Identification of linear features at geothermal field based on Segment Tracing Algorithm (STA) of the ALOS PALSAR data

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Identification of linear features at geothermal field based on Segment Tracing Algorithm (STA) of the ALOS PALSAR data

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Abstract. Indonesia has about 40% of geothermal energy resources in the world. An area with the potential geothermal energy in Indonesia is Wayang Windu located at West Java Province. The comprehensive understanding about the geothermal system in this area is indispensable for continuing the development. A geothermal system generally associated with joints or fractures and served as the paths for the geothermal fluid migrating to the surface. The fluid paths are identified by the existence of surface manifestations such as fumaroles, solfatara and the presence of alteration minerals. Therefore the analyses of the linear features to geological structures are crucial for identifying geothermal potential. Fractures or joints in the form of geological structures are associated with the linear features in the satellite images. The Segment Tracing Algorithm (STA) was used for the basis to determine the linear features. In this study, we used satellite images of ALOS PALSAR in Ascending and Descending orbit modes. The linear features obtained by satellite images could be validated by field observations. Based on the application of STA to the ALOS PALSAR data, the general direction of extracted linear features were detected in WNW–ESE, NNE–SSW and NNW–SSE. The directions are consistent with the general direction of faults system in the field. The linear features extracted from ALOS PALSAR data based on STA were very useful to identify the fractured zones at geothermal field.

Keywords: Segment Tracing Algorithm (STA), ALOS PALSAR, geothermal, extracted linear features, Wayang Windu.

1. Introduction
Indonesia is located on the world ring of fire along with many volcanoes which potentially providing the geothermal energy resources. The potency of geothermal resources owned by Indonesia reached about 13,440 MW to 28,100 MW of potential resources and 14,473 MW of reserves spread across 265 locations throughout Indonesia archipelago. However, the current production is about 1189 MW (4%) which used to generate the electricity [1]. Thus, the comprehensive understanding about the geothermal system is indispensable for continuing the development. One of area that shows the potency of geothermal energy resources is Wayang Windu field located at West Java Province.

Geological structures such as faults and their associated fracture zones are an important aspect in the exploration of geothermal systems. Faults can provide permeable paths for geothermal fluids (through zones of fractured rocks) where the study of their pattern can help often to delineate the productive parts...
Detection of the surface geological structure presented in the form of linear features in the image using optical sensor data hampered some problems such as the canopy of vegetation, clouds, and weather conditions. Meanwhile the direction and quantity of surface geological structures are important for geothermal exploration because it could accommodate the fluid flows and surface manifestations. Although the visual interpretation is effective to track the linear features in images, this technique is not efficient, especially for large study area or multiple datasets [3]. To overcome this problem, the satellite imagery with the microwave sensor could be an option in the detection of geological structures within a certain region. The advantage of satellite imagery is able to operate in any weather conditions and without acquisition time providing accurate surface observation.

A method for determining the linear features is Segment Tracing Algorithm (STA). The principle of the STA is to detect a line of pixels as a vector element by examining local variance of the gray level in the digital image, and to connect retained line elements along their expected directions. The advantage of this method is able to observe the linear features of the low contrast and parallel to the sun’s azimuth [4].

2. Study area
Wayang Windu geothermal field took the name after Mt. Wayang and Mt. Windu, the two small lava domes without historic eruption history [5]. The field is located at Pangalengan town, approximately 40 km to the south of Bandung city, the capital of West Java Province (Figure 1). The elevation of study area is about 1500 to 2100 m above sea level [6].

Several thermal manifestations including fumaroles, hot springs, mud pools and altered soil are situated along the slopes of the mountain range. Fumaroles which are located between Mt. Wayang and Mt. Windu show temperatures about 93°C to 96°C, and therefore slightly superheated if we compared to the normal water boiling point at altitudes of 2000 m. Hot springs which are located in altitudes about 1495 to 1985 m reach temperatures 41°C to 88°C. Water discharge hot springs are bicarbonate type, except for the hot springs which is located near the fumaroles has discharge acid sulfate water [7]. The geothermal system at Wayang Windu field was classified as transitional between vapor and liquid dominated systems [8].

