Using Formosat-2 Satellite Images to Manage Hillside Land Cover Change in Taipei City

The Origin of Multi-scale Monitoring Mechanism

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Abstract — This study aims to develop a model of using Formosat-2 satellite images to detect vegetation changes in 15,000-hectare hilly areas in Taipei City. This model is expected to assist Geotechnical Engineering Office under the Taipei City Government in establishing a Multi-scale Monitoring Mechanism to monitor hillside development for the purpose of soil and water conservation.

***Index Terms* — NDVI, change-vector analysis, the direction of change vector, Formosat-2 satellite image**

I. INTRODUCTION

Since illegal hillside development has often caused destruction of ecological balance, leading to disasters on slope land, hillside development should be subject to regulation. However, on-site investigation of hillside development is quite difficult due to topographic ruggedness.

In order to implement the slope land management effectively and timely, the Taipei City Government, since 2010, has established a long-term monitoring model based on Formosat-2 satellite images to detect hillside development cases in violation of the Soil and Water Conservation Act. The actual violations consist of those without soil and water conservation plans and those without implementation of soil and water conservation treatment according to approved plans.

This study acquired Formosat-2 satellite images once a month in 2010-2012 for a. image processing; b. detection of image changes; c. on-site verification; d. data analysis for feedback rectification.

For image processing, this study orthorectified Formosat-2 satellite images of 8^m x 8^m ground resolution (taken in four spectral bands) and 2^m x 2^m panchromatic images and then fused these images, attached coordinates and removed images of cloud and shadow.

In image change detection, ortho-rectified images were used to compute Normalized Difference Vegetation Indices (NDVI) and then determined the standard deviation of NDVI based on reference to violation records of illegal hillside development cases in 2010. In 2011 and 2012, this study used NDVI, multi-spectral change vector analysis (MSCVA) and image intensity change (IIC) to obtain 18 combinations of analysis results, Then five combinations were selected for convolution transform and Fourier transform to interpret changes in image.

Results of image changes were used for priority assessment. Selected cases were sent to park rangers for on-site verification. Based on the verification results, cases of suspected violation were submitted to process by city officials. The reason that causes complication in interpretation can be attributed to five types: changes of natural vegetation, man-made changes, influence of cloud and shadow, strong surface reflectance from land features and other factors.

Results of on-site verification and re-verification were used to improve interpretation of image changes, with accuracy rate increasing from 66.2% in 2011 to 70.28% in 2012.

II. IMAGE PROCESSING

Through application with the National Space Organization (NSPO), this study acquired satellite images taken with least influence of clouds in each month for pre-processing including ortho-rectification, image fusion, removal of cloud/shadow influence and 1/1000-scale division for subsequent detection of image changes.

A. Orthorectification and image fusion

In order to eliminate difference in altitude between the bottom and top of a land feature, this study acquired 4m-resolution digital terrain model (DTM) through the Department of Urban Development under the Taipei City

Government as well as ephemeris data and ground control points provided by NSPO to orthorectify images to conform image coordinates to land features and overlap images with cadastral and other maps.

This study processed Level-1 Formosat-2 multi-spectral and panchromatic (black &white/color) images to produce Level-4 images and orthorectifed these images through attaching coordinated based on ground control points and elevations. The orthorectified images were then overlapped with road maps published by the Institute of Transportation under the Ministry of Transportation and Communications to check conformity.

To enhance detection accuracy, in this study we fused 2m-resolution panchromatic images with 8m-resolution multi-spectral images to produce 2m-resolution color fused images..

B. Removal of cloud/shadow influence and 1/1000 division

Influence of clouds on satellite images vary with daily weather conditions, while influence of shades depends on angles of sunlight which vary with seasons as well as height of buildings. In this study, we used ArcGis software to selectively remove clouds and shades. Since 2011, this study adopted 1/1000 maps, with filing code numbers the same as those of digital topographic maps published by Department of Urban Development, to divide and code satellite images to facilitate batch processing for detection of image changes.

All hillside areas in Taipei City are covered by the fifth and sixth strips of Formosat-2. Through 1/1000-scale division, there were 197 cloud-free images covered by the fifth strip, 204 images by the sixth strip and 43 images by the overlap of the two strips. Thus, there were a total of 444 images in each period and 2,664 images in six periods.

