Detecting and analysing “Urban Villages” in the Pearl River Delta using multi-source remote sensing data

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Abstract

‘Urban villages’ is the Chinese version of informal settlement. It is a unique phenomenon that comprises mainly low-rise and congested, often illegal buildings surrounded by new constructions and high-rise buildings. Due to a lack of an unambiguous definition allowing for a spatial delineation of such areas, this article investigates a joint use of high-resolution optical and SAR satellite data through building extraction and 3D reconstruction of urban villages in Shenzhen, China. First, potential urban village footprints are extracted through a combined image fusion analysis of multispectral GaoFen-1 (GF-1) and high resolution TerraSAR-X radar (SAR) imagery. Then, building height estimation is performed on the basis of interferometry principles using interferometric X-band SAR (InSAR) from the Tandem-X mission. It can be demonstrated that urban villages and surrounding urban areas are clearly distinguishable through particular combinations of optical data, SAR data and height information. In particular, a rigid analysis identified three types of information as most suitable: 1) Normalized Difference Vegetation Index (NDVI), 2) contextual parameters such as edge and line density from GF-1 multi-spectral imagery, and 3) textural parameters such as Grey-Level Co-occurrence Matrix (GLCM) variables from TerraSAR-X imagery. The additional height information from InSAR clearly improves the detecting of taller buildings surrounding the urban villages. In conclusion, the fusion of SAR and optical imagery can effectively reveal the footprint characteristics of urban villages. It is an effective means to reduce the effects of layover, shadow and dominant scattering at building location. The 3D building reconstruction model based on urban village footprint maps can reduce the continuous alteration of layover and shadow areas from high-rise buildings in the dense urban area.

Introduction

Informal settlements are a world-wide phenomenon. Urban villages belong to the Chinese version of the informal settlement phenomenon. However, there is no definitive definition of urban villages or a general systematical theory on such locations. Monitoring and modeling informal settlements is crucial for understanding informal settlements genesis and development in general. Many previous studies that applied the VHR optical data have been conducted to detect and analyze informal settlement, (e.g. Graesser et al. 2012; Kuffer and Barrosb 2011; Netzband and Rahman 2009; Hofmann et al. 2008; Mayunga, Coleman, and Zhang 2007b), but not many used SAR data for informal human settlement observations (Taubenböck et al. 2010; Stasolla and Gamba 2008), especially high resolution TerraSAR-X imagery has barely been employed for dense urban areas, such as urban villages analysis so far (Taubenböck and Kraff 2013, Reigber et al. 2007).

SAR systems, which are highly attractive due to their independency of daytime and weather., has undoubtedly started a new era for acquiring geographical coverage information. Especially the new satellite configuration of TerraSAR-X and TanDEM-X provides single-pass 3D mapping of the earth with unprecedented geometric resolution, allowing for improved detection and extraction of building positions and shapes (Gernhardt et al. 2010). Nevertheless, the SAR images are mainly corrupted by speckling, shadowing, multisource, layover, as well as side lobes from buildings. These problems make the interpretation of such high resolution SAR images in urban areas to an interesting but difficult topic.

The overall objective of this research is to illustrate the physical characteristics of urban villages and show the natural environmental difference of urban villages with surrounding urban areas. Multi-source data (TerraSAR-X, TanDEM-X and GF-1 optical images) will be integrated to address the following issues attributed to urban village definition:

1. What physical characteristics of urban villages can be measured using optical and SAR images?
2. Do urban villages in the Pearl River Delta have homogeneous or heterogeneous physical characteristics?
3. Do urban villages have definitive physical differences compared to the surrounding urban structures?

Study areas and Methods

The Pearl River Delta is one of the most densely urbanized regions in the world and one of the main hubs of China’s economic growth with a combined population of 57.15 million at the end of 2013. Urban villages are the by-products of the rapid urbanization in the Pearl River Delta region, where the city develops around what once were isolated farming and fishing villages. They are surrounded by rising skyscrapers, transportation infrastructures and other modern urban constructions. The appearance of urban villages is not only out of urban planning, infrastructure construction and other forms of administrative regulations, but has also led to a number of social problems. Therefore, how to monitor the urban villages and analyze their environmental characteristics is

crucial for the sustainable urban development research.

We propose the following applications for the analysis of GF-1 images, TerraSAR-X and TanDEM-X images for urban villages in the Pearl River Delta. The methodology can be subdivided into the following sections (shown in Table 1), to comprehensively study the impact of spectral information, contextual information, textural information and radiometric textural information for urban area mapping in different types of study regions.

Table 1. Spatial features analysis of urban villages

Characteristics	**Data sources**	**Spatial features in VHR images**
Spectral features	GF-1	NDVI
Textural features	GF-1 & TerraSAR-X	Building densities
		Building layout patterns
		Building size
	TerraSAR-X & TanDEM-X	Height information

Scientific originality and innovation

This study explores the potential of TerraSAR-X, TanDEM-X data in monitoring urban villages. For high resolution space-borne TanDEM-X, this is a unique opportunity to study the complexity of signal interpretation in the geometrically complex urban village landscape. In addition, the composition of high resolution optical images-GF-1 and TerraSAR data will increase the detection accuracy of the physical characteristics (including the structure, shapes and locations of informal settlements, and the optical (GF-1)-SAR fusion framework will benefit for further urbanization analysis.

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