3. Data
The Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard the Advanced Land Observing Satellite (ALOS) with two orbits mode, i.e. toward north (Ascending) and toward south
(Descending) flight directions was used in this study (see Figures 2A and B). Ascending and Descending images have a size of 800 × 800 pixels with a resolution of 30.72 m × 30.72 m.

![Images of ALOS PALSAR image with ascending and descending modes](image)

**Figure 2.** ALOS PALSAR image with: (a) Ascending mode (hereinafter referred as Ascending image), (b) Descending mode (hereinafter referred as Descending image)

4. **Methodology**

Linear features represent the geological structure with a different hue contrast and relief in the images. Segment Tracing Algorithm (STA) is linear features extraction method consist of five main steps [4, 9]. The program used for the linear features extraction is developed using MATLAB syntax.

4.1. **Segment Tracing Algorithm (STA)**

*Step 1.* Local window with array size of 11 × 11 pixels is set around a centered pixel which will be judged whether it is a line element or not (Figure 3). The sixteen directions at 11.25° intervals passing through the center of the window defined to examine a local variation of gray levels along a line. The numbers shown in Figure 3 denotes the examples of line directions. The direction that minimizes the variation is assumed the valley direction and expressed by a symbol \( k_{\text{min}} \).

![Segment Tracing Algorithm](image)

**Figure 3.** Local window with array size of 11 × 11 pixels and scan lines at \( \pi/16 \) radian intervals used in the Segment Tracing Algorithm (STA).
**Step 2.** Let a gray level at location \( x \) by \( z(x) \). Along the direction perpendicular to \( k_{\min} \), that is \( k_{\max} \), squared secondary differentiation for gray levels, \( \lambda \), is calculated by:

\[
\lambda = (z(x))^2 \left( \frac{d^2z(x)}{dx^2} \right)^2
\]

Expressing the mean and standard deviation of \( \lambda \) by \( m \) and \( \sigma \), a dynamic threshold \( T \) defined as:

\[
T = m + \mu \sigma, \mu = \phi_1 \left( (1 + \sin \theta)^{-\frac{1}{3}} - 0.5 \right)
\]

where \( \theta \) is the included angle between the sun’s azimuth \( (s_p) \) and \( k_{\max} \), and \( \phi_1 \) is a constant. The line elements that lie in the closer direction of \( s_p \) have a lower threshold level. If the value calculated at the centered pixel of the window is above the threshold, the pixel is retained as a line element \( (p) \).

**Step 3.** Judging whether \( p \) represents a ridge or valley feature was performed and \( p \) was eliminated when it is assumed to be distributed at a ridge.

**Step 4.** This routine linked to the derived line elements. The distance between \( p \) and connectable pixels was examined within the distance \( D \) from \( p \) by the following formula:

\[
D = \phi_2 \left( 1 + \sin \theta^* \right)^{-\frac{1}{3}} + \phi_3
\]

where \( \theta^* \) is included angle between \( s_p \) and \( k_{\min} \), then \( \phi_2 \) and \( \phi_3 \) are constants. The value \( D \) is a dynamic threshold where two pixels lying parallel to \( s_p \) and having a larger distance which could be linked.

**Step 5.** A centerline for the line elements, which have similar directions and intersect each other is obtained from the \((x, y)\) coordinates of the line elements using Principal Component Analysis.

### 4.2. Interpretation

After linear features were obtained, the Rosette diagram was used to determine the major direction of linear features in the study area, either for Ascending or Descending images. Interpretation of linear features was then validated by using the field data (fault system at study area) in order to know the relationship between the linear features extraction and the actual field conditions.

### 5. Result and discussion

Segment Tracing Algorithm (STA) was used to extract the linear feature structures which interpreted as fault or fracture based on ALOS PALSAR data with Ascending and Descending modes (see Figures 4 and 5). In the Rosette diagram, ratios of the counts of individual linear feature to the total amount of all linear features for the Ascending and Descending image along each direction was calculated. In the Ascending image, WNW–ESE direction is the most dominant direction than the others. In the Descending image, linear feature direction more varied in all directions compared with linear features of Ascending image.