III. IMAGE CHANGE DETECTION, ANALYSIS AND CHECKLIST

Image change analysis was to discern changes in images through comparing multi-temporal image data collected at different period of time, as described below.

A. Global image NDVI vegetation change detection method (January-June 2010)

The initial image change detection in Taipei city used EARDAS software to orthorectify images covered by the fifth and sixth strips. As the first frequency band used to take Formosat-2 images is red light while the fourth one is infrared ray, NDVI was calculated based on spectral reflectance of vegetation via these two wave bands using the formula below

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

Mean and standard deviation values of NDVI were calculated and 1.5 x standard deviation was a critical value. If image change between two periods was larger than the critical value, it meant an increase or decrease in vegetation. If image change was smaller than the critical value, there was no significant change in vegetation.

Table 1. Statistical results of image change analysis during January-June 2010

Two periods for comparison		Change from vegetation to non-vegetation	Change from non-vegetation to vegetation
First	Second		
May 2009	January 2010	5,595	2,281
January 2010	February 2010	4,985	772
February 2010	March 2010	1,503	4,879
March 2010	April 2010	9	11,262
April 2010	May 2010	2,208	12,899
May 2010	June 2010	5,008	649
May 2009	June 2010	747	30,230

Through comparison of the penalty records from May 2009 to June 2010 for violation of soil and water conservation regulations (58 illegal hillside development cases in total), it was found that most of the illegal cases were unable to be detected using 1.5x standard deviation of NDVI. For improvement, this study used the coordinates of the 58 penalty records to subdivide the images into 200m x 200m image blocks (100 x 100 pixels) to examine if changes could be detected. The results are shown in Table 2.

Table 2. Results of interpretation of image blocks

Able to be detected	Unable to be detected	Shaded by military facilities	Total number of cases
41	15	2	58
70.69%	20.69%	3.45%	100%

B. .Global image analysis results of vegetation change detection method (July-December 2010)

Based on the aforementioned experience, three methods of image analysis were used to generate eighteen different combination results, as described below.

1) NDVI criteria：

The aforementioned critical value was adjusted as the standard deviation of NDVI. A image change (the first period minus the second period) larger than the mean plus the critical value represented a decrease in vegetation. If image change is smaller than the mean minus the critical value, it meant an increase in vegetation. However, if the change ranges between the two critical values, it represented no significant change in vegetation.

2) MSCVA criteria：

Since color information can help distinguish images, this study used multi-spectral change vector analysis (MSCVA) by adding images taken in more frequency bands in different periods as independent coordinates in the Euclidean coordinate system for calculating length of change vectors using MATLAB software. Similarly, mean and deviation of vector length were used to determine changes, with formulae as follows:

The pixel combination of percentage in each band (CP)

$$\text{CP ij}= \frac{\text{DN ij}}{\sum_{j=1}^{4}\text{DN ij}} \text{x}100\%$$

DN ij: The DN of pixel i in band j. (2)

Change vector

$$=\sqrt{(R'_{\text{time 1}} - R'_{\text{time 2}})^2 + (G'_{\text{time 1}} - G'_{\text{time 2}})^2 + (B'_{\text{time 1}} - B'_{\text{time 2}})^2 + (NIR'_{\text{time1}} - NIR'_{\text{time 2}})^2} \quad (3)$$

3) IIC criteria：

This study used IIC (image intensity change) through converting 2m color images into 2m intensity images and calculating the mean and standard deviation of changes in intensity image. If change in image intensity (the first period minus the second period) was larger than the mean plus the standard deviation, there was an increase in image intensity; if that was smaller than the mean minus the standard deviation, there was a decrease in image intensity; if that fell between the two values, there was no significant change in intensity.

Among the three types of changes, the rank of importance is MDVI > MSCVA > IIC. Groups 1, 4, 7, 10, 13 and 16 all showed significantly reduced vegetation, however, only groups 4, 10 and 16 showed significant change in MSCVA, thereby these three groups were used as criteria to select cases for on-site verification . In particular, this study analyzed image blocks regarding 13 hillside development cases without soil and water conservation plans. This study was unable to detect image changes at the corresponding coordinates of case sites or nearby for four cases due to influence of clouds or shades, but was able to detect significant image changes for eight cases. Therefore, the average accuracy of image change analysis was 61.54% (8/13).

