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Automatic detection of ridges in lunar images using phase symmetry and phase congruency

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ABSTRACT

Lunar surface exploration is increasing rapidly. These exploring satellites provide a large number of high resolution images containing topographical information. The topographical information in lunar surface are craters, ridges, mountains and grabens. Extracting this topographical information manually is time-consuming. Hence, an automatic feature extraction is favored. This paper presents a novel approach using image processing techniques to automatically detect ridges in lunar images. The approaches adopted for this development includes phase symmetry, phase congruency and morphological operations to automatically detect significant ridges. The phase symmetry extracts symmetry features with discontinuities, phase congruency extracts features lying in low contrast regions and morphological operations such as thinning and pruning are used to obtain significant ridges. The proposed novel approach experiments on a test set of different regions. These different region images are obtained from different sensors (LROC, Selene and Clementine) having different spatial resolution and illumination variation. The results obtained are compared with the plan curvature method; and they are evaluated based on true and false detection of ridge pixels. Irrespective of illumination variation and spatial resolution, the proposed approach provides better results than the plan curvature method and its detection rate is approximately 92%.

1. Introduction

The eagerness for knowledge about our neighboring satellite moon has led to the launch of several lunar missions. Since the 1960s, our neighboring satellite moon has been an important topic of research to understand the origin and the lunar crustal evolutionary processes. Recently, Japan's Selene, India's Chandraayan-1 and NASA's Lunar Reconnaissance Orbiter Camera (LROC) have been launched to explore the moon.

There are many topographic features on the lunar surface. Among them ridges are more significant ones and play a key role in the investigation of crustal evolution of the moon and planets. Ridges are formed by structural modifications that have occurred on the lunar surface. Geologically, a ridge is a feature consisting of a chain of mountains or hills that form a continuous elevated crest for some distance. In an image it is defined as points having an extremum in the direction of the largest surface curvature. To identify a significant ridge feature we need a dimensionless quantity such as, an illumination and contrast invariant measure. Lunar images provide a dynamic and unstructured environment; objects in lunar image can appear with arbitrary brightness and contrast. Hence, these invariant quantities are important in computer vision (Kovesi, 1996) for ridge detection. Phase symmetry is a dimensionless quantity, that detects the symmetry feature that is independent on illumination and contrast of the image. Phase symmetry reduces the regions into symmetry regions with discontinuities in a symmetry image. Phase congruency is a method of edge detection, particularly robust against variation in illumination and contrast. It has been noted that edge like features have many frequency components in the same phase and also reflects the behavior of an image in the frequency domain (Kovesi, 1991, 1999).

The aim of this paper is to automate the process of ridge detection in lunar images using phase symmetry and phase congruency. Ridge is a symmetry feature in an image, invariant to illumination and contrast. The lunar image is subjected to a phase symmetry method that detects ridges. The phase symmetry image obtained contains discontinuities in symmetry features. Phase congruency is used to detect features in the discontinuities of the symmetry image and the threshold of the resulted image is obtained using the Otsu method (Otsu, 1979). The segmented image has more features than required; these insignificant

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ridges are removed using morphological operations to result in a ridge map.

2. Background

Symmetry is an important mechanism used to identify the structure of objects. A limited number of approaches have been attempted in symmetry detection. Atallah (1985) describes an algorithm represented objects in terms of points, line segments and circles. Phase symmetry quantifies symmetry around a pixel irrespective of the directions in which symmetry is found. The measure of symmetry is based on the analysis of local frequency information. The points of symmetry and asymmetry give rise to easily recognized patterns of local phase. This phase information can be used to construct an illumination and contrast invariant measure of symmetry of objects. Myerscough and Nixon (2004) were the first to address the localization issue of the original phase congruency method proposed by Kovesi (2000). The authors indicated that the phase congruency map exhibits an odd behavior resulting in additional feature response that surrounds the true image feature. They concluded that more study was required to obtain a robust feature detector based on their proposed method.

