HAZARD SURVEY USING MULTITEMPORAL SATELLITE IMAGERY

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ABSTRACT:

The World Bank has reported Taiwan as the most vulnerable country in terms of the percentage of exposed areas and multiplicity disaster. During the past decade, a number of natural disasters have occurred in Taiwan, especially two critical ones, i.e. Chi-Chi earthquake and Typhoon Morakot. In the first event, the earthquake was with a magnitude of 7.3 on the Richter scale and caused seriously damage on Sep. 21, 1999. The second one is Typhoon Morakot that accumulated more than 2,700 mm precipitation in 72 hours over a large coverage in Aug. 2009. The typhoon caused floods, landslides, and debris flow in the Central and South Taiwan. Therefore, the survey for the landscape change for hazard monitoring is an important task. Satellite imagery that provides capabilities to monitor landscape with large coverage area is an excellent tool for disaster survey.
Landscape changes due to the earthquake and the typhoon are detected in this study. First of all, satellite images are orthorectified. Then the normalized difference vegetation indices (NDVI) are calculated to detect the vegetation changes. Considering the slope derived from a digital elevation model (DEM), the landslide areas are estimated. For Chi-Chi earthquake, we analyze the changes over last 11 years in the Central Taiwan. It is found that the landslides keep on growing for 11 years with little vegetation recovery since the earthquake in Da-Jia River areas. Another reported case is about Typhoon Morakot, which produced a huge landslide that destroyed whole Shiao-Lin village with 565 casualties.

1. INTRODUCTION

According to the World Bank report in 2005, Taiwan is the most vulnerable country in terms of multiplicity of hazards. Hazard monitoring, thus, is an important issue in Taiwan. During recent years, there are several studies focusing on this objective using aerial photos (Chang and Liu 2006), satellite imagery (Hsiao et al. 2003), synthetic aperture radar (SAR) imagery (Noferini et al., 2006; Luckman et al., 2007), and the light detection and ranging (LIDAR) data including ground-based systems (Dubbini and Zanutta 2005) and airborne systems (Gleen et al. 2006). For long term landscape monitoring, multi-temporal satellite imagery is a practicable way.

Central Cross Island Highway is one of major roads for communicating eastern and western part of Taiwan. Because the route directly passes through the backbone-mountain belt of Taiwan, its geological condition and cliff-cutting construction make it fragile to seismic activities (Hung, 2000). As a result, some parts of this road have been seriously destroyed since Chi-Chi earthquake occurred on Sep. 21, 1999 (Chen and Hawkins, 2009). According to literature reports, this earthquake might lead to other disasters. The followed heavy rainstorms have been continuously increasing the scale of disaster for years. A large amount of landslide and debris flow areas have been created in surrounding areas (Chen and Petley, 2005). To understand the long-term land changes caused by Chi-Chi earthquake and followed rainstorms, this study focuses on the detection of the landslide areas after the earthquake. A study from 1999 to 2009 to monitor landscape change on yearly basis is carried out using satellite images.

For the sample of Typhoon Morakot, the demonstration area Shiao-Lin village locates in South Taiwan. Typhoon Morakot brought heavy rainfall and led landslides and debris flows. It is reported that the rainfall reached 1,500mm, 2,300mm and 2,700mm in 24hours, 48hours, and 72 hours, respectively. Total number of casualties reached 675. Out of them, 565 casualties were in Shiao-Lin village due to Typhoon Morakot triggered landslides. In addition to the employment of DEMs, this study also uses satellite images to observe the landscape changes in Shiao-Lin village.

