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Three-dimensional information extraction from GaoFen-1 satellite images for landslide monitoring

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ABSTRACT

To more efficiently use GaoFen-1 (GF-1) satellite images for landslide emergency monitoring, a Digital Surface Model (DSM) can be generated from GF-1 across-track stereo image pairs to build a terrain dataset. This study proposes a landslide 3D information extraction method based on the terrain changes of slope objects. The slope objects are mergences of segmented image objects which have similar aspects; and the terrain changes are calculated from the post-disaster Digital Elevation Model (DEM) from GF-1 and the pre-disaster DEM from GDEM V2. A high mountain landslide that occurred in Wenchuan County, Sichuan Province is used to conduct a 3D information extraction test. The extracted total area of the landslide is 22.58 ha; the displaced earth volume is 652,100 m^3; and the average sliding direction is 263.83°. The accuracies of them are 0.89, 0.87 and 0.95, respectively. Thus, the proposed method expands the application of GF-1 satellite images to the field of landslide emergency monitoring.

1. Introduction

Landslides occur frequently in China and can result in large losses; therefore, these geological disasters are sources of increasing concern (Huang, 2009). For example, a series of landslides were caused by the Wenchuan earthquake in Sichuan Province in 2008 (Qi et al., 2010; Huang et al., 2012; Xu et al., 2013; Sun et al., 2015) and by the Yushu earthquake in Qinghai Province in 2010. When China's high-precision and high-resolution satellite system for environmental and disaster monitoring is complete, landslide emergency responses will be supported by new data sources, such as those from the GaoFen-1 (GF-1) satellite and the ZiYuan-3 (ZY-3) surveying satellite. The GF-1 satellite, which has a capability of side-view imaging, can acquire two overlapping multi-spectral and panchromatic images rapidly, which is helpful for generating a Digital Surface Model (DSM) from across-track stereo image pairs. Then, the area, volume and other landslide-related information can be extracted efficiently and accurately shortly after a landslide occurs.

Considerable research has been conducted on applying across-track stereo satellite data. Many high-resolution remote sensing satellites, such as the SPOT, QuickBird, GeoEye-1 and WorldView-2 satellites, have side-view capabilities and adaptive base-height ratios, making it possible to obtain across-track stereo image pairs to generate DSMs (Kieffer et al., 2006; Toutin, 2006; Tong et al., 2010; Aguilar et al., 2014; Zhang et al., 2014). Stereo image localization algorithms based on the Rational Function Model (RFM) are often used to generate DSMs (Tong et al., 2010). The elevation accuracy of the generated DSM is influenced by the sensors, the number of control points, the radiation characteristics and the imaging time interval (Aguilar et al., 2014), and usually ranges from 2 to 5 m, although the DSMs generated from QuickBird can achieve a 1 m elevation accuracy (Tong et al., 2010). However, the time interval between the two images in an across-track stereo image pair often span more than a month, which limits the accuracy of the results.

Methods designed to extract 3D terrain-change information have been applied to landslide monitoring. In addition to satellite stereo image pairs (Cheng et al., 2004; Sarkar and Kanungo, 2004; Borghuis et al., 2007), aerial images (Leprince et al., 2007; Weirich and Blesius, 2007), Light Detection And Ranging (LiDAR) data (Ardizzone et al., 2007; Corsini et al., 2009; W. Chen et al., 2014) and Interferometric Synthetic Aperture Radar (InSAR) data (Hilley et al., 2004; Lauknes et al., 2010; Lu et al., 2012; Zhang et al., 2012; Rocca et al., 2014; Feng et al., 2015) are also used to obtain elevation models to extract landslide 3D information (Xia et al., 2007; Perks, 2010; Razak et al., 2013; F. Chen et al., 2014; Jebur et al., 2014; Li et al., 2014). Terrain-change detection methods that update a Digital Elevation Model (DEM) simultaneously or perform a DEM subtraction of two phases are the most frequently used methods of 3D terrain-change detection (Xia et al., 2007; Perks, 2010). Automatic matching algorithms are also used to automatically detect landslides (Li et al., 2014), and advanced 3D processing is performed to measure the volume of the landslides (Jebur et al.,

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2014). However, both the theory and methods of extracting 3D terrain-change information are still immature (Xia et al., 2007); therefore, further studies of 3D terrain-change information extraction method for landslides have theoretical significance.

Recently, object-oriented image analysis methods have been applied to identify landslide boundaries by using many diagnostic features such as spectral, textural and morphological characteristics (Lahousse et al., 2011; Lu et al., 2011; Martha et al., 2011; Behling et al., 2016). Object-oriented image analysis methods for landslide identification perform better than pixel-based methods (Blaschke, 2010; Stumpf and Kerle, 2011; Moosavi et al., 2014); however, the existing object-oriented methods do not elaborate on the topographic characteristics of landslides in detail and require a comprehensive application of all the landslide characteristics.

