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GEOL 1460: Introduction to Remote Sensing

Lab Report #3- Due 11/29/17

Using TIR/SAR Data to Measure Age and Surface Roughness of Kilauea Volcano in Hawaii

**1. Executive Summary**

The aim of this work was to manipulate two images of the Kilauea Volcano in Hawaii by using TIR and SAR data. A decorrelation stretch was performed on the image to enhance color separation. To further manipulate the TIR image, convolutions and morphology techniques were used. The kernel was morphed into a high-pass filter to enhance feature edges and offers multiple views of the surface. The decorrelation stretch performed on the TIR image altered the colors in the image, indicating the lava flows as basaltic. Then, by loading wavelengths in both HH and HV configurations, it allowed for determination of surface roughness. The surface roughness values for each wavelength remained constant due to the different ranges between wavelengths. Vegetation was identified in the image by use of the HV bands, showing a sharp division where the lava flow separated from vegetation. It was determined through calculating surface roughness that the youngest lava flows were the smoothest.

**2. Introduction**

Thermal Infrared (TIR) and synthetic aperture radar (SAR) technology enable scientists to measure emissivity and surface roughness, along with other characteristics, of individual landmarks through the use of satellites. TIR measures heat emitted from a surface, while SAR radar measures surface roughness as a function of the travel time of the radar pulse. SAR is a type of active radar that artificially enlarges the antenna length to create a smaller azimuth resolution. For this work, the aim was to manipulate two images of the Kilauea Volcano in Hawaii by using TIR and SAR data to estimate the relative ages and surface roughness of lava flows from the volcano. Primary data was collected from the Kilauea Volcano using SAR data on August 4, 1990 and was collected using TIR data on October 30, 2006. Through the use of techniques such as decorrelation stretches and like polarizations, relative ages and other properties of the lava flows can be determined.

**3. Methods**

3.1 TIR Image

The TIR image of the Kilauea Volcano collected by an Advanced Spacebourne Thermal Emission and Reflection Radiometer (ASTER) satellite had a pixel size of 90m and wavelength region of 8.29 to 11.3. A decorrelation stretch was performed on the image on bands 14, 12, and 10 to enhance color separation of significant band-to-band highly correlated data. A principle component (PC) analysis was conducted to complete a decorrelation stretch. A PC analysis ensures that data is highly correlated in order to create an eigenvector. This eigenvector shows the digital number (DN) values that are varied in a systematic way from band to band, where high number bands are thrown away, allowing the closer DN values to be compared without noise. In a PC analysis, band 1 is the most correlated and therefore topography and temperature can be observed. The histogram was conducted using emissivity normalization so that only the highest recorded level emissivity value would be shown, as indicated in Figure 2. Then, temperature values were restricted locating the hottest pixel of the TIR image. The reference channel approach helps explain this process, where a maximum emissivity is assumed and assigned to one wavelength. Then, to separate emissivity and temperature, the Planck Equation is used:

E= hv

The radiant temperature at specific wavelength is derived and the new temperature is used to derive the remaining emissivity values. To further manipulate the TIR image, convolutions and morphology techniques were used. The kernel was morphed into a high-pass filter to enhance feature edges. This technique removed all low frequency features and accentuated linear features in the image by averaging the DN values. After, the kernel was once again converted into a high-pass directional filter to highlight linear features. This modified the observing angle used to view topography in the image, offering multiple views of the surface.

 3.2 AIRSAR Image

The second image was a radar image, with varying levels of radar return, retrieved using SAR. C, L, and P radar bands were used to load the image, at 5.3, 23.5, and 68 cm wavelengths respectively. Loading these wavelengths in both HH and HV configurations allowed for enhancement of the image. The HH polarization sends and receives data horizontally, and is useful because most objects have a vertical profile, allowing energy to scatter back easily to a horizontal receiver. The HV configuration was also used because it highlights vegetation on a surface. Additionally, by inferring the radar illumination direction from a large shadow in the image and using statistics about the radar satellite’s range and azimuth values, it was possible to calculate the height of the object creating the shadow and therefore estimate the height of the volcano at that specific pixel. Geometry was used to calculate unknown values, as well as measuring the length of the shadow in pixels. Then, the Raleigh Criteria equations to were used to relate surface roughness to amount of backscatter:

smooth if: h < λ/ 221.25 tan θ

rough if: h > λ / 221.25 tan θ

where θ = 45º

These equations calculate the surface roughness for the HH polarization in each wavelength band. A strong radar backscatter value indicates that there is a rough surface on the ground, because uneven topography causes light to scatter multiple directions due to the radar hitting surfaces at differing angles. A low value of backscatter indicates smooth surface, because the light hits the surface and reflects back evenly. The bands in the image were placed into like polarizations so a color composite image could be created, making it easier to view the image realistically. After creating the composite image, the relative ages of the lava flows could be determined.

