EARTHQUAKE DESTRUCTION ASSESSMENT OF URBAN ROADS NETWORK USING SATELLITE IMAGERY AND FUZZY INFERENCE SYSTEMS

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ABSTRACT:

The idea of assessing the damages to roads network after earthquake strikes has been referred as a matter of importance for performing every systematically planned activity in the affected region. When gathering information about the devastated region is crucially costly and time-consuming and in most cases impossible, high-resolution satellite imagery is hired to provide fast and accurate information for every assessment and evaluation processes. Therefore, this research is mainly focused on design and development of a method to evaluate the damages to the roads network, using pre-event digital vector map and post-event high-resolution satellite imagery. In this case, using pre-event digital vector map and post-event satellite imagery, the roads network is extracted and then processed for determination of road blocks across city roads network. The existence of many violating objects at the scene of satellite imagery may mislead the process of finding blocked roads. Therefore, violating objects are detected and removed through Fuzzy engines. Then, analyzing the spectral and textural properties and comparing specific computed set of descriptors, the damage and no-damage objects are marked. Through inspecting the results, hiring Fuzzy Inference Systems, the blocked road sections in the region are detected. The proposed method is evaluated using digital vector map and QuickBird Pan-sharpened images of the city of Bam, located southwest of Iran regarding to the devastating earthquake in December 2003. The visual inspections have confirmed the capabilities of the method for evaluation urban road network after earthquake strikes.

1. INTRODUCTION

Among all elements of urban infrastructure and lifelines, urban roads network, also known as transportation lifeline, has been referred as a critical factor in social and economical life of urban residents and a vital tool for deploying goods and services in every part of the city. It should be considered that the strike of any hazardous power of nature such as earthquakes may violate the functionality of city roads network and as a result, any road dependent activity, required after disasters would be interrupted. Therefore, the necessity of assessing the damages to the roads network after earthquakes is considered as a major basic task for deploying accurately designed plans for rescue and relief, rebuilding and recovery missions. When the most damage assessment techniques are costly time-consuming expert dependent direct procedures, the invention of a new method for fast and accurate damage assessment is vitally important.

Since the advent of high-resolution satellite imagery and the spread of commercial image acquisition systems, the use of these highly enriched information sources for every automatic detection, recognition and assessment tasks, was the key points in many recent researches and papers (Huyck, 2004; Adams, 2007). The ability of providing highly accurate satellite data after earthquake strikes without making any violation in the critical situation of the affected city in the soonest possible time, has encouraged specialists for invention of assessment techniques on the basis of satellite images(Chiroiu, 2002; Gusella, 2005). On the other hand, complications and diverse characteristics of different information sources of high resolution satellite imagery and the intrinsic property of uncertainty in detection and recognition procedures, justifies the idea of hiring the brand new intelligent computing techniques such as Fuzzy Inference Systems.

Here, the design and development of a method for assessing the damages to the road network using high resolution satellite images is proposed. The general challenge of destruction assessment using spatial information is concentrated in two sections:

1- Positioning and extracting the target objects using pre-event spatial data (road extraction)
2- Determination and evaluation of the damages to the extracted objects using post-event spatial data.

As a matter of fact, the proposed algorithm is supposed to utilize both pre-event and post-event spatial data, which could be presented in raster and vector formats. Therefore, Roads are extracted considering pre-event spatial data and then evaluated using post-event high-resolution satellite imagery.

2. A REVIEW ON ROAD EXTRACTION METHODS

Road extraction techniques are the basic notes of composing a damage assessment method, inspecting roads. Regardless of the importance of reviewing road extraction techniques in positioning and extracting road segments in the image, the overall orientation of road extraction and damage evaluation processes and algorithms are closely adjoined.

