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Landform classification using a sub-pixel spatial attraction model to increase spatial resolution of digital elevation model (DEM)

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ABSTRACT

The purpose of the present study is preparing a landform classification by using digital elevation model (DEM) which has a high spatial resolution. To reach the mentioned aim, a sub-pixel spatial attraction model was used as a novel method for preparing DEM with a high spatial resolution in the north of Darab, Fars province, Iran. The sub-pixel attraction models convert the pixel into sub-pixels based on the neighboring pixels fraction values, which can only be attracted by a central pixel. Based on this approach, a mere maximum of eight neighboring pixels can be selected for calculating of the attraction value. In the mentioned model, other pixels are supposed to be far from the central pixel to receive any attraction. In the present study by using a sub-pixel attraction model, the spatial resolution of a DEM was increased. The design of the algorithm is accomplished by using a DEM with a spatial resolution of 30 m (the Advanced Space borne Thermal Emission and Reflection Radiometer; (ASTER)) and a 90 m (the Shuttle Radar Topography Mission; (SRTM)). In the attraction model, scale factors of (S = 2, S = 3, and S = 4) with two neighboring methods of touching (T = 1) and quadrant (T = 2) are applied to the DEMs by using MATLAB software. The algorithm is evaluated by taking the best advantages of 487 sample points, which are measured by surveyors. The spatial attraction model with scale factor of (S = 2) gives better results compared to those scale factors which are greater than 2. Besides, the touching neighborhood method is turned to be more accurate than the quadrant method. In fact, dividing each pixel into more than two sub-pixels decreases the accuracy of the resulted DEM. On the other hand, in these cases DEM, is itself in charge of increasing the value of root-mean-square error (RMSE) and shows that attraction models could not be used for S which is greater than 2. Thus considering results, the proposed model is highly capable of increasing the spatial resolution of DEM (the new DEM with high spatial resolution). In the next step, in order to prepare the geomorphology map using topographic position index (TPI), the DEM with scale factor of (S = 2) was used, touching neighborhood serves as input. The landform classes were extracted by using TPI with the new DEM; consequently, the attraction model extraction showed details of landforms that make them more separable than the landform map prepared by utilizing the 90 m spatial resolution DEM. Moreover, the results showed that the landform of the 90 m spatial resolution DEM (S = 2, T = 2) and ASTER DEM 30 m were similar to each other, these results indicate a high accuracy of the proposed attraction model.

1. Introduction

The topographic maps, aerial stereo-photos, satellite imagery and digital elevation models (DEMs) were used as inputs for landform classification in the geomorphology science. In some recent researchers Concerning the landform classification, DEMs have been used in the following researches: (Atkinson, 2005; Burrough et al., 2000; MacMillan et al., 2000; Migoń et al., 2013; Mokarram and Danish, 2015; Mokarram et al., 2015; Saadat et al., 2008; Schmidt and Hewitt, 2004; Verhagen and Drăguţ, 2012) .

There are different methods for extracting landforms including the classification of terrain parameters (Dikau, 1989; Dikau et al., 1995), filter techniques (Sulebak et al., 1997), cluster analysis (Dikau, 1989; Dikau et al., 1995; Etzelmüller, 2000) multivariate

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statistics (Adediran et al., 2004); mathematical morphology (Guru and Dinesh, 2004) and multi-scale analysis of the digital elevation models (Mokarram et al., 2015). In gemorphologic researches, DEMs play a great role as the geographic information data base used for extracting basic components and terrain parameters.

One of the important properties of DEM is the spatial resolution which represents the accuracy of DEM (Takagi, 1998). Visually, the spatial resolution can change features derived from DEMs and thus can influence on models associated with them (Gallant and Hutchinson, 1997; Haile and Rientjes, 2005; Omer et al., 2003). There are many studies that uses DEMs with different resolutions (Hutchinson and Dowling, 1991; Jenson, 1991; Wolock and McCabe, 2000). Noticeably, there are some methods for increasing the spatial resolution of DEM. For example, an integration of the 2-D hydraulic model and the high-resolution LiDAR-derived DEM has been used for floodplain flow modeling (Shen et al., 2015). One model of increasing the spatial resolution is the attraction model that is based on the sub-pixel.

The sub-pixel algorithm divides a pixel into sub-pixels by considering the spatial dependence (Atkinson, 1997). This model treats a pixel as a combination of surrounding pixels which are affecting a central one based on their distance. The first linear optimization technique for sub-pixel mapping algorithm was introduced by (Verhoeye, 2002) and was inspired by Atkinson (1997).

