Field Verifications of Geological Structures Related to SAR Detected Lineaments

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Abstract. Identifying geological structures is a crucial step in geological field mapping. One common technique to interpret geological structures is using lineament analyses on the satellite imagery. The usual encounters is many lineaments do not concordance to the geological structures. Overcoming the problem, we used dual orbit Synthetic Aperture Radar (SAR) images to obtain lineaments related to geological structures at ground level. In this paper, we presented the sensitivity of the lineaments detection method visually and automatically using Yamaguchi and modified Segment Tracing Algorithm (mSTA) methods, respectively. The Yamaguchi method is a visual lineament detection using an optimum image-scale and resolution. The method was used to detect lineaments based on visual limitation of the interpreter. On the contrary, the mSTA method is an automatic lineament detection utilizing SAR backscattering intensity images in opposite Line of Sight (LOS). Accordingly, we compared the effectiveness between the visual and automatic detection methods in detecting the faults and joints correctly at ground surface. The verification of detected lineaments at the field was then performed and analyzed to obtain comparison of the effectiveness between two lineaments detection methods. The direction of joints at EKA-01 were oblique 45 degrees to Yamaguchi method, and 25 degrees to mSTA method. Besides, the direction of faults and joints at EKA-10 were oblique 5 degrees to Yamaguchi method, and 2 degrees to mSTA method. mSTA method has smaller offset angle to field measurements than Yamaguchi method, indicating that the automatic is more effective and representative to detect lineaments related to geological structures than visual method.

1. Introduction
Lineaments detection both visually and automatically have been developed many years ago. Lineaments detection using visual interpretation needs an experienced skill and expert [1]. In this study, we used the Synthetic Aperture Radar (SAR) to detect lineaments related to geological structures. The SAR image can be acquired regardless of cloud cover and under all weather conditions. The image can identify small topographic relief with high spatial resolution using oblique microwave radiation [2].

We used SAR data generated by a microwave sensor with wavelength of 1-100 cm [3]. The L-band of SAR sensors provides a deeper detection target than optics due to long-wavelength capability to penetrate canopy vegetation [4]. Accordingly, the L-band of SAR image is supposed to be more accurate to detect lineaments related to geological structures than optic images. In this study, we used backscattering intensity images of Phased Array type L-band Synthetic Aperture Radar (PALSAR) from
Advanced Land Observing Satellite (ALOS) to detect lineaments related to geological structures. The Yamaguchi and mSTA methods were used to detect lineaments visually and automatically. Both methods utilized the SAR dual orbit mode.

The most important step in this study was field observation. Field observation was intended to verify the detected lineaments using visual and automatic methods that related to geological structures correctly on ground level. Following the step, we analyzed and parameterized the lineaments that associated correctly with geological structures at field. We also compared the effectiveness between the two methods. The Dieng volcanic complex in Central Java was selected as the study area because of volcanic and local tectonics setting (Figure 1).

![Figure 1](image)

**Figure 1.** Study area is located in Central Java and presented on red square (A). Hillshaded map of SRTM 30 m shows study area in Dieng Plateau, West Java, Indonesia, composed by hills and valleys (B).

2. **SAR Image Data Collection**

Digital Elevation Models (DEM), aerial photographs, and satellite images are the common data to interpret geological structures including faults and joints by the geologists. DEM is the most frequently used data to detect linear features such as contour density, river turn, or hill ridge [1]. In this study, we used Synthetic Aperture Radar (SAR) image derived from an Advanced Land Observing Satellite
(ALOS). ALOS was one of the world's largest earth observation satellites whose function is to collect global and high-resolution land observation data.

ALOS is composed of three main sensors: Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM), Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2), and Phased Array type L-band Synthetic Aperture Radar (PALSAR). ALOS data that we used in this study were obtained from PALSAR because of its capability to penetrate the atmospheric and surface layer using L-band frequency [5]. Meanwhile, ALOS PRISM has capability to generate DEM using X-band (short wavelength) with 3 cm wavelength. Therefore, ALOS PALSAR with L-band (23.5 cm) is better to detect lineaments [6].

ALOS PALSAR has azimuth and range. Azimuth is the satellite track or so called orbit. PALSAR has two orbits, ascending and descending (Figure 2). Ascending is when satellite move from south to north direction, while descending is when satellite move from north to south direction. Both orbits have opposite range. Range is the satellite’s radar Line of Sight (LOS). The ascending orbit range is heading east, while the descending orbit range is heading west. The ascending and descending orbit were utilized to increase the obtained ground targets including lineaments.

![Ascending and Descending Orbit](image)

**Figure 2.** The illustration of ascending and descending orbit indicated satellite illumination from West or East and heading from North or South, respectively.