Diverse road extraction techniques have been introduced since the first appearances of satellite images and direct data acquisition systems such as Radar SAR and LIDAR (Bajcsy, 1976; Bacher, 2005). In general, all methods of road extraction could be categorized according to the utilized spatial data, and the algorithms to produce desired results. The spatial data could be in the range of satellite aerial high and low resolution satellite images to LIDAR and digital vector maps. In (Bacher 2005) a method is proposed, using high-resolution multi-spectral IKONOS imagery for extraction of roads on the basis of supervised classification and edge detection techniques. In the method presented in (Baumgartner, 1999), road extraction from aerial gray value images, hiring context information and Ribbon snake is practiced. In (Hu, 2004), fusing high resolution satellite and LIDAR data, better results for road extraction in urban area are achieved. On the other hand, the proposed method in (Klang, 1998) has hired the information content of digital vector map accompanied with satellite imagery to perform road extraction.

Various different algorithms have been introduced for road extraction. Among them, snakes models (Gruen 1997), Hough Transform (Hu, 2004), Artificial Neural Networks (Bhattacharya 1997; Valadan Zoej, 2004), Dynamic Programming (Gruen 1995) and Multi-resolution Analysis (Baumgartner, 1999; Couloigner 2000) can be referred.

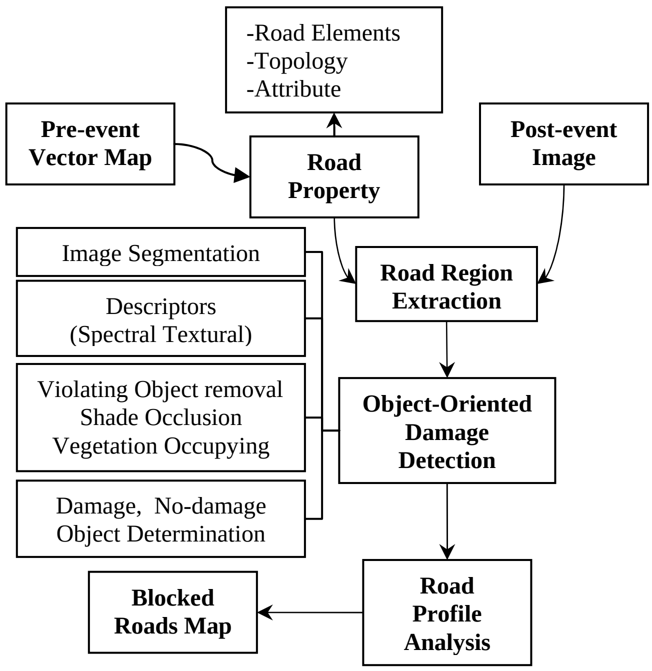

Figure 1. The flowchart of the proposed method

3. PROPOSED METHOD FOR URBAN ROAD DESTRUCTION ASSESSMENT

3.1 General Overview

As mentioned, in this paper a method is proposed for evaluation of roads earthquake destructions using pre-event vector maps and post-event high-resolution satellite imagery. The flowchart of the proposed method is presented in Figure.1.

Generally, the method is presented in two sections. Firstly, the properties of road elements in the vector map including spatial coordinated, topological information and attributes are extracted. Road elements are the smallest road segment composed of a set of start-end points. As a result, the start-end point coordinates of each road elements and properties such as width and type are acquired. The information is directly used for locating road regions in the post-event satellite image. In the second section, analyzing the extracted road regions, damaged parts are determined.

3.2 Road Regions Extraction

Acquiring road elements coordinates and properties, vector road sections are overlaid onto geo-referenced satellite image. The corresponding pixels which are located in the road locations considering coordinates and width are extracted as road regions in post-event map. From now, the processing element of the algorithms is proposed as each set of pixels in each road regions.

3.3 Object-Oriented Damage Detection

3.3.1.Image Segmentation: The proposed method is hiring an object-oriented detection process for assessing roads characteristics. So, each extracted road region should be divided into sub regions, called objects, within which each share a specific characteristic. Generating objects is performed though image segmentation. The object-oriented process categorizes each object to each proposed class.