2. METHODOLOGY

This paper presents two cases in hazard survey. The first case uses time series satellite images to detect the trend of landslide changes in the past decade. The second case reconstructs a tree-dimensional cyber village to simulate the landscape change. In the first case, there are two major parts in this study, namely, (1) ortho-rectification, and (2) landslide detection. The first step performs the modelling for sensors' orientation parameters. Ephemeris data and ground control points are used to establish the correlation between the object and the image space. Then, processed images are orthorectified using DEMs and sensor's orientation parameters for the data comparison. In the second step, we detect land changes with time series satellite images. The fundamental techniques contain normalized difference vegetation index (NDVI) and change vector analysis (Sohl, 1999) to identify bare-soil areas. The intensities of each

candidate pixel in different bands are projected to the feature space for the comparison of feature vectors. In the identification process, we also consider terrain relief to extract landslide candidates based on digital elevation models (DEMs). Then, the new generated landslide and debris flow areas in each detection period is classified by the unsupervised classifier and visual interpretations (Silapaswan, 2001). We, thus, locate those changed areas by comparing serial satellite images. Furthermore, the trend of landslide areas can also be delineated for further investigation in the first event. In the validation, this investigation manually evaluates the detected results with the indices of overall accuracy and kappa statistics.

The second case contains two parts: (1) ortho-rectification, and (2) village modelling. In this case, we use time series satellite images to produce orthoimages with DEMs. We collect previous aerial photos to reconstruct 3D village models using stereo photogrammetric technique, e.g. building models and DEMs. Finally, this investigation combines satellite orthoimages, building models, digital elevation models to represent the landscape change in a three-dimension environment.

3. EXPERIMENTAL RESULTS

This investigation collects serial SPOT and FORMOSAT-2 satellite images for hazard monitoring, e.g. earthquakes and typhoons. In this paper, we select two test areas: (1) central cross high way of Taiwan and (2) Shiao-Lin village. In the first area, the orthorectified SPOT multi-spectral images have 10m spatial resolution for monitoring Chi-Chi earthquake from 1999 to 2009. On the other hand, the second area also uses FORMOSAT-2 multi-spectral images to locate the landslide areas in Shiao-Lin village with spatial resolution of 8m. The locations of two test areas are shown in Figure 1a and 1b, respectively. The validation of detected results has 0.91 overall accuracy and 0.82 kappa statistics.

After analyzing the collected images, the landslide and debris flow areas for each period of time can be obtained. As an example, Figure 2(a) and 2(b) show the distributions of bare-soil areas in false colors in 1999. The difference after Chi-Chi earthquake is plotted as red areas before and after Chi-Chi earthquake. Notice that the images used in this study are the simulation products of original multi-spectral images to make them looked natural in color. From Figure 2, it is clearly known that the Chi-Chi earthquake caused the major disaster and created huge amount of landslides. This study also computes the accumulation of the detected land changes from 1999 to 2009.

According to the change detection results, the statistics charts of land change status are illustrated in Figure 3. The plot demonstrates that that the Chi-Chi earthquake was the main event to trigger the land changes in this area. However, in the next 4 years, although the subsequent tropical rainstorms had been continuously increasing the landslide and debris flow areas, the rates seem to be slower year by year. Unfortunately,