The number of extracted linear features in Ascending image was larger than in Descending image. The number of linear features in the Ascending and Descending images is 10,167 and 9842 respectively (see Table 1). In this case, the range direction affects the appearance of linear features in the image, i.e. toward East (Ascending) and West (Descending) directions (see Figure 2).

Composite Rosette diagram was obtained by a combination of linear features in Ascending and Descending image, where counts of individual linear features to total amount of all linear features for Ascending and Descending image along each direction were also calculated. Extracted linear features from ALOS PALSAR (Ascending and Descending) image showed the three major directions, i.e. N305°E, N335°E and N15°E. WNW–ESE is the most dominant direction than the others, where it was counter-clockwise according to the increasing order of fracture abundance (see Figure 7a).

In this study, we use the field data which formed permeable fault system in Wayang Windu showed 27 faults. These structures influenced the geothermal fluid path to the surface [10]. The overlay of linear features and fault system was conducted to know the position of faults and linear features in the image.
Subset area was arranged to determine the relationship between extracted linear features of imagery with the field data (fault system). The boundary of subset area was arranged based on the maximum and minimum coordinates of the faults (see Figure 6).

**Figure 4.** Extracted linear features and the directions derived from Ascending image.
At subset area, the number of linear features in the Ascending and Descending images is 1706 and 1602, respectively. The major direction of linear features is N285°–305°E, N335°E and N25°E. In this case, WNW–ESE direction is dominant, while NNW–SSE and NNE–SSW directions are subordinate (see Figure 7b). The major direction of fault system at Wayang Windu field is N295°E, N330°E, and N35°E (see Figure 7c).
Figure 6. Overlaying between extracted linear features and fault system at Wayang Windu field [10].

Table 1. Summary of extracted linear features at Wayang Windu field

<table>
<thead>
<tr>
<th>Image</th>
<th>Orbit mode</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full image</td>
<td>Ascending</td>
<td>10,167</td>
</tr>
<tr>
<td></td>
<td>Descending</td>
<td>9842</td>
</tr>
<tr>
<td>Subset area</td>
<td>Ascending</td>
<td>1706</td>
</tr>
<tr>
<td></td>
<td>Descending</td>
<td>1602</td>
</tr>
</tbody>
</table>
Figure 7. (a) The direction of linear features in Ascending and Descending images (full image), (b) The direction of linear features in Ascending and Descending images (subset area), (c) The direction of faults in Wayang Windu, (d) Comparing the major direction between fault system and extracted linear features in subset area.

Based on the general direction of fault system and extracted linear features in subset area, the different direction between WNW–ESE and NNE–SSW is about 10°, and the NNW–SSE is about 5° (see Figure 7d). The WNW–ESE direction is dominant, while NNW–SSE and NNE–SSW directions are subordinate. Those directions showed appropriateness between extracted linear features and the field data. Thus, extracted linear features in these directions are more representative for the fault system in Wayang Windu. In general, it can be said that the major direction of extracted linear features and fault system were similar.

Extracted linear features using Segment Tracing Algorithm (STA) for ALOS PALSAR (Ascending and Descending) data can help to explain phenomena in the field. In other words, these extracted linear features could support to identify the fractured zones in the geothermal field.

In order to determine the areas that have the geothermal potency, we need to know the geological structures more intensively. In the geothermal system, the fluid will flow upward through permeable zones which are generally derived from the geological structure, so that the higher density of structure, the greater level of permeability. For this purpose, Linear Feature Density (LFD) could be used as the further work. In order to obtain better results, LFD could be modeled spatially using geostatistical approach by taking into account the spatial aspects of extracted linear features.

6. Conclusion

Extracted linear features derived from Ascending and Descending images produced 10,167 and 9842 data, respectively. The major direction of linear features from the imagery was WNW–ESE. Extracted linear features were validated by the fault system in the field. At subset area, the number of linear
features in Ascending and Descending were 1706 and 1602, respectively. In addition, the general direction of extracted linear features and fault system were similar as: WNW–ESE, NNW–SSE, and NNE–SSW. The directions showed appropriateness between extracted linear features and the field data. Thus, extracted linear features from ALOS PALSAR dual orbit (Ascending and Descending) using Segment Tracing Algorithm (STA) could support to identify fractured zones in Wayang Windu geothermal field.

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References