We used four scenes ALOS PALSAR backscattering intensity images including two scenes for each ascending and descending orbit. The detail of SAR data used in this study was listed in Table 1. The ALOS PALSAR level 1.1 data in Single Look Complex (SLC) with Fine Beam Dual (FBD) polarization mode were selected.
Table 1. The ALOS PALSAR backscattering intensity images used in this study.

|   | 1    | 2    | 3    | 4    |
|---|------|------|------|------|
| Data set | ALOS | ALOS | ALOS | ALOS |
| Beam mode | FBD  | FBD  | FBD  | FBD  |
| Path     | 7030 | 7040 | 3760 | 3770 |
| Row      | 432  | 432  | 97   | 97   |
| Acquisition date | 2010-11-18 | 2010-11-18 | 2011-02-27 | 2011-02-27 |
| Level    | 1.1  | 1.1  | 1.1  | 1.1  |
| Type     | Ascending | Ascending | Descending | Descending |

The ALOS PALSAR backscattering intensity image generation was performed through five main steps, multilooking, speckle filtering, geocoding, mosaicking and reprojecting. Multilooking was increasing focus without losing resolution, speckle filtering was minimizing the noise from surrounding objects, and geocoding was correcting the slant to ground coordinate. Then, we mosaicked and reprojected both ascending and descending of ALOS PALSAR backscattering intensity images using a geographic coordinate system (Figure 3). Finally, the images were ready to be used for lineament extraction as the following methods.

Figure 3. The Ascending (A) and descending (B) ALOS PALSAR backscattering intensity images show the ground surface in opposite Line of Sight (LOS) as a basis to detect the lineaments in the study area.

3. Visual Lineaments Detection using Yamaguchi Method

Linear features have been studied by geologists for decades. The lineament definition has been introduced since the early 20th century [7]. The early published paper explained about the correlation between lineaments and geological structures such as joints and faults was reported in [8]. Lineaments detection on satellite imagery has been recognized as one of the main features that the lineament length varies from a few to hundreds of kilometers [9]. The lineament is a mappable linear or curvilinear feature of a surface whose parts align in a straight or slightly curving relationship [10].

We used the Yamaguchi method to detect lineaments visually on ALOS PALSAR backscattering intensity images. The Yamaguchi method works based on an optimal image scale and resolution for lineaments detection [2]. If the magnification rate of the image is higher than the spatial resolution, the
patterns in the image will be vague and only showed small area observation in a field of view. On the contrary, if the reduction rate is lower than spatial resolution, the original data quality will decrease owing to data reduction [2]. According to the Yamaguchi method, we used the Yamaguchi equation to optimize lineaments detection without decreasing image quality or the observation area (Figure 4). The visual lineaments detection is mainly depending on the quality of the image and the proficiency of the user [11]. According to the Yamaguchi method, the lineaments will be optimum to be traced if $R \times S = 0.1 \text{ mm}$. The $R$ is ground resolution determined by the imaging system and the $S$ is image scale. Since the $R$ of ALOS PALSAR images used in this study are 25-m, the sufficient scale to detect lineaments will be $1:250,000$. Identifying lineaments manually using Yamaguchi method means to mark every linear feature that we could observe with bare eyes on determined image-scale. Every linear feature should be more than 0.4 centimeters long (=1 km at ground). Accordingly, we could identify 1170 lineaments in total for ascending and descending images (Figure 5). Since the Yamaguchi method is dependent on the visual limitation of the interpreter, some lineaments are dis-concordance to the geological structures. Then, we have to analyze and obtain some additional parameters to interpret the geological structures based on detected lineaments.

Figure 4. Corelation between optimum image-scale and resolution showed that lineaments detection can be performed efficiently with $R \times S = 0.1 \text{ mm}$ [2].
4. Automatic Lineaments Detection using mSTA Method

The Segment Tracing Algorithm (STA) method is proved as an effective method to detect lineaments automatically using a Digital Elevation Model (DEM) data [12]. Since the spatial resolution of ALOS PALSAR images is higher than DEM, the lineaments detection process should be more accurate and efficient. The lineament detection using STA and ALOS PALSAR images termed as modified STA (mSTA) was developed to find the fracture permeability at geothermal field [5]. Principally, the mSTA method detects lineaments automatically based on various intensity patterns on backscattering intensity images. Extracted linear features using Segment Tracing Algorithm (STA) could support to identified the fractured zones [13].

Preceding the automatic lineament detection using mSTA method, the image preparation was applied including resizing the backscattering intensity images in ascending and descending images to obtain the same pixel size, rows, and columns. We used the ascending and descending images with size 1771 columns, 1455 rows. The image resolutions are 22 and 23 m in X and Y coordinate. There were 2951 detected lineaments in total using mSTA method (Figure 6).
5. **Interpretation Techniques to Obtain Lineaments related to Geological Structures**

Interpretative structures were made manually by considering the result of lineaments detection using the Yamaguchi and mSTA methods. The regional geological structure was used as a guide for a wide observation area. We used some additional parameters to correctly interpret geological structures for the Yamaguchi method, due to excessive noises from mountainous terrain that caused Yamaguchi’s main lineament strikes to differ from others. Based on the lineaments detection result, we obtained main lineament strikes for each method is North on Yamaguchi method and Northwest on mSTA method (Figure 7).

