manual extraction.

#### 3.1 Automatic Lineament Extraction

The line option of Geomatica extracts linear features from an image and records the polylines in a vector segment. The line is controlled by the global parameters, as shown in Table 1.

| Name | Description                        |
|------|------------------------------------|
| RADI | The radius of filter in pixels     |
| GTHR | The threshold for edge gradient    |
| LTHR | The threshold for curve length     |
| FTHR | The threshold for line fitting error |
| ATHR | The threshold for angular difference |
| DTHR | The threshold for connecting distance |

Table 1: global parameters of Line
The Line module considers one image channel as input. If it is 16-bit or 32-bit, then the image is first scaled to 8 bit spending a nonlinear scaling routine, and the output of the program is a vector segment that contains linear features as extracted from the image. If the database output channel is specified, a binary edge image (which results from thresholding the gradient) will be saved in the specified channel.

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

The parameter GTHR gives the thresholding value of the gradient image. This value should be in the range of 0 to 255. The operator can test with another GTHR value and choose one which produces an appropriate binary image. And if the ON pixels in the image seem to be too thin, the value of GTHR should be diminished. While if the ON pixels are dense and noisy, the GTHR value should be increased. According to this input edge image, it is vital to have sufficient data in the edge image as the consequent lineament extraction procedure is.

Numerous other parameters control the lineament extraction process. The FTHR is the tolerance for fitting line segments to a (curved) lineament. It is specified in a number of pixels. The value of LTHR is the most petite of a curve’s length to be measured as lineament for extra consideration. The term ATHR is the most prominent angle between two vectors for them to be connected. The DTHR is the most considerable distance between two vectors for connecting (PCI Geomatica Manual, 2001).

### 3.2 LINE Algorithm

The LINE algorithm consists of three phases: thresholding, curve extraction, and edge detection. In the first phase, the edge strength image is thresholded to find a binary image. Each ON pixel of the binary image denotes an edge element. The GTHR parameter provides the threshold value. In the second phase, curves are delineated from the binary edge image. This stage comprises numerous substeps: (1) a thinning algorithm is utilized to the binary edge image to create pixel-wide skeleton curves. Then and there, a sequence of pixels for every curve is delineated from the image. Every curve with the number of pixels less than the parameter value LTHR is rejected from extra processing. A delineated pixel curve is transformed to vector form by fitting piecewise line segments to it. The resulting polyline approximates the original pixel curve where the FTHR parameter specifies the maximum fitting error (distance between the two). Finally, the algorithm links pairs of polylines that satisfy the following criteria:

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

In the third phase, the Canny edge detection algorithm is utilized to create an edge strength image. The Canny edge recognition algorithm has three substeps. (1) the input image is filtered through a Gaussian function whose radius is set by the RADI parameter. (2) gradient is calculated from the filtered image. (3) those pixels whose gradient are not local maximum are repressed.

### 3.3 Manual Lineament Extraction

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

Firstly, the image is smoothed with an average low pass filter to eliminate the noise for manual lineament extraction. Following the smoothing process, the directional filtering method is selected for the lineament extraction because the directional nature of Sobel kernels (Table 2) generates an effective and faster way to evaluate lineaments in four principal directions (Süzen et al., 1998).

| N-S | NE-SW | E-W | NW-SE |
|-----|-------|-----|-------|
| -1 0 1 | -2 -1 1 | -1 -2 -1 | 0 1 2 |
A lineament in a space image or an aerial photo can present darker pixels in the middle and lighter on both sides. When directional filtering is carried out to the image, the lineaments show light color, surrounded by dark-colored pixels. After the filtering process, the lineaments are digitized manually with a scale of 1:1500. There are 6215 lineaments with a total length of 130040 meters in the study area.

3.4 Geo-referencing of the lineament
After lineaments are extracted using PCI geomatica software in the form of victors, the results are saved inline shapefiles and imported in ArcGIS software to build up a table of attributes. The created table consists of coordinates of the start, mid-point, and end of every single lineament.

3.5 Visualization of Lineaments
A table of attributes of the lineament created in ArcGIS is imported into rockware software to present the results better. The data are shown in the form of a rose diagram for bearing and the length of the lineaments.

4. Results
For the contrast of the manually digitized and automatically extracted lineaments more successfully, the manually created lineament map is subjected to further.

The raw image holds agricultural fields and village houses in the southern part. For this reason, an area of interest is created by eliminating these areas by digitizing. In the reference lineament map produced manually, a boundary for the area of interest is formed. The reference data overlay the automatically extracted lineaments, and the lineaments in the restricted areas are deleted.

The field boundaries, village, and mine roads are seen as a lineament in the automatic extraction process. Hence the vectors that correspond to the roads of the mines are also removed. The resultant lineament map made by manual digitizing is known in figure 3.
The automatically delineated lineament maps are overlayed with the area of interest, and the lineaments outside this area are removed. The gold mine roads are easy to detect, so the streets are also removed. After these processes, the number length and of the automatically extracted maps are found.

5. Accuracy assessment
To confirm the approach’s applicability, the results achieved from automatic lineament delineation need to be tested. To test the accuracy, two different methods are surveyed.

In the first method, rose diagrams for manually and automatically extracted maps are created, and the major orientation of the lineaments is compared.

To test the reliability of the results, previous studies in the region by Dafalla (2013) and field investigations are considered.

In the second method, the near-face lineaments with the face discontinuities are matched. The face discontinuities are presented with the same process that is applied to the Ikonos imagery.

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

5.1 Analysis of Directional
For the applications of a rose diagram, the ‘Line Best Fit’ technique is used. This process uses the direction of a straight line computed with a least-squares approximation of a line element. This method uses the direction of a straight line that is computed with a least-squares approximation of a line element. A simple illustration of the process is known in Figure 4.
The rose diagram of the automatically created lineaments is provided in Figure 5.

Rose diagrams generally specify the similarity in major discontinuity directions. The manually drawn reference lineament map has the major trend of NE-SW. Similarly, the automatically extracted lineament maps have a similar major orientation. Above and beyond the similarities of the rose diagrams, a reliable field investigation is essential for more accurate analysis. Detailed research by Dafalla (2013) is measured for the major Discontinuity alignments. The orientations are initiated from the pole spreading data defined by Dafalla (2013). The pole distribution is provided in Figure 6(A).
From the pole distribution of the sets of discontinuity, two significant discontinuity orientations are delineated. From these outcomes, it can be easily seen that Dafalla's (2013) results and the extracted lineaments have the same orientation. Except for one set that is accepted as the minor discontinuity set in the field.

The most appropriate mine for extracting lineaments is used for further analysis from the field studies carried out. As the Ikonos image from the year 2002, a mine that is abandoned would be more proper. To realize the applicability of the methodology in mining sites, face discontinuity sets are extracted. Again, directional filters are applied with the digital images of the quarry's face for the face lineament extraction.

The face lineaments are extracted by the same technique, which is Sobel filtering. The images were taken with a 2-megapixel digital camera. To fit the face lineaments with the surrounding ones filtering the face images in three directions (N-S, NW-SE, NE-SW) is appropriate.

6. Conclusion
In this research, decreasing the cost and increasing the efficiency of detecting discontinuity sets are directed. Also, automatic extraction of the lineament produces more effective results. To check the automatic lineament extraction reliability, manual lineament extraction is referred to as a reference. As a result, the final operating parameters for the automatic lineament extraction process of LINE are determined. The manual extraction of lineaments and field studies and previously detected discontinuity sets verified the results. For the future application of this study, the accuracy assessment of the process may be studied detailly to match the lineament map according to the location (pixel numbers) of the lineaments detected.

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