Multi-sensor Assessment of Geological Lineament Detection

Ainyafiatty Ariffin¹, Nor Aizam Adnan² and Abdul Rauf Abdul Rasam²

¹Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia.
²Applied Remote Sensing and Geospatial Research Group, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia.

nor_aizam@uitm.edu.my

Abstract. The advances in remote sensing technologies and geographical information sciences are applicable in various branches of geosciences. The high availability of remote sensing data provides a wide range of spatial and spectral resolutions that can be utilized for lineament mapping purposes, especially in detecting geological linear features in remote areas. The aim of this study is to compare multi-sensors active and passive remote sensing technologies in lineament mapping, based on automatic image processing tools. Landsat 8, Sentinel 1 and Sentinel 2 satellite data will be processed to detect lineaments between the state boundaries of Selangor and Pahang in the Peninsular Malaysia, with reference to the published geological map. In detail, lineaments will be automatically extracted after image enhancement processes. Then, the output will be imported in a geo-graphical information system to further analyze the extracted lineaments. Overall, statistics descriptions, density, and orientations analysis indicate a correlation between the extracted lineaments and the geology of the area. Furthermore, lineaments extracted from Sentinel 1 radar images show the most significant result. Sentinel 1 data indicated about 6396 extracted of lineaments with 2465.93km total length as compared to Sentinel 2 with only 2637 lineaments extracted and total length of 1045.92km. The accuracy assessment of matching lineaments provides the Sentinel 1 as the best sensor compared to both the Sentinel 2 and the Landsat 8, with root mean square errors (RMSE) equal to 1.660, 1.743 and 2.757, respectively. Therefore, both remote sensing technologies and geographical information sciences can be effectively integrated within the field of the structural geology, thus allowing the mapping of lineaments in a more practical, cost and time effective way.

1. Introduction

Lineament can be defined as any extensive linear feature on the Earth’s surface representing faults, folds and fractures in the field of the structural geology. Lineament can be visually identified based on topographical data and geophysical measurements reflecting the rock’s properties [1]. The early lineament mapping experiments by means of remote sensing technologies began with the interpretation of aerial photographs, and keep developed from non-enhanced to digitally enhanced satellite images [2]. Previous studies in the field of the lineaments mapping highlighted that the automatic lineaments detection from satellite images is the most practical method to produce lineament maps [3,4]. However, the output will vary according to the employed satellite images, due to the different spatial and spectral resolution of the available sensors.

At the authors’ knowledge, there are no particular studies about which satellite images produce the most consistent output respect to the map generated through conventional mapping techniques.
Therefore, the presented study aims to assess the accuracy of lineament maps produced from the passive and active remote sensing data of Landsat 8, Sentinel 2 and Sentinel 1 sensors that undergo automatic lineament detection, by assuming as reference the published geological map. It is also designed to highlight the importance of GIS in geospatial analyst while analysing the geometry of the output data.

This study will contribute significant and vital guide for geologists or other potential users in detecting lineament without being in contact with the physical geology of the study area. For example, lineaments map being used to identify sustainable groundwater supplies [5] and detect potential landslide area [6]. Thus, they can utilize the output for supporting sustainable developments in fulfilling economic and social needs.

2. Materials and Methods

2.1. Study Area

The study area is located between Pahang and Kuala Lumpur, and it extends approximately for 800 km² (see figure 1). It covers several mountainous peaks along the Titiwangsa Range, which naturally divides the east and west coast of the Peninsular Malaysia. The area of interest includes two major geological fault lines, the Bukit Tinggi Fault and the Kuala Lumpur Fault which trending Northwest to Southeast (NW-SE) and related to the movements of Indo-Eurasia plates [7]. This area is significant for lineament mapping since the fault lines are interrelated with the occurrence of earthquake and geohazard phenomena [8].

![Figure 1. Geological setting of the study area that significant with lineament mapping (JMG,2012)](image)

2.2. Data and Processing

Within the study, the passive remote sensing data of Landsat 8 OLI and Sentinel 2 were acquired from the United States Geological Survey (USGS) website, while the active remote sensing data of Sentinel 1 Synthetic Aperture Radar (SAR) was acquired from the European Space Agency (ESA).