Table 3. Results of IIC analysis

Group.	NDVI-based changes*	MSCVA-based changes*	IIC-based changes*
0	●	—	●
1	—	—	●
2	+	—	●
3	●	+	●
4	—	+	●
5	+	+	●
6	●	—	—
7	—	—	—
8	+	—	—
9	●	+	—
10	—	+	—
11	+	+	—
12	●	—	+
13	—	—	+
14	+	—	+
15	●	+	+
16	—	+	+
17	+	+	+

*●：Not significant, ＋：Significant increase, —：Significant decrease

B. C. 1/1000 Map image analysis results (January-December 2011)

In contrast to groups 4, 10 and 16 which showed significant reduced vegetation, there are non-vegetation cases that showed change patterns shown in groups 9 and 11 where

NDVI change is irrelevant. This study selected groups 4, 9, 10, 11 and16 for convolution transform and Fourier transform using ERDAS and then undertook NDVI, MSCVA and IIC image change analysis based on 1/1000-scale batch processing using Matlab software.

For results of analysis, this study calculated coordinates of center points of areas with image changes and integrated coordinates with corresponding cadastral data, 1/1000 map code numbers, administrative districts and patrol zones for soil and water conservation. This study, among hillside development sites covered by each of the fifth and sixth Formosat-2 strips, selected the largest 30 ones by land size as candidates for on-site verification. Through on-site checking, hillside development sites with images influenced by clouds, shades or military facilities or with incorrect image data were deleted from the candidate list and other sites were selected. Each month, there were about 30 sites selected from coverage by the fifth and sixth strips each for on-site verification for soil and water conservation.

For each of selected sites, soil and water conservation patrolmen under Taipei City Government used GPS coordinates, satellite images and topographic maps in on-site checking. There were 422 on-site checking cases in total and two UAV (unmanned aerial vehicle) surveys of sites which were enclosed and thus unable to be checked in 2011.

Of 33 illegal hillside development cases found in 2011, 21 could be detected based on image change analysis, with accuracy rate of 64%.

D. 1/1000 Map image analysis results (January-December 2012)

In addition to continued image-based analysis of vegetation changes, this study engaged in detection of non-vegetation changes based on analysis of image texture and Fourier transform.

In this study, hillside development cases to be reported for on-site verification were divided into three grades in terms of priority and gradually ended selection of non-illegal cases (including legal ones and those under agricultural assistance). Specifically for questionable results of on-site checking, this study undertook in-house analysis and on-site re-verification (13 cases in total).

Based on detection of vegetation changes, 401 hillside development cases were reported for on-site checking. Of the reported cases, 222 ones were of top-priority grade, including 156 ones found to have significant vegetation changes and 50 ones needing further checking. Through analysis of the 50 cases, it was found that vegetation changes, although possibly but not significant, resulted from natural causes, man-made processing, influence of cloud and shadow as well as too strong surface reflectance. Cases with natural and man-made vegetation changes were included in databases for screening out similar cases in the same areas. Cases with accurate detection of vegetation changes were those found to have significant vegetation changes through on-site checking, with vegetation changes including natural and man-made changes. The overall accuracy of vegetation change detection reached 83%.

There were 14 hillside development cases fined for violation of soil and water conservation regulations and of which, eight cases were detected using image change analysis in this study, with an accuracy level of 57.1% (8/14). The failure in detection for the other six cases was due to interference with images from cloud and shadow. Therefore, after excluding the technological constraint, the detection could reach 100% accuracy. For reference, one of every 28 cases reported for on-site checking was found illegal with penalty.

IV. Recommendation

Based on our experiences in the past three years, we believe that in addition to regular information exchange, the city government should establish a patrol working system and a on-site checking system as well as an online operating system using electronic forms to save time in handling paper documents. For on-site checking, the city government should organize a UAV working to undertake aerial surveys for real-time monitoring of slope disasters and others. Finally, all of information should be integrated with GIS platforms to provide necessary information for working staff members and decision makers.

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