3.3.2.Descriptors: Descriptors are tools for translating the information content of spatial data to the language of logic and mathematics. Comparing the computed descriptors for each generated object, the damage detection procedure is performed. A wide range of commonly used descriptors can be considered for violating objects removal and damage objects determination, revealing spectral and textural information (Haralick 1979). Table 1, presents some prominent studied descriptors.

3.3.3.Violating Objects Removal: The analysis of objects to recognize damage and no-damage objects is not as easy as it seems. In practice, the road regions from the post-event satellite data are not only composed of damaged and undamaged objects. In reverse there are 。some violating objects that could make challenges in objects recognition procedure. Four types of violating objects are detected considering road regions which are 1-Shade 2-Occlusion 3-Vegetation and 4-Occupying objects

The shade is generated from the low Sun angle and elevated features. Shade may cover the surface of the road completely or partially and interfere with recognition process. Occlusion is the result of low imaging angle and elevated object such as trees and specially buildings. Vegetation in the road region may consist of trees and lawn and should be determined for better recognition and finally, occupying objects which are literally located on the surface of the road such as cars must be removed.

The existence of those violating objects, directly affects the final results so they should be detected and removed out of assessing process. Therefore, four distinct procedures should be designed for these objects detection and removal. Each procedure utilizes its own set of descriptor and Fuzzy Inference System to assign each region to each category. Though this procedure, all violating objects are detected and removed.

3.3.4.Damage, No-damage Objects Determination: After detecting and removing the violating objects, the remaining objects can be classified to damage and no-damage. The procedure could be very the same as detecting violating objects and is performed considering its own set of descriptors and Fuzzy Inference System. As a result, each object in the road region is completely assigned to one of violating objects or categorized as damage or no-damage.

Descriptors	Formulation
Mean	$\bar{C}_L = \frac{1}{n}\sum_{i=1}^{n} C_{Li}$
StdDev	$\sigma_L = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(c_{Li}-\bar{c}_L)^2}$
Semi Vari	$\gamma(h) = \frac{1}{2\rho(h)}\sum_{1}^{\rho(h)}\{z(x_i)-z(x_i+h)\}^2$
Homogeneity	$\sum_{i,j=0}^{N-1}\frac{P_{i,j}}{1+(i-j)^2}$
Ang Sec Mom	$\sum_{i,j=0}^{N-1} P_{i,j}{}^2$
Entropy	$\sum_{i,j=0}^{N-1} P_{i,j}(-\ln P_{i,j})$
Dissimilarity	$\sum_{i,j=0}^{N-1} P_{i,j}\,\lvert i-j \rvert$
Contrast	$\sum_{i,j=0}^{N-1} P_{i,j}(i-j)^2$
Min/max Dif	Max-Min

Table 1. Descriptors studied in the research

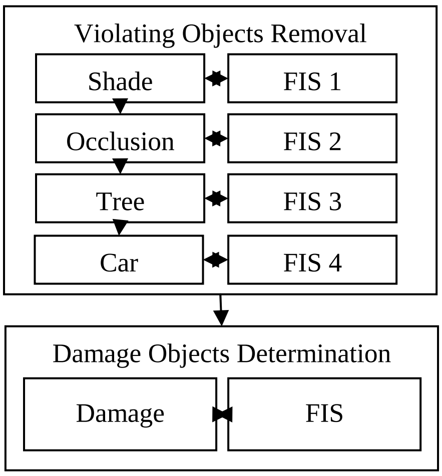

Figure 2. Fuzzy Inference Systems for violating objects removal and damage objects determination

3.4 Road Profile Analysis

As a result of performing damage objects determination, all the objects are classified to one and only one class. Nevertheless, the results do not reveal any information for assigning a road blocked or unblocked. Therefore, through counting pixels, assigned to each class along each cross profiles of the road, the position of the blocks on the roads network can be determined. The counted pixels are normalized and then analyzed through a Fuzzy Inference System to determine if any cross profile of the road region is blocked. Positioning the centre of road blocks, they are projected onto the digital vector map where network analysis can be performed for every route based application.

