Object-based image analysis to support numerical tsunami modeling

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**ABSTRACT**

In response to tsunami disaster at the early stage, integrating remote sensing products with numerical modeling proved to be useful to enhance the capability of early damage estimation. The information derived from high-resolution satellite images would well represent the current status of the surface roughness and the land use conditions that would be used in the numerical modeling of tsunami inundation. This research aims at developing a new object-based image analysis solution for automated extraction of object of interest from satellite images and hence, to support numerical tsunami modeling. As time is a critical factor, less user interaction and fast computing are the priorities in design and implementation of the proposed solution. Its performance is demonstrated with a QuickBird and an IKONOS images acquired over Ban Nam Ken, Thailand. In such a residential area, building mainly contributes to the resistance value in numerical modeling. The test shows that over 70% of building could be successfully extracted. Further work will extend the implementation onto grid-computing platform.

1 INTRODUCTION

Recently, very-high-resolution satellite images such as Quickbird and IKONOS have been extensively used in disaster management applications (Chesnel et al. 2007; Chini et al. 2008; Saito et al. 2004; Vu et al. 2005; Vu et al. 2007). With regards to tsunami disaster, the integration between numerical modeling and remote sensing technologies would enable the quick damage estimation after a tsunami attack as proposed by Koshimura and Yanagisawa (2007). Koshimura et al. (2010) then proposed a framework integrating of remote sensing, GIS and numerical modeling to assess the impact of tsunami disaster. In the first step, numerical modeling of tsunami inundation and fragility function helps to estimate the potential damage. It is necessary to timely update the surface roughness to derive the right resistant value for tsunami numerical modeling using remote sensing products. In the following steps, such results in addition to post-disaster remote sensing images helps to detect the real damage situation on the ground. Developing an automated image analysis approach is crucial to report tsunami damage for post-disaster response under time pressure.

To be applicable at the early stage, fast data processing speed is critical. Analyzing very-high-resolution satellite images, however, is more complicated than doing the coarser images as more aspects of information can be captured. The conventional pixel-based method often fails in handling such high-resolution images and the local context must be concerned in image processing. Object-based approach exploiting the information contained in an image to describe contexts in various ways is a solution (Vu et al. 2006). How to produce the result quickly is really a challenge in development of a suitable object-based solution here.

This study aims at developing such a solution to delineate the building footprints from high-resolution satellite images. Based on a scale-space analysis, objects are initially categorized into groups according to their sizes. Subsequently, shape and spectral information are exploited in further
classification to remove the irrelevant objects. Finally, building objects are extracted and used in computation of the occupation ratio (or surface roughness) value. Specifically designed as a part of a tsunami early damage estimation system, less user interaction and fast computing are the priorities. The extracted objects will contribute as the resistance in numerical modeling (Koshimura and Yanagisawa, 2007). Ban Nam Ken village, Thailand where were heavily devastated by the 2004 Indian Ocean tsunami is selected as a test site. The developed algorithm is applied to the 2002 IKONOS and the 2006 Quickbird images.

2 METHODOLOGY

2.1 Pre-processing

Pan-sharpening is the first step if the acquired satellite image is provided with separate panchromatic and multispectral bands. In implementation here, we employed an improved colour-normalized pan-sharpening method (Vu et al. 2007). From the pan-sharpened image, the 1st component image is derived with principal component analysis. The first component generally contains majority of information to form the initial objects. If only one of those data sets is available, the single-band panchromatic image can be directly used.

To prepare for a hybrid pixel-object spectral classification in the final step, the pixel-based K-mean clustering is deployed. The three products, i.e. pan-sharpened image, classified K-mean image, and the 1st component image, are the required input for the coming analysis. To facilitate the processing, a simple mask can be applied to exclude the seawater area.

2.2 Multi-scale analysis

A scale-space based on level set transformation (Meyer and Maragos, 2000) is generated for the 1st component image. Focusing in extraction of building structures, which are often in compact shapes, flat disc of increasing size is used. In addition, buildings are quite small comparing to other object types; the maximum size concerned can be about 41x41, which is adjustable depending on the study area and the spatial resolution used.

Across the scale-space, the small objects will vanish when the disc size increases. Thus, each pixel belongs to different objects on different scales and the ones within a neighbour behave a similar way across the scale-space. Tracking the behaviours of all pixels enable the initial grouping them to objects.

2.3 Shape and spectral analysis

If the multi-spectral images are used, threshold applied on near-infrared band and vegetation index helps to remove irrelevant land cover types like water body and vegetation. It is to speed up the computation in the following step as the number of concerned objects is reduced.