We used the same parameters to interpret structures for both Yamaguchi and mSTA methods. The first used parameter was detected lineaments continuity. Continuous lineament from segments was the main parameter to interpret structures based on detected lineaments. The second parameter was observing morphology that related to linear features in the PALSAR backscattering intensity image.

Based on the selected parameters, we obtained 14 interpreted structures using the Yamaguchi method and 24 interpreted structures using mSTA method (Figure 8). In this case, it was more accurate and easier to interpret structures using detected lineaments from mSTA method. We also compared the main strike direction between regional geological and interpretative structures using Yamaguchi and mSTA methods. The rose diagrams show that both methods and regional structures have the same main direction, which is Northwest, and both interpretative structures looked similar to each other (Figure 9).
Figure 7. Rose diagrams of lineaments main strike direction toward North using the Yamaguchi method (A) and Northwest using mSTA method (B). Dots indicate approximate strikes of regional geological structures.

Figure 8. Interpretative structures derived from Yamaguchi lineaments detection presented by orange lines (A) and mSTA presented by yellow lines (B). Both interpretative structures look similar to each other.

Figure 9. The strike direction of Yamaguchi interpretative structures (A) and mSTA interpretative structures (B). The diagrams show Northwest as major strike direction. Dots indicate approximate strikes of regional geological structures.
6. Field Verification and Geological Observation

Geological structures were determined as joints and faults on field observation. The trend of geological structures was measured to analyze the oblique angle between interpretative structures and geological structures. Observation and measured geological structure was done at 12 locations. Two locations have more structural data than others, therefore these locations were used to analyze the main strike direction. These locations were noted as EKA-01 and EKA-10 (Figure 10).

EKA-01 has joints as geological structures found on field observation. There were 56 joint measurements in total. EKA-10 has faults and joints on field observation. There were 3 fault and 11 joint measurements. Major strike direction of field structures and interpretative structures in both areas are Northwest.

![Figure 10](image-url)  
*Figure 10. All observation locations at study area for verification were presented by red dots, focus analyses area and field observation photos of EKA-01 and EKA-10.*
7. Interpretation and Discussion

Although we had 14 and 24 interpreted structures from Yamaguchi and mSTA methods respectively, the observed structures at field are limited due to dense vegetation, access, and thick weathering. Therefore, there are only two structures measured properly at the field (EKA-01 and EKA-10). Geological structures were measured classified their main strike direction according to their type and dimensions. Geological structure measurements were carried out using basic geological methods, but main direction analysis differed structures by their type and size of dimensions. Therefore, joints and faults had different proportions on the analysis. Two meters long fault also had different proportions to ten meters long fault.

The main strike direction of joints on EKA-01 was N275°E (Figure 10). The main strike direction of interpretative structure on that location using Yamaguchi and mSTA methods were N320°E and N300°E, respectively. The main strike direction was oblique 45 and 25 degrees to Yamaguchi and mSTA interpretative structure. On EKA-10, the main strike direction of joints and faults was N298°E. Yamaguchi and mSTA interpretative structures were N293°E and N300°E, respectively (Figure 11). The main strike direction was oblique 5 degrees to Yamaguchi and 2 degrees to mSTA interpretative structure. Yamaguchi method generates bigger offset than mSTA method. This might be caused by fewer lineaments detected in total using Yamaguchi than mSTA methods.

Continuous lineaments associated with visual linear features on PALSAR backscattering intensity image were proven related to geological structures at field observation. We can conclude that both methods could be used to detect lineaments. Smaller offset angle between mSTA method and field measurements indicated that mSTA method was proven to be more accurate than the Yamaguchi method.

Our study is an improvement in geological structure mapping. Detecting linear features using mSTA method on SAR images and comparing it with fault system have been done before [13]. The major direction of linear features and fault systems in their study area were similar. The improvement in our study is measuring the oblique offset between detected lineaments and geological structures on field.

![Figure 11. The relative lineament strike direction using Yamaguchi and mSTA methods compared to field observation and measurement at EKA-01 (A) and EKA-10 (B).](image)

8. Conclusions

Lineaments that related to geological structures could be detected both visually using the Yamaguchi method and automatically using mSTA method. The lineaments detection using Yamaguchi method needs additional parameters to correctly obtain the geological structures. Lineaments related to geological structures were presented by continuous lineaments and focussing on lineaments that associated with linear morphology, exclude lineaments related to radial features from mountainous terrain. The detected lineaments using mSTA method are more representative to identify geological structures than Yamaguchi method because of their agreement with regional geological structure and field verification. The direction of joints at EKA-01 was oblique 45 and 25 degrees to Yamaguchi and
mSTA methods, respectively. In addition, the direction of faults and joints at EKA-10 was oblique 5 degrees to Yamaguchi and 2 degrees to mSTA method.

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