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Comprehensive comparison of VHR 3D spatial data acquired from IKONOS and TerraSAR-X imagery

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Abstract

With the launch of very high resolution (VHR) optical and synthetic aperture radar (SAR) remote sensing satellites such as IKONOS and TerraSAR-X, a new era has begun in 3D spatial data acquirement. IKONOS provided the first VHR data is still being preferred for many remote sensing applications. TerraSAR-X is considered as a revolution in SAR imaging as a result of 1 m resolution imaging capability. The imaging principles of these satellites are quite different and include advantages and disadvantages that have considerable effects on the quality of acquired 3D spatial data.

In this research, we aim to compare qualities of high resolution digital elevation models (DEMs) generated from IKONOS and TSX imagery based on a reference model. Quality assessment was realized considering two main components as accuracy and visuality on different land classes. Results of comprehensive analyses indicate that the qualities of 3D data derived from IKONOS and TSX HS are almost identical and DEMs of both satellites can be used for various applications.

Keywords: IKONOS; TerraSAR-X; DEM; Quality assessment; Comparison

1. Introduction

The digital surface model (DSM) is a three dimensional (3D) digital cartographic representation of Earth surface with X, Y planimetric coordinates and altitude Z. It is the primary 3D product of space-borne remote sensing containing points located on the top of visible non-terrain objects such as buildings, forest, and vegetation. By eliminating these points, the digital elevation model (DEM) is obtained that represents only the bare topography. Although having similar concept, DEM differs from digital terrain model (DTM) that includes further information derived from linear features such as breaklines and mass points. DEMs are one of the most important data required for geospatial analysis due to the fact that they represent the 3D structure of the terrain. These models can be generated by conventional ground surveying, air-borne laser scanning (ALS), photogrammetry and space-borne optical and synthetic aperture radar (SAR) imagery. Among these methods, ground surveying, aerial photogrammetry and ALS are time consuming, expensive and they cover relatively narrow areas with respect to space-borne remote sensing. Therefore, optical and SAR imagery have been used widely for DEM generation (Jung Hum and Linlin, 2010; Toutin and Gray, 2000).

In order to generate DEMs from optical images, at least two images forming a stereoscopic configuration are required. Then, image orientation and image matching processes should be performed, respectively (Jacobsen, 2003). In SAR imagery, four different methods such as clinometry, stereoscopy (radargrammetry), interferometry and polarimetry (Toutin and Gray, 2000; Xi et al., 2009) are used for DEM generation that include more sophisticated processing steps in comparison with optical imagery (Hoja et al., 2006). These methods have respective advantages and disadvantages against each other. Since

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interferometric DEM generation is a cost efficient method and it provides high accuracy products in regions of high coherence we preferred to generate DEMs using interferometry rather than radargrammetry (Crosetto and Pérez, 1999; Gelautz et al., 2003; Yu et al., 2010). SAR interferometry (InSAR) is drawing attention of researchers with the availability of suitable very high resolution (VHR) (≈1 m) TerraSAR-X and COSMO-SkyMed interferometric image-pairs. In addition, TanDEM-X was launched to acquire data of same interest area from slightly different looking angles by synchronizing TerraSAR-X using single-pass interferometry principle for the elimination of atmospheric de-correlation.

Optical and SAR imagery have their own advantages and disadvantages for DEM generation that are originated from sensors they use. First of all, SAR systems are capable of acquiring data independent of weather conditions and time of data acquisition. However, optical sensors can only operate at day time under cloud free weather conditions (de Oliveira et al., 2011; Lee et al., 2005; Yamane et al., 2008). Secondly, optical imagery provides more sufficient resolution for object recognition than SAR imagery. Moreover, sun angle is an important parameter for optical imagery that causes shadows. Similarly, incidence angle should be taken into consideration for SAR imagery due to shadow, layover and foreshortening effects (Schreier, 1993).