The shape analysis through compactness and complexness criteria is carried out to categorize different object types with similar spectral reflectance. Compactness is computed as the ratio between the area and the perimeter of the objects whereas complexness is computed as the length of the object skeleton plus the number of skeleton branches. The man-made objects tend to have higher compactness value and lower complexness values. The shape code computed as the ratio of compactness over complexness is then introduced. Higher shape code is more likely to be building objects.
When the shape code is computed, the merge process is started. Two adjacent objects are investigated based on integration analysis of the shape code, size, and histogram similarity to decide whether they should be merged. Finally, object attributes including ID, area, spectral, and shape code are computed and assigned to each extracted objects. The ID, area and shape code are added from the previous steps whereas spectral attribute is a result of hybrid pixel/object-based spectral clustering using the majority rule.

3 RESULT AND DISCUSSION

IKONOS image acquired June 24, 2002 presents the status before the 2004 tsunami attack whereas the QuickBird image acquired February 28, 2006 presents the current status. The false-colour-composite images of 2 test areas are shown in Figure 1. An example of multi-scale presentation is given in Figure 2. Except the pre-processing step which is flexible depending on the data availability, from the second step the processing is fully automated with 4 modules. They are scale-space generation, cross-scale cluster, object form and object selection. Totally 6 parameters are required for the whole process.

![Figure 1. FCC images of the test site (a) 2002 IKONOS and (b) 2006 QuickBird](image1.png)

![Figure 2. Demonstration of a 3-scale space.](image2.png)
Extracted buildings in the test areas are shown in Figure 3 by their assigned IDs. Visually, the extraction produced the satisfactory outcomes. Comparing with manual extraction, the automated detection achieved over 70% for both correctness and completeness measurement. The detailed object-based accuracy assessment is given in Table 1. It was difficult to judge the right boundary of each building due to the ambiguity of spectral signatures of the building roof. In comparison between the results from the automated detection to the one by the manual detection, the overlap ratio and the areas were used to decide the corresponding objects.

Two images introduced different difficulties in discrimination of buildings from others. The 2002 IKONOS image presents the status of the village before the 2004 tsunami attack in which the spectral reflectance of the building roof is quite uniform. However, it is much similar to that reflected from the asphalt road. Moreover, it was unable to detect individual house due to the low and similar height of adjacent houses. About 2 years after the 2004 tsunami attack, the village was not fully recovered as shown in the 2006 QuickBird image. Spectral reflectance from the newly built houses could be classified into 4 groups only one of which were clearly distinguishable. The result infers that a better spectral resolution is needed as the new 8-band WorldView-2 image, hopefully.

![Figure 3. Extracted buildings site (a) 2002 IKONOS and (b) 2006 QuickBird](image)

<table>
<thead>
<tr>
<th>Table 1. Object-based accuracy assessment</th>
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<tr>
<td><strong>IKONOS 2002</strong></td>
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<tr>
<td>No. of buildings</td>
</tr>
<tr>
<td>Corrected</td>
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<tr>
<td>Total</td>
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<tr>
<td>Correctness = 73.53%</td>
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Parallel processing is implemented on a multi-core PC exploiting the multi-thread capability of IDL (Interactive Data Language). Such an approach of implementation makes the proposed solution is usable for everyone on one hand and to speed up the computation on another hand. The generation of 4-scale space from an image of 1200 x 1600 pixels on a PC with dual-core 2.13 GHz CPU and
3GB RAM could improve about 10 seconds when switching from the single-thread and dual-thread modes. Much faster computation can be achieved with quad-core computer.

The code implementation, however, needs to be further improved to achieve a satisfactory computation time. Initiated from a sequential processing, the algorithms should be fully converted to a parallel way. The current development focuses in task parallel implementation. To be applicable for a very large disaster area, data parallel implementation may be also necessary. The ultimate goal is to implement on grid-computing platform using Grid Message Passing Interface (GridMPI) as it will be a part of a newly developed tsunami damage estimation system. It is also recommended to deploy the developed tool for various data sets to improve the current codes.

4 CONCLUSION

The paper has introduced a newly developed object-based image analysis tool to extract building footprint from high-resolution satellite images. The outcomes provide the input for the computation of resistant value in tsunami numerical modeling. The test using QuickBird and IKONOS images produced a good result. It is recommended that better spectral resolution is necessary for a better accuracy and implementation needs to be further improved. The main goal for the development presented in this paper is to serve the tsunami modeling. However, the proposed approach is applicable for feature extraction in general and would be extendable to damage mapping.

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REFERENCES