The multispectral images from Landsat 8 and Sentinel 2 sensors undergone pre-processing stages of image through directional filtering, histogram equalization and principle component analysis (PCA), within the ERDAS IMAGINE™ software. Image enhancing techniques like directional filtering can sharpen the boundary between adjacent units, while the histogram equalization adjusts images intensities in order to enhance the pixel contrast and the PCA reduce redundant data to make it more visible for interpretation [9,10,11]. Sentinel 1 data was only calibrated in SNAP without undergoing image enhancing stages, mainly due to the large files sizes that are unsupported by ERDAS IMAGINE™.
The satellite data were then used for automatic lineament extraction by means of the LINE Algorithm of the PCI Geomatica™ package, and the outputs of the extracted lineament were finally analyzed and evaluated through the spatial analyst toolsets of the ArcGIS™ toolbox to visualize the number, length, density and orientations of the lineament (Figure 2).

Figure 2. General methodology in data pre-processing, processing and post-processing

In particular, the generated lineament maps were compared with the available geological map by means of spatial overlay techniques and buffering, in order to investigate the relationship between the trend of extracted lineaments and the structural geology of the study area. Matching and non-matching area of extracted lineaments that tolerate with the buffer regions were then used to calculate the RMSE.

3. Results and discussion
Qualitative and quantitative data analysis with respect to the number, length, density and orientations of extracted lineaments reveal the relationship between the extracted lineaments themselves and the available geological map. Table 1 shows the quantitative values of the geometries of the extracted lineaments as well as the RMSE for each sensor while Table 2 describes statistics of linear features in the geological map that associated within the study area.

Table 1. Statistical results of the extracted lineaments from the different tested sensors

|                     | Landsat 8 | Sentinel 1 | Sentinel 2 |
|---------------------|-----------|------------|------------|
| Number of lineaments| 1608      | 6396       | 2637       |
| Total length (km)   | 687.841   | 2465.930   | 1045.929   |
| Minimum length (km) | 0.03      | 0.222      | 0.300      |
| Maximum length (km) | 3.229     | 2.088      | 1.417      |
| Mean                | 0.428     | 0.386      | 2.626      |
| Standard Deviation  | 0.254     | 0.174      | 0.104      |
| RMSE                | 2.757     | 1.660      | 1.743      |
Table 2. Statistical of linear features in the existing geological map

|                         | Main fault line | Lineament |
|-------------------------|-----------------|-----------|
| **Number of lines**     | 5               | 33        |
| **Total length (km)**   | 100.231         | 203.502   |
| **Mean**                | 20.044          | 6.166     |
| **Standard Deviation**  | 10.918          | 7.183     |

Density analysis refers to the correlation analysis that significant to the geological information of the area and the rose diagrams represent the orientations of the lineaments based on the end point of the coordinate indicating the trend of the structural features in the geological relation of the study area (Figure 3).

Figure 3. Lineament density maps (top) and rose diagrams (bottom) of lineament extracted from Landsat 8, Sentinel 1, and Sentinel 2 sensors, respectively.

From the statistical descriptions, Sentinel 1 data was able to provide the highest number of lineaments extraction compared to the Landsat 8 and Sentinel 2. Lineament density maps were indicating Sentinel 1 as the densest area that mainly covered in red zone with value of more than 2.5 lines per square kilometres. This is deliberately related to the length and the number of counts in the lineament map as large occupancy of extracted lineaments increase the frequency of lineaments per unit area. The rose
diagrams show that most of the lineaments extracted from the Landsat 8, Sentinel 1 and Sentinel 2 data are trending NW-SE, which is in accordance with the orientation of the major fault lines of Bukit Tinggi Fault and Kuala Lumpur Fault.

The generated lineament maps were being evaluated with geological map by GIS overlay techniques to display the relationship, pattern and correlation of the data (Figure 4). The proximity analysis that involve buffering was conducted to infer the relationship between the trend of lineaments with the structural geology of the study area. In general, the intersection region between the fault and extracted lineament lines can be seen if the features zoomed in to the buffered area (Figure 5). Matching and non-matching area of lineaments that tolerate with the buffer regions were observed and used to calculate the RMSE.

**Figure 4.** Overlay of the extracted lineaments from Landsat 8, Sentinel 1 and Sentinel 2 to the geological map

**Figure 5.** Example of matching and non-matching lineaments to the buffered zone
The map evaluation with the overlay and proximity analysis indicate that these satellite images can be utilised to map the lineament as most of the automatically extracted lineaments do intersect with the major fault line and following the trend of the geological structures of the map. The automatically extracted lineaments can be inferred as geological linear features before being analysed for specific purposes of study. RMSE result also indicating lineament extracted from Sentinel 1 has the least error followed by Sentinel 2 and Landsat 8 respectively. Similar finding was obtained by [12] with Sentinel 1 using HV and VV polarizations indicated the highest accuracy as compared to the Landsat and Sentinel 2 data. Furthermore, a study by [13] found that Sentinel 1 performance of the radar data in extracting geology lineament is much better as compared to those optical data such as Sentinel 2, Landsat and ASTER.