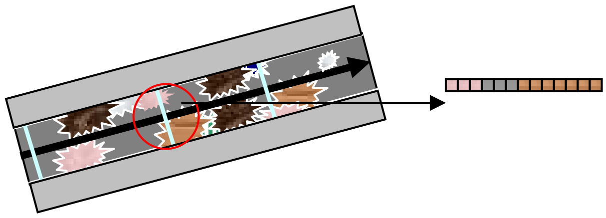

Figure 3. Cross profiles proposed to inspects blocked section

4. EXPERIMENTS AND RESULTS

To inspect the capabilities of the proposed method in locating blocked sections of the roads network, experiments and tests are performed utilizing pre-event digital vector map and post-event QuickBird Pan sharpened high-resolution satellite images of the city of Bam located south west of Iran, regarding to the devastating earthquake strike in December 2003.

Figure 4. High-resolution satellite Imagery and overlaid digital vector map

Acquiring road elements information, road regions are extracted. In this case, the algorithm extracts the road region according to the road width from attribute data. If no width data exists, the algorithm can use a default width, mentioned by the operator.

For the purpose of object-oriented analysis of the road regions, image segmentation is performed on the basis of Watershed algorithm. To achieve better borders between objects, some edges are enhanced before image segmentation is applied.

As discussed in previous sections, violating objects must be removed for a better assessment of damages. Considering the regional property of the experiment data, only car and shade objects are detected and removed. For each case a Fuzzy Inference System is designed and developed considering specific set of descriptors and membership functions. For the purpose of damage object determination, the same process is hired with specific set of descriptors and Fuzzy Inference System. Descriptors used for each detection procedure are listed in Table 2.

In addition, the results are processed and cleaned up to be prepared for profile analysis. So, morphological opening is applied to achieve smooth values and to handle probable noises. To perform simpler pixel count, the road region is projected according to track orientation. The final results are illustrated in Figure 5.

Process	**Descriptors**
Car	Mean , StdDev
Shade	Mean , StdDev Semivar1
Damage	Mean, Dissimilarity Semivar1 Contrast

Table 2. The list of descriptors selected for every FIS

The road profile analysis is performed to generate a criterion for locating blocks on the city road network. In this case the results of Fuzzy Inference Systems for Shade and Damage, regarding to each cross profile of the road regions are put together via a Fuzzy Inference System, to mark locations, where the road is completely or critically blocked. The input data and results of Fuzzy Inference System are depicted in Figure 6. Low values in the output graph indicate high probability of existence of a road block. Values under an empirical value of 0.2 are assumed to be blocked roads.

The stated procedure is performed to all road regions in the area and results are evaluated through visual inspections. As shown in Figure 7, Among 17 detected blocks on the roads network, 16 were detected correctly, where no undetected road blocks was found on the region.