the Typhoon Mindulle resulted in severe landslides and debris flows in this area in 2004. Nonetheless, its increasing rate was lower constantly in the following years and even was a negative value in 2007. It implies that the vegetation has certain healing ability and the land in this area has the chance to recover provided that the scale of natural disaster happened over there are small enough for several years.
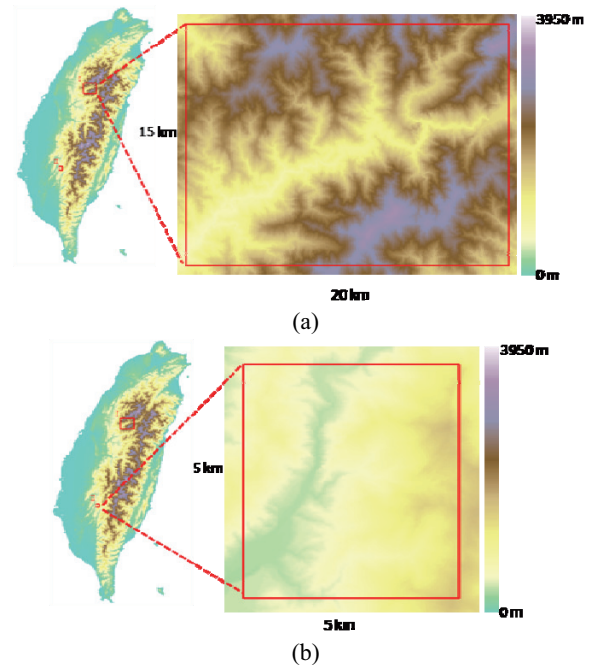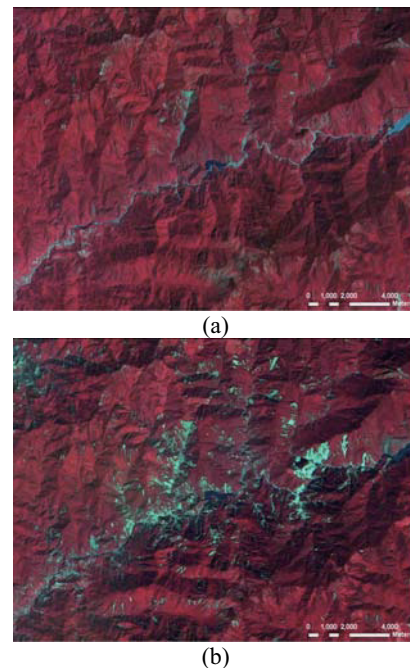

(a)

(b)

Figure 1. The locations of test areas
(a) the first area; (b) the second area
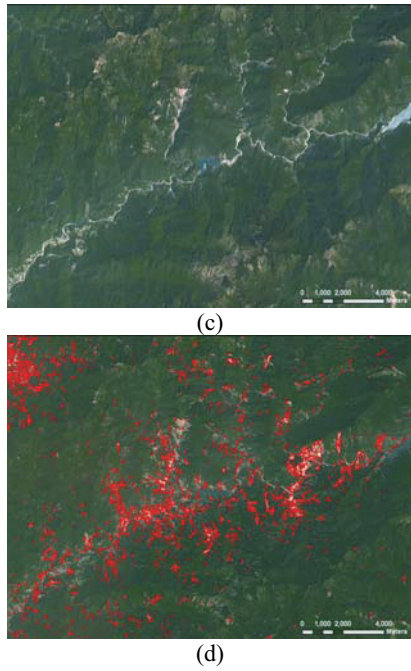

(a)

(b)

(c)

(d)

Figure 2. A comparative sample images of detected results
(a) SPOT-2 image in false colors on 1999/04/01 (before)
(b) SPOT-1 image in false colors on 1999/10/12 (after)
(c) SPOT-2 image in true colors on 1999/04/01 (before)
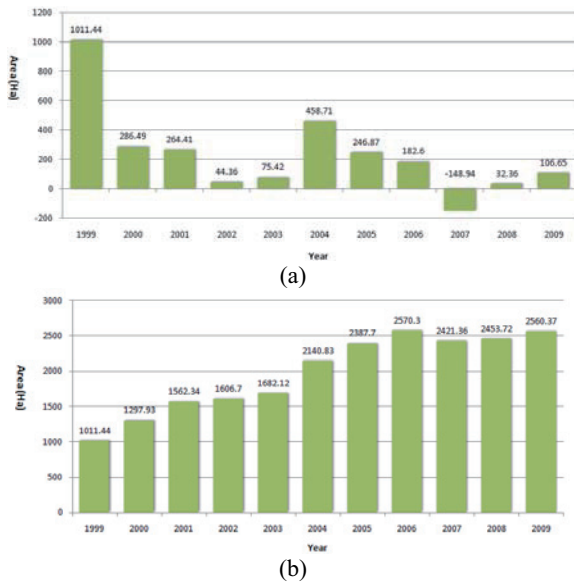(d) SPOT-1 image in true colors on 1999/10/12 (after)

(a)

(b)

Figure 3. Statistics plots of land changes
(a) increments of landslides for each year
(b) accumulated landslide for each year