4. Conclusion
The presented research highlighted that active remote sensing data (Sentinel 1) provides better result than the passive ones (Landsat 8 and Sentinel 2) automatic lineaments extractions. With the existence of ranges satellite images that vary in spatial and spectral resolutions, its benefits users in utilizing the data based on their preference and decision-making skill. Thus, geographical information system and remote sensing technologies can be effectively integrated and employed in the field of lineaments mapping, especially for less accessible areas as well as contributing for innovative technologies and sustainable industrialisation.

References
[1] Tiren, S. Lineament interpretation Short review and methodology (SSM--2010-33) (2010).
[2] Akhir, J. Lineaments in enhanced remote sensing images: An example from the Upper Perak Valley, Perak Darul Ridwan. June, 115–119 (2004).
[3] Adiri, Z., El Harti, A., Jellouli, A., Lhissou, R., Maacha, L., Azmi, M., Zouhair, M., & Bachaoui, E. M.. Comparison of Landsat-8, ASTER and Sentinel 1 satellite remote sensing data in automatic lineaments extraction: A case study of Sidi Flah-Bouskour inlier, Moroccan Anti Atlas. Advances in Space Research, 60(11), 2355–2367 (2017).
[4] Farahbakhsh, E., Chandra, R., Olierook, H. K. H., Scalzo, R., Clark, C., Reddy, S. M., & Dietmar, R. M.. Computer vision-based framework for extracting geological lineaments from optical remote sensing data. 1–17 (2018).
[5] Mogaji, K. A., Aboyi, O. S., & Omosuyi, G. O. Mapping of lineaments for groundwater targeting in the basement complex region of Ondo State, Nigeria, using remote sensing and geographic information system (GIS) techniques. International Journal of Water Resources and Environmental Engineering, 3(7), 150–160. (2011)
[6] Ramli, M., Yusof, N., Yusoff, M., Juahir, H., & Shafri, H. Lineament mapping and its application in landslide hazard assessment: A review. Bulletin of Engineering Geology and the Environment, 69. 215-233 (2010).
[7] Abdul Halim Abdul Latiff, A. E. K. Velocity Structure and Earthquake Relocations at Central Peninsular Malaysia Region. Sixth International Conference on Geotechnique, Construction Materials and Environment, December, 1–6 (2016).
[8] Lat, C.N., & Ibrahim, A. T. Bukit Tinggi Earthquakes:November 2007 – January 2008. Bulletin of the Geological Society of Malaysia 55. 81-86 (2009)
[9] Thannoun, R. G. Automatic Extraction and Geospatial Analysis of Lineaments and their Tectonic Significance in some areas of Northern Iraq using Remote Sensing Techniques and GIS. International Journal of Enhanced Research in Science Technology and Engineering, 2(2), 1–11 (2013).
[10] Marghany, M., & Hashim, M. Lineament mapping using multispectral remote sensing satellite data (2014).
[11] Estornell, J., Martí-Gavliá, J. M., Sebastiá, M. T., & Mengual, J. Principal component analysis applied to remote sensing. Modelling in Science Education and Learning, 6(7), 83 (2013).
[12] Javhar, A., Chen, X., Bao, A.; Jamshed, A., Yunus, M., Jovid, A., Latipa, T. Comparison of Multi-Resolution Optical Landsat-8, Sentinel-2 and Radar Sentinel-1 Data for Automatic Lineament Extraction: A Case Study of Alichur Area, SE Pamir. Remote Sensing, 11, 778 (2019). https://doi.org/10.3390/rs11070778

[13] Adiri Z., El Harti A., Jellouli A., Lhissou R., Maacha L., Azmi M., Zouhair M., Bachaoui EM. Comparison of Landsat-8, ASTER and Sentinel 1 satellite remote sensing data in automatic lineaments extraction: A case study of Sidi Flah-Bouskour inlier, Moroccan Anti Atlas, Advances in Space Research, 60(11), 2355-236. (2017). https://doi.org/10.1016/j.asr.2017.09.006.