Tian and Yang (2009) have developed a novel method for computing the localized phase congruency in X-ray imagery. According to their results, the new method that is, rotation invariant computed in a localized manner, is faster than the original phase congruency and exhibits sub-pixel accuracy. The method has been tested successfully in the X-ray imagery, but its applicability is still to be proven for general-purpose and satellite images. Morphological techniques such as medial axis transform, thinning, and 'grass fire' algorithms can be applied only to binary objects. A survey of these approaches is provided by Xia (1989). A difficulty with morphological approaches is that they are very sensitive to minor variations in the outlines of objects; a notch in an object contour will propagate several symmetry axes, complicating the representation of an object (Field, 1987). Phase congruency and phase symmetry analysis, compute the frequency components via a transform such as 2-D Gabor wavelets of pixel intensities, and then examine the relative phases of the frequency components locally (Kovesi, 1997, 1999). Phase congruency assigns numbers that are proportional to the amount of local in-phase agreement in the frequency components (Kovesi, 1996). Phase symmetry assigns higher numbers (more symmetry) where frequency components are closer to their maximum or minimum cycle points and lower numbers (less symmetry) where frequency components are closer to the inflection points in their cycles (Kovesi, 1997). It is a specialized search for symmetries and partial symmetries in structure, whereas phase congruency is less specific.

3. Dataset used

Datasets from NASA's lunar exploration satellite Lunar Reconnaissance Orbiter (LRO), Japan's Selene (Kaguya) and NASA's Clementine were used in this research. The LROC's Wide-Angle-Camera component (WAC) provides images at a spatial resolution of 75 m/pixel in five visible bands passes over a 100 km swath at an orbital altitude of 50 km. The Selene (Kaguya)'s Terrain Camera (TC) provides an image at a spatial resolution of 10 m. The Field Of View (FOV) is around 22.4° in full mode, 19.3° in nominal mode and 9.65 in half mode. It has 2 (stereo) bands taken in the wavelength of 0.43–0.85 μm with a bandwidth 420 nm. The NASA's Clementine's Ultraviolet/Visible Camera (UVVIS) provides images at a spatial resolution of 125 m. The details of image characteristics of dataset used are discussed in Table 1.

4. Proposed methodology

Lunar images (LROC, Clementine and Selene) differ in brightness rather than color distributions. Hence, the proposed methodology involves pre-processing. The flow diagram of the proposed methodology is shown in Fig. 1.

The automated procedure for ridge detection consists of pre-processing, calculating phase symmetry, phase congruency (Kovesi, 2003), segmentation, post-processing and finally the ridge detection. In preprocessing, the lunar image is converted to grayscale image and the median filter is used to get rid of noise. The phase symmetry of the filtered image is computed by providing smallest filter wavelength and the number of filter scales as parameters, this contributes to the detection of lateral continuous line – like regions of discontinuity that are symmetric in nature. In order to reduce region of discontinuities, phase congruency is applied and it ensures that features lying in low contrast are detected. The global thresholding is obtained using the Otsu method (Otsu, 1979) and it is applied to segment the image. The segmented image is reduced into skeletal structures using thinning operation and the insignificant ridge features are removed using morphological operation. The unwanted branches in ridge are removed using pruning technique to determine the significant ridge.

4.1. Phase symmetry

Any discrete signal can be expressed by the sine and cosine functions with specific amplitudes, giving rise to a set of scale waves in the time domain that synthesize the original signal. Kovesi (2000) showed that symmetries and asymmetries give rise to special phase patterns in the image intensity values. The Fourier series of points of symmetry is either at minima or maxima of their cycle.

At a point of symmetry, the absolute value of the even-symmetric filter is large and the absolute value of the odd-symmetric filter is low. The natural way to quantify symmetry is to subtract the absolute value of the even-symmetric filter output from the odd-symmetric filter output. This corresponds to subtracting an absolute value of the cosine of the phase angle from the sine of the phase angle as indicated in Eq. (1) (Kovesi, 1997). To combine information from filter responses over multiple scales, a weighted average is formed. It is the difference between the absolute values of an even and odd filter responses at each scale which is weighted by the magnitude of the filter response vector at each scale A_n in Eq. (2). The sum of these weighted differences is

Table 1
Characteristics of an image dataset used for ridge detection.

Satellite	Sensors	Spatial resolution (m)	Wavelength (μm)
LRO	LROC-WAC	75	0.41, 0.56, 0.60, 0.64 and 0.68
Selene (Kaguya)	Terrain Camera (TC)	10	0.43–0.85
Clementine	Ultraviolet/visible camera (UVVIS)	125–250	0.41, 0. 75, 0.90, 0. 95 and 1.0