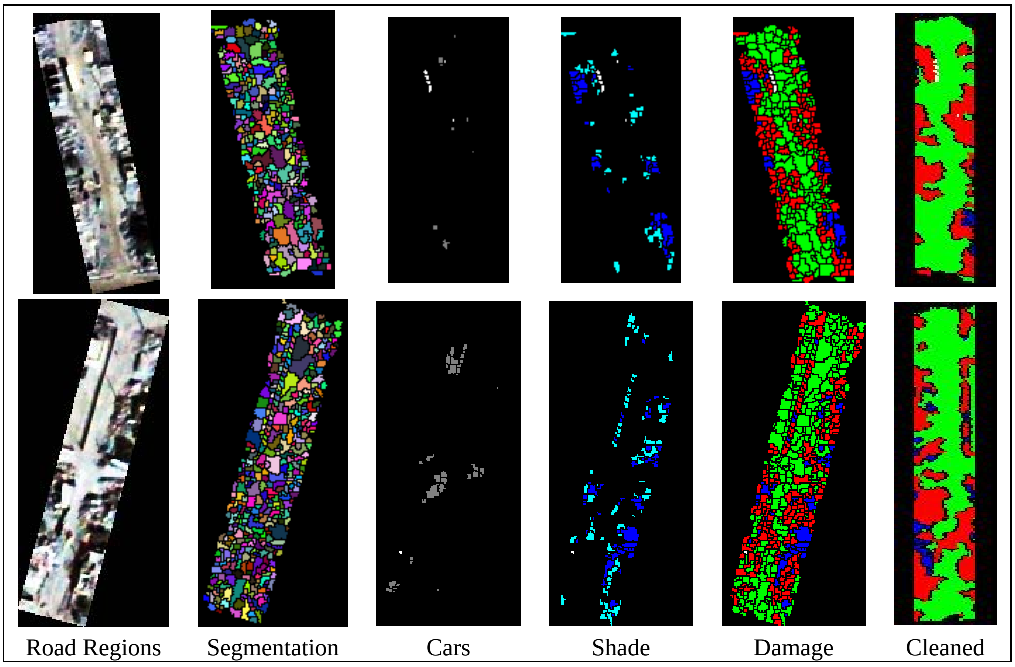

Figure 5. The results of the process of object-oriented damage detection

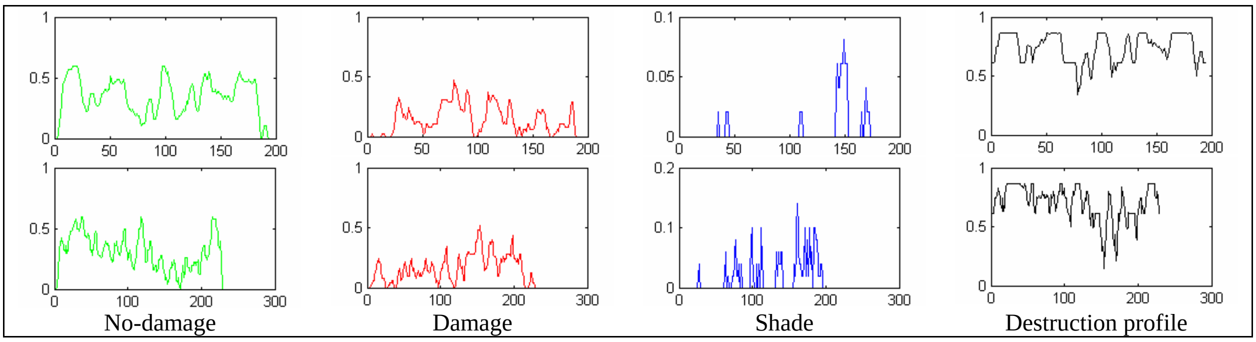

Figure 6. Road profile analysis input and results

5. CONCLUSIONS

This research is dedicated to propose a method for roads network functionality assessment after earthquake strikes. The results indicate a high level of conformity according to visual inspection. In conclusion, the key points in this research could be listed as below:

1- The use of high-resolution satellite imagery information content.
2- The utilization of digital vector maps for the purpose of locating road elements.
3- The idea of hiring Fuzzy Inference Systems for a better handling of uncertainty.

On the basis of this research one might consider that the use of high-resolution satellite images is an effective tool for evaluating road networks after earthquake strike. In this way, the use of accurately generated digital vector maps for extraction of roads in post-event satellite image is supposed to increase the reliability of results. Where deterministic approaches can not handle the uncertainties, Fuzzy Inference Systems are presented to provide acceptable solutions.