The results of this study will enrich the methods currently applied for remote sensing based landslide monitoring and provide a basis for emergency decision making with regard to the effects of landslides and conducting disaster relief work, thus demonstrating its extensive applicability and practical significance.

2. Study area

The study area is located in Wenchuan County, Sichuan Province. Since the 2008 Wenchuan earthquake, the geological structures of Wenchuan County have remained unstable, and landslides of various sizes often occur (Q. Chen et al., 2014). On July 22, 2013, a high mountain landslide affected a large area of Zuwan Village in Caopo Township, Wenchuan County, resulting in the deaths of 28 local farmers and burying approximately 6.7 ha of arable land. The center of this landslide is located in 103°26′53″E, 31°17′10″N. Fig. 1 shows a sketch map of the delineated study area for this landslide.

Table 1
Satellite parameters of GF-1.

Parameter		Value
Resolution	Panchromatic	2 m
	Multi-spectral	8 m
	Wide-field viewer (WFV)	16 m
Image width	Panchromatic/multi-spectral	60 km
	Wide-field viewer (WFV)	800 km
Revisit cycle		4 days

3. Materials and methods

3.1. GF-1 data

The GF-1 satellite has the advantages of high spatial resolution, a large imaging width and a short imaging time interval (You and Pei, 2015; Zhang et al., 2015); thus, it is especially suitable for landslide emergency monitoring. GF-1 acquires more data during emergency situations; therefore, DSM generation from GF-1 can be completed in a shorter time after a disaster occurs than can DSM generation from other satellites, meeting the needs of disaster emergency responses. The satellite parameters of the GF-1 are shown in Table 1.

Two phases of post-disaster images from the GF-1 satellite for the study area were acquired from the China Center for Resources Satellite Data and Application (http://www.cresda.com/CN/) as listed in Table 2. The time interval between the two images is short and the

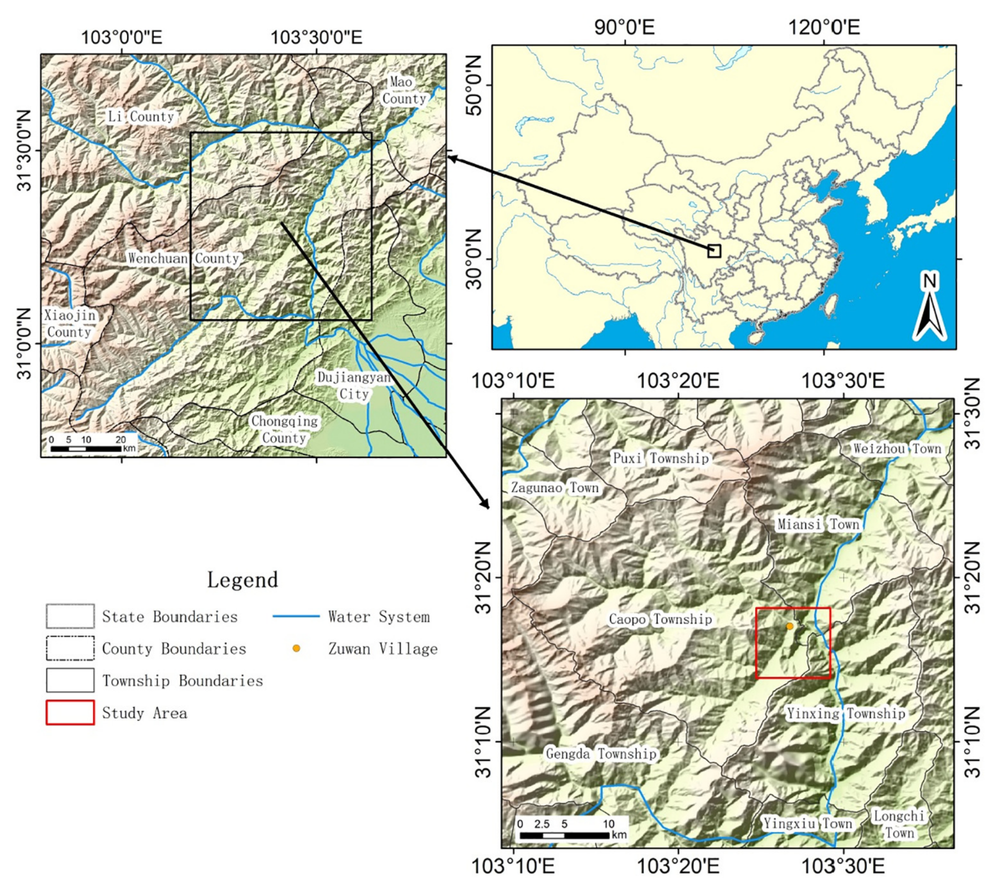

Fig. 1. Sketch map of the study area in Caopo Township, Wenchuan County.