The second case delineates the damage area at Shiao-Lin village caused by Typhoon Morakot. Because of the concentration and accumulation of heavy rainfall, floods eroded the slopes of valley areas and took a huge amount of mud from upper stream to lower stream. Figure 4 indicates rainfall distributions from August 7th to 10th, 2009. Furthermore, Figure

5(a) and 5(b) illustrate the landscape changes in Shiao-Lin village within the red polygon. The damaged areas reach 210 hectares. Figure 5(c) also indicates the histogram of elevation changes. The deep red and deep blue mean the maximum decreased elevation and the maximum increased elevation. The maximum elevation difference reaches 85m (Chen et al., 2010).
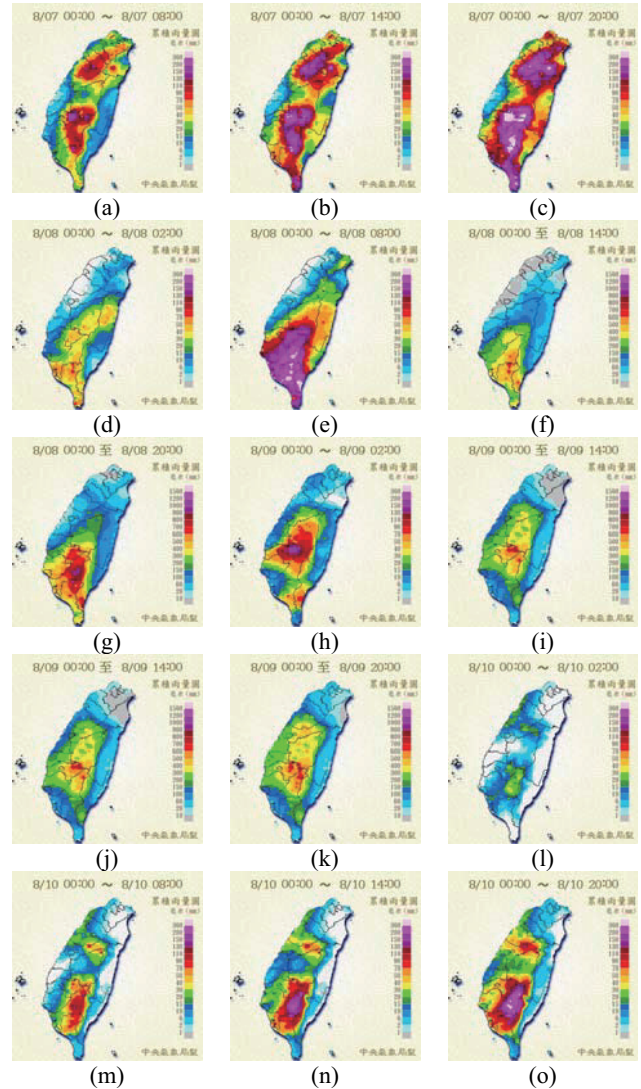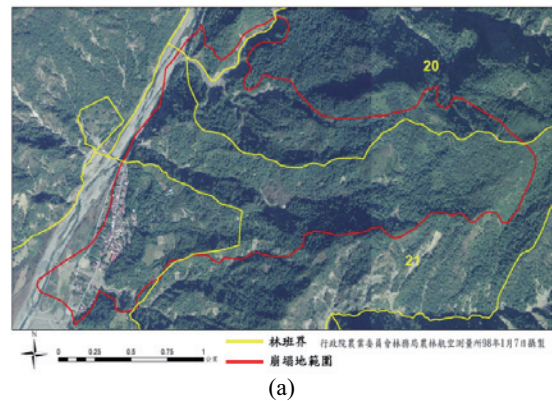