**4. Results**

4.1 TIR Image

The decorrelation stretch performed on the TIR image altered the image from black and white to shades of magenta, blue/purple, and cyan, indicating that the lava flows from Kilauea were basaltic, having higher levels of olivine and labradorite rather than quartz. In the thermal wavelength region, pink represents Labradorite and blue indicates that the substance is silica poor—typical of Hawaiian flow, as depicted in Figure 1. The original decorrelation stretch image had a region of bright yellow below the volcano, which is most likely an ocean, explained by the dark lava flow that flows into the yellow region. The temperature of pixel (274,38) was 288.304 K, while the hottest pixel in the TIR image was determined to be 370.76 K. This pixel is most likely the site of a spot where lava is still actively present. A decorrelation stretch proved to be the most useful because the image could be viewed as realistic colors once the previously stretched data was rotated back to the original axis. Additionally, switching to a high-pass filter enhanced the topography of the volcano, allowing specific lava flows to darken. The directional high-pass filter’s optimal angle for viewing was determined to be 135º, as displayed in Figure 3.

 4.2 AIRSAR Image

The pulse duration was found to be 5.59 x 10^-5 for the sensor by using the speed of light and the ground resolution. The surface roughness values for each wavelength remained constant due to the different ranges between wavelengths. For example, Phh had a large wavelength region and allowed for much more space between estimated values; however, Chh was restricted to a much smaller numerical range. It was determined through like polarizations that the youngest lava flows in the image recorded the smoothest surface roughness. The lava flow that appeared the smoothest was in the northwest section of the image, dated at 43 years old and 58 years old, where as the image dated 1919 was much rougher. The backscatter return is minimal because of a lack of vegetation growing on top of the flows, creating uneven topography and rough surface. Additionally, as the wavelength of the image was increased, there was a noticeable change in the amount of variation in the Kilauea image. There was a greater contrast apparent in the P wavelength because a larger range of values allows for more enhancement of the features. Vegetation was identified in the image by use of the HV bands and in the areas with bright radar return, northeast of the crater. There was a sharp division where the lava killed off vegetation. This sharp division on the surface is attributed to the topography of the image, making the are darker and smoother than where vegetation was growing. The lava rushed down the side of the volcano after erupting, but the regions northeast of the lava flow were uninterrupted and vegetation was still able to grow. The surface of Halemaumau Crater showed up extremely dark and much duller in the image as it is site of the most recent eruption, making the surface smooth.

**5. Conclusion**

Using TIR and SAR technology allows for enhancement and modification of images to interpret composition and topography. The Hawaiian flows were determined to be composed mostly of labradorite and olivine. By modifying two images of the Kilauea Volcano in Hawaii using decorrelation stretch and radar enhancements through like polarizations, the relative age of past lava flows was determined. The lava flow that appeared the smoothest was in the northwest section of the image, dated at years 1974 and 1959, whereas the 1919 image appeared much rougher and older. Measuring backscatter through active radar technology proved to be of use for an accurate estimate of ground surface roughness. Topography shows the abrupt change between lava flow and vegetation. By using techniques such as these, remote sensing can be used to accurately and safely monitor volcanic activity.



Figure 1: A subset image of the Kilauea crater showing the mostly magenta and purple-blue lava flows, indicating the basaltic composition.



Figure 2: Spectral Profile plotting Emissivity vs. Wavelength for pixel (274, 38) in the TIR image of Kilauea Volcano. The histogram values of the image were manipulated by using emissivity normalization. This pixel has a temperature of 288.304 K.



Figure 3: Depiction of the Kilauea Volcano lava flows at a 135º using the high-pass directional filter. This angle more sharply defines the edges in the image and shows the darkest lava flows.