The attraction model algorithm spatially depends on the neighborhoods of the central pixel which is attracted by surrounding sub-pixels. Another possibility is the hypothesis of sub-pixel interaction as introduced by Koen Mertens (2003) and Atkinson (2005). In order to reach at a pixel state with the maximum number of sub-pixels with identical neighboring classes, there are several methods such as the genetic algorithms and pixel swapping in which the initial pixel fraction values are considered as a constraint (Atkinson, 2005; Koen Mertens, 2003).

The present paper focuses on the landform classification by using the attraction model analysis of DEMs. In order to classify landforms, it is important to determine DEM with high resolution as the input data. The size and the space of landforms show clustering around the spatial resolution characteristic (Evans, 2012). The attraction model has always been used to increase the spatial resolution of satellite images (Atkinson, 1997; S et al., 2008; Verhoeye, 2002; Xu et al., 2013); however, There is not any study about this model which was performed regarding DEMs. In this study, authors applied a selected sub-pixel method to increase the spatial resolution and the accuracy of DEMs served as an input for landform classification in the areas of north of Darab, Fars province, Iran. The landform classification is performed by using a topographic position index (TPI). The generated landform maps via the attraction model DEM and the primary DEM (Shuttle Radar Topography Mission (SRTM)) were compared as well. Generally, the present used methodology is summarized as followings:

1. At first, the attraction model is run on SRTM DEM with spatial resolution of 90 m.
2. Then in the attraction model, the quadrant, touching methods and scale factors of 2, 3 and 4 are tested for each neighboring method.
3. After that, an RMSE index is calculated for each output of the attraction model and consequently the DEM with the lowest RMSE is selected.
4. Finally, the TPI model is applied to the original SRTM DEM. Besides, the extracted DEM from the attraction model is compared to the obtained result.

The Fig. 1 shows the general steps which has down in this study.

2. Material and methods

2.1. SRTM and ASTER GDEM

The joint Japanese–US Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) version 2 was released in October 2011. Version 2 was released 3 years after version 1 by the Ministry of Economy, Trade and Industry (METI) of Japan cooperating with the United States National Aeronautics and Space Administration (NASA) (Rexer and Hirt, 2014). ASTER GDEM is the most complete mapping of the earth ever made, covering 99% of its surface. The elevation difference between SRTM and ASTER products was evaluated by using the root mean square error (RMSE) which was found to be less than 50 m (Nikolakopoulos, 2006).

Shuttle Radar Topography Mission (SRTM) is an international mission which is aimed to produce digital elevation models. SRTM consisted of a specially modified radar system that flew on board the Space Shuttle Endeavour during the 11-day STS-99 mission in February 2000. In order to get the acquire topographic data, the SRTM payload was outfitted with two radar antennae. The raw data are restricted for the government use. For the rest of the world, only three arcsecond (90 m) data are available (Nikolakopoulos, 2006).

However, some reviewers have commented that the true resolution is considerably lower than that and it is not as good as the SRTM data (Rexer and Hirt, 2014):

– ASTER GDEM data were downloaded from (http://gdem.ersdac.jspacesystems.or.jp) for free. Authors of the present study call it as a DEM 30 m.
– SRTM DEM data were downloaded from (http://srtm.usgs.gov) for free. Authors name it a DEM 90 m.
– Ground station points gathered from surveys were done by National Cartographic Center of Iran (NCC).

Preprocessing of DEMs were achieved by using ARCMAP version 10.3. An attraction model was achieved by using Matlab version 2013 R2.

2.2. Attraction sub-pixel model

A sub-pixel mapping was first introduced by Atkinson (1997). This method is used to extract a spatial distribution of various classes in a mixed pixel (Xu et al., 2014). The sub pixel method keeps a spatial dependence into account among sub-pixels in a pixel surrounded by other pixels (Atkinson, 1997). Attraction models are vastly used in geo-statistic studies (Mertens, 2008). These models can divide each mixed pixel into a set of sub pixel fractions and can locate different classes in a pixel.

In the present study two quadrant and touching neighboring methods are used. In the quadrant neighborhood, a neighbor pixel is the only pixel in the same quadrant whereas in the touching neighborhood, a neighbor pixel is defined as a pixel which physically touches a sub pixel. A sample of two neighborhood methods with different scale factors are shown in Fig. 2 (Mertens and Chawla, 2014) in which all the pixels which attract a sub-pixel are explained with the same color as the sub-pixel.

In attraction models, a scale factor (S) shows the number of sub-pixels in each central pixel. In the present paper, two neighborhood methods with S = 2, 3, 4 are examined.

It must be noticed that both neighboring methods are the same when S = 2. The aforementioned neighborhoods (Fig. 2) can now be formulated as (1)–(3) (Mertens and Chawla, 2014):