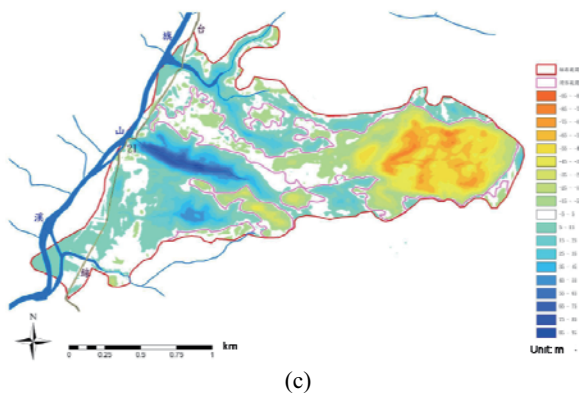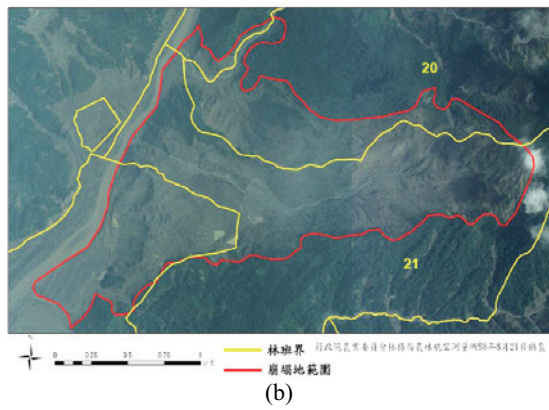Figure 4. The rainfall distribution of Typhoon Morakot

(a)

(b)

(e)

(f)

Figure 6. The simulation of Shiao-Lin village
(a)(c)(e) screenshots before Typhoon Morakot
(b)(d)(f) screenshots after Typhoon Morakot

(c)

Figure 5. The FORMOSAT-2 images and changed areas
(a) before Typhoon Morakot;(b) after Typhoon Morakot;
(c) elevation changes

4. CONCLUSIONS

This study proposes a scheme to detect and analyze the changes of landslide areas using time series satellite images and digital elevation models. After the detected results, those dangerous candidate areas are spotted to provide the information for hazard monitoring and mitigation. In an addition, detected results have the capability to visualize the environmental change with multiple geodata. The results may support the government to decide appropriate solution for the reconstruction of infrastructures.

Otherwise, we also employ aerial stereoscopy to reconstruct tree-dimensional building models from previous photos for the simulation. Building facades of all reconstructed models are represented with generic textures. The relative modelling qualities in X-axis, Y-axis, and Z-axis reach 0.17m, 0.27m, and 0.25m, respectively. This paper combines satellite images, aerial photos, DEMs and building models to visualize the environmental change caused by Typhoon Morakot. Figure 6 shows the difference in Shaio-Lin village in Aug. 2009. The number of damaged buildings reaches 278, and the casualties reach 565 people.
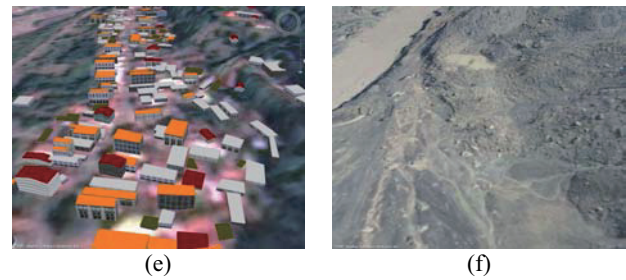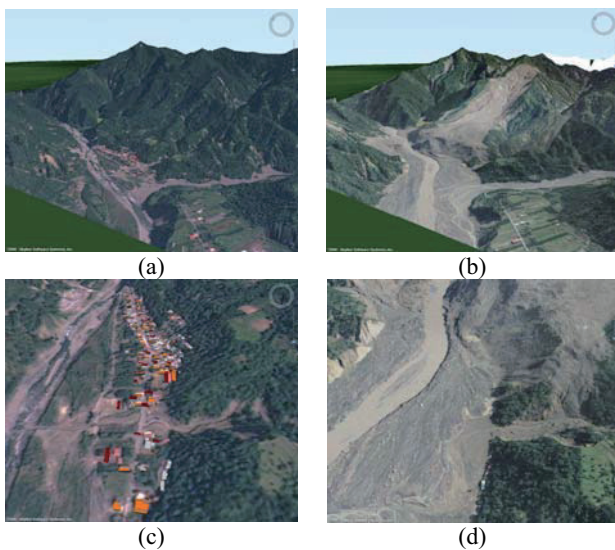
5. REFERENCES

