


The Role of Significant Digits of Fractal Dimension for the Measurement of Texture in SAR Images

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ABSTRACT

The present work deals with fractal-based texture measurement of synthetic aperture radar (SAR) images. Various land classes have been identified by classifying SAR images, and the fractal dimension is estimated for differentiating the classes. Three types of SAR images, viz., synthetic images, simulated SAR images, and satellite SAR images, have been used in the study. An issue with fractal dimension-based measurement is how many digits after decimal point should be considered for estimating fractal dimension? Since fractal dimension is calculated as a ratio, the major challenge is the decidability of significant digits for land classes. The issue has been overcome by discussing the feasibility of fractal dimension for the land classes defined by USGS and the calculated ratio for 200×200 values. As an achievement of the work, it is concluded that two digits of the decimal are sufficient to represent the fractal dimension of land classes.

KEYWORDS

Fractal Dimension, Fractal Geometry, Image Classification, Image Texture, SAR Image, Textural Analysis

1. INTRODUCTION

The image texture is defined as the variation of image tone at scales smaller than the scales of interest. The scale has a pivotal role while discussing the texture of any object since the texture solely depends on the scale of the study. Thus, it is mandatory to study the object possessing texture in such a way that the variation of tone can be observed. It is possible by studying the objects not only in a pixel-to-pixel order but also in the pixel neighborhoods. As a matter of fact, there is no meaning of texture for the single pixel since the variation of tone necessarily requires more than one pixel. Various researchers (Myint, 2003; Pentland, 1984; Petrou & Sevilla, 2006) have proposed different methods to identify and measure the texture in satellite images, e.g., grayscale level co-occurrence matrix (GLCM), autocorrelation index, Gibb's distribution, fractals, wavelets, etc. However, fractal-based features are more popular due to the fact that fractals represent natural objects in a more accurate way (Korayem et al., 2019; Riccio & Ruello, 2015; Zhou et al., 2019). The notion behind using fractals for textural analysis is two folded— first, fractals model the natural objects as well as natural images

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in the best way, and second, the textural features can better be studied by non-Euclidean geometry and hence by fractals (Pentland, 1984).

There are numerous methods available to estimate the fractal dimension of digital images, e.g., box-counting method (Côté et al., 2018; Konatar et al., 2020; Korayem et al., 2019), Triangular Prism Surface Area Method (TPSAM) (Clarke, 1986), variogram method, Differential Box-Counting (DBC), isarithm method, Fourier spectrum method (Feng et al., 2017; Sun et al., 2006), and Two Dimensional Variation Method (2DVM) (Berizzi et al., 2006). When digital images are concerned, the value of the fractal dimension lies between 2.0 and 3.0; however, the number of significant digits representing the fractal dimension has not been exercised much.

Usually, the fractal dimension is estimated up to four digits of the decimal in most of the literature. Mandelbrot had estimated the value of various fractal objects to four digits in his classic work (Mandelbrot, 1982), e.g., $D=0.6309$ for Cantor's dust, $D=1.2618$ for Koch curve, $D=1.5000$ for coastline dimension of quadric Koch curve, $D=2.9656$ for triadic fractal foam, etc. However, he had also mentioned the fractal dimension of a surface of zero-volume and infinite area as 2.58497, which contained 5 digits after the decimal point. Clarke (1986) used six digits to represent the value of fractal dimension for the sample images. Florindo et al. (2012) mentioned that there are two categories of fractal dimension estimation approaches, viz., the Hausdorff-Besicovitch dimension and the Bouligand-Minkowski dimension from which the later approach estimates the dimension of two objects differing by fourth significant digit. Bérubé and Jébrak (1999) reported that most of the available methods, including box-counting method, estimate the value of the fractal dimension at a precision of ± 0.1 . Sun & Southworth (2013) have estimated four digits of decimal for fractal dimension in the data presented; however, in the discussions, they used only two digits of fractal dimension. Liu et al. (2014) proposed the modified differential box-counting method, where they used two digits of decimal to represent the fractal dimension. Further, Nayak & Mishra (2016) have proposed an improved approach to estimate the fractal dimension of color images and showed the results with four and six digits of decimal. Keshavarzi & Ball (2017) have used four digits of fractal dimension in their experiments.

The domain of this problem shrinks to a smaller set when the fractal dimension of satellite images for land classes is considered. It has been established that land classes can be differentiated on the basis of their fractal dimension (De Jong & Burrough, 1995), and similar land classes should possess the same or nearly equal value of the fractal dimension. But it is not clear how many digits are needed to differentiate two land classes. This question has been raised in the present paper and attempted to answer based on experimental values. As far as the benefit of estimating the fractal dimension for a significant number of digits is concerned, the first benefit is to save the number of bits to store the values. Another benefit is to save the computation time involving the floating-point values representing the fractal dimension.

The paper is organized in the following manner. In section 2, the material and methods is discussed which describes the textural measures for SAR images, the importance of fractal geometry and fractal dimension estimation methods in brief. The data set used in the present study and the methodology is also discussed in this section. The section 3 includes the results of various phases discussed in the methodology. The discussion involving various issues faced in the present study is given in section 4 and the conclusions are described in section 5.

2. MATERIAL AND METHODS

2.1 Textural Measures Used for SAR Image Analysis

The variation of tone, i.e., texture in digital images, may arise due to two phenomena, viz., the variation of the albedo and variation of shape of imaging object (Petrou & Sevilla, 2006). The texture caused by albedo is due to the variation in the reflection of an incident wave at various parts of the imaged

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