Since the end of 1990s, with the advent of first commercial VHR IKONOS imagery, scientists have conducted many experiments on high resolution optical DEM generation. Currently, IKONOS is being widely used for high resolution 3D data acquisition with other VHR missions such as GeoEye Inc., Worldview, Quickbird and Orbview. On the other side, SAR imaging technologies were improved with high acceleration by means of VHR commercial SAR missions such as TSX. TSX, launched in 2007, is accepted as a revolution in space-borne SAR.

The primary objective of this study is to compare high resolution DEMs of IKONOS and TSX. High resolution DEM generation from IKONOS imagery has been studied by many researchers, some of them are Cheng and Toutin (2001), Dong and Song (2010), Ki In et al. (2003), Rau and Chen (2005), Toutin (2004), Toutin and Cheng (2001). Similarly, there are quite a few publications on high resolution DEM generation using TerraSAR-X imagery, some of them can be listed as Dana et al. (2008), de Oliveira et al. (2011), He et al. (2010), Kiefl et al. (2010). This paper differs from aforementioned researches by demonstrating a robust statistical and visual evaluation of both DEMs that are generated for the same test site in Istanbul with equal grid spacing.

Towards these objectives, the paper is organized as follows: Section 2 describes the test site and the characteristics of used IKONOS and TSX image-pairs. Section 3 summarizes the optical and InSAR digital surface model (DSM) generation workflow and DSM-DEM conversion. Section 4 includes the quality assessment of DEMs and results and Section 5 summarizes the conclusions.

2. Test site and data sets

The test site covers 80 km^2 area on the European side of Istanbul surrounded by the Bosphorus, Marmara Sea and Golden Horn. It is mostly occupied with buildings and rarely open and forest regions. The elevation varies from sea level to 90 m for bare topography. The reason why we choose this site is availability of a suitable high resolution reference DEM derived by digital photogrammetry. Fig. 1 depicts the landscape of test site and the frequency distribution of terrain slope that was computed using all points of 1 m gridded reference DEM. Terrain inclination is one of the most significant factors in accuracy assessment of DEMs. In principle, the accuracy of a DEM decreases in inclined parts of topography. According to Fig. 1, it can be observed that ≈%32 of the topography is nearly flat in the test site and the rest varies between 1.7° and 15.6° which makes the test site suitable for accuracy assessment applications.

For this study, high resolution panchromatic (PAN) IKONOS and spotlight mode TSX image-pairs are used that overlap with reference model borders. The world's first commercial very high resolution optical satellite IKONOS (means image in Greek) was launched in 1999 by GeoEye Inc., USA. It has PAN and multispectral (MS) sensors and is able to take images with a ground resolution of 1 m (PAN) and 4 m (MS) with 11.3 km swath width from 681 km orbital altitude. The height-to-base (h/b) ratio of used stereo-pair was 1.6 (angle of convergence 35°) and the sun elevation angle is 65.5° (Alobeid et al., 2009).

TSX is capable to operate two types of spotlight modes called as spotlight and high resolution spotlight (HS), respectively. Between these two types of spotlight mode just the geometric azimuth resolution is different in order to increase the azimuth scene coverage of spotlight mode. While images of spotlight mode cover 10 km × 10km (length and width) area with 2 m azimuth resolution, TSX HS images resample 5km × 10 km area and offer 1 m azimuth resolution. During the observation of a particular ground scene the radar beam is steered like a spotlight so that the area of interest is illuminated longer and hence the synthetic aperture becomes larger. The maximum azimuth steering angle range is ±0.75° (Roth, 2003). Fig. 2 shows the image-pairs of IKONOS PAN and TSX HS and the following Table 1 presents the characteristics of TSX HS scenes.

3. DEM generation methodology

IKONOS and TSX DSMs were generated applying optical stereoscopy and interferometric processing workflow respectively. The world's first commercial VHR optical satellite IKONOS was launched to space in 1999 by GeoEye Inc., USA. It has PAN and MS sensors and is able to take images with a ground resolution of 0.82 m (PAN) and 3.28 m (MS) with 11.3 km swath width from 681 km orbital altitude. The PAN IKONOS image-pair used in