Chang, K.T, and Liu, J.K., 2006. Landslide Features Interpreted by Neural Network Method Using a High-Resolution Satellite Image and Terrain Data – A Joer-Fen-Ell Mountain Case, Journal of Photogrammetry and Remote Sensing, Vol.11, No.2, pp.161-174. (In Chinese)

Chen, H. and Hawkins, A.B., 2009. Relationship between earthquake disturbance, tropical rainstorms and debris movement: an overview from Taiwan, Bulletin of Engineering Geology and the Environment, vol. 68, no. 2, pp. 161-186.

Chen, H. and Petley, D.N., 2005. The impact of landslides and debris flows triggered by Typhoon Mindulle in Taiwan, Quarterly Journal of Engineering Geology and Hydrogeology, vol. 38, no. 3, pp. 301-304.

Chen, C.C., LI, H.H., Wang, C.Y., Chen, Y.C., Hsieh, Y.S., Lin, M.L., Chen, K.H., Lin, K.F., Chem, S.H., Li, K.T., Cheng, K.S., Kuo, I.Y., Chen, L.C., and Chen, M.C., 2010. Investigation report of the disaster factors of Typhoon Morakot in Shiao-Lin, Namasia, and Tao-Yuan of Kaoshiung County , Public Construction Commission. (in Chinese)
http://www.pcc.gov.tw/pccap2/FMGRfrontend/DownloadQuoteFile.do?fileCode=F2010030259 (accessed 11 Apr. 2010)

Dubbini, M., and Zanutta, A., 2005. Terrestrial Laser Scanning for Landslide Movements Detection, In International Workshop on "3D Digital Imaging and Modeling: Applications of Heritage, Industry, Medicine and Land", 17-18 May.

Gleen, N. F., Streutker, D. R., Chadwick, D. J., Thackray, G. D., and Dorsch, S. J., 2006. Analysis of LiDAR-Derived Topographic Information for Characterizing and Differentiating Landslide, Geomorphology, Vol.73, pp.131-148.

(a)

(b)

(c)

(d)

Hsiao, K. H., Yin, C. Y., Liu, J. K., Yu, M. F., and Wang, C. L., 2003. Landslide Identification Using SPOT Imageries and Aerial Photographs, Journal of Photogrammetry and Remote Sensing, Vol.6, No. 4, pp. 29 – 42. (In Chinese)

Hung, J. J., 2000. Chi-Chi earthquake induced landslides in Taiwan, Earthquake Engineering and Engineering Seismology, vol. 2, no. 2, pp. 25-33.

Luckman, A., Quincey, D., and Bevan, S., 2007. The potential of satellite radar interferometry and feature tracking for monitoring flow rates of Himalayan glaciers, Remote Sensing of Environment, 111: 172-181.

Noferini, L., Pieraccini, M., Mecatti, D., Macaluso, G., Luzi, G., and Atzeni, C., 2006. Long term landslide monitoring by ground-based synthetic aperture radar Interferometer, International Journal of Remote Sensing, 27(10):1893-1905.

Sohl, T., 1999. Change analysis in the United Arab Emirates: an investigation of techniques, Photogrammetric Engineering and Remote Sensing, vol. 65, no. 4, pp. 475-484.

Silapaswan, C.S., Verbyla, D.L., and Mcguire A.D., 2001. Land cover change on the Seward Peninsula: the use of remote sensing to evaluate the potential influences of climate warming on historical vegetation dynamics. Canadian Journal of Remote Sensing, vol. 27, no. 5, pp. 542-554.