Figure 7. Road blocks, Black circles: correct detection, White circle: wrong detection

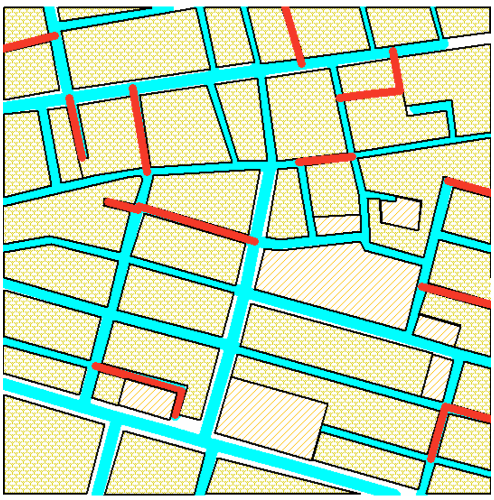

Figure 8. Blocked road map, inaccessible edges are marked

REFERENCES

Adams, B. J. Friendland, C. J. Ghosh, S. Wwomble, J. A., 2007. Engineering and Organizational Issues Before, During and After Hurricane Katrina. Volume 2. Remote Sensing, Advanced Damage Detection for Hurricane Katrina., Available from http://mceer.buffalo.edu/publications/Katrina/06SP02-web.pdf

Bacher, U., Mayer, H., 2005. Automatic road extraction from multi-spectral high resolution satellite images Proceedings of the ISPRS Workshop CMRT 2005 Object Extraction for 3D City Models, Road Databases and Traffic Monitoring - Concepts, Algorithms and Evaluation Vienna - Austria, 29-30 Aug 2005.

Bajcsy, R. , Tavakkoli, M., 1976. Computer Recognition of Roads from Satellite Pictures. IEEE Transaction Systems, Man , and Cybernetics 1976 6(9)623-637.

Baumgartner, A. , Steger, C. , Mayer, H., Eckstein, W., Heinrich, E., 1999. Automatic road extraction based on multi-scale, grouping, and context. Photogrammetric Engineering and Remote Sensing, vol. 65, no. 7, pp. 777–785.

Bhattacharya, U., Parui, S.K., 1997. An improved backpropagation neural network for detection of road-like features in satellite imagery. International Journal of Remote Sensing, vol. 18, no. 16, pp. 3379–3394.

Chiroiu, L. , Andre, G., 2002. Damage assessment using high resolution satellite imagery: Application to 2001 Bhuj, India, earthquake [A/OL], In: EERI eds. Proceedings of 7th US National Conference on Earthquake Engineering: Urban Earthquake Risk [C]. Oak-land, USA.

Couloigner, E., Ranchin, T., 2000. Mapping of urban areas : A multiresolution modeling approach for semiautomatic extraction of streets. Photogrammetric Engineering and Remote Sensing, vol. 66, no. 7, pp. 867– 874.

Gruen, A., Li, H., 1995. Road extraction from aerial and satellite images by dynamic programming. ISPRS Journal of Photogrammetry and Remote Sensing, vol. 50, no. 4, pp. 11–20.

Gruen, A., Li, H., 1997. Semi-automatic linear feature extraction by dynamic programming and LSB-Snakes. Photogrammetric Engineering and Remote Sensing, 63(8), August 1997, pp. 985-995.

Gusella, L., Huyck, C.K, Adams,B.J., Hung Chung, S.C., 2005. Damage Assessment with Very-High Resolution Optical Imagery Following the December 26, 2003 Bam, Iran Earthquake , University of Bologna.

Haralick, R.M.,1979. Statistical and Structural Approaches to Texture. Proceedings of IEEE 67 (5),786–804.

Hu, X., Tao, C.V., Hu, Y., 2004. Automatic Road Extraction from Dense Urban Area by Integrated Processing of High Resolution Imagery and Lidar Data. Proceedings of ISPRS XXth Congress, Istanbul, Turkey, July 12- 23, 2004.

Huyck, C.K., Adams, B.J., Cho, S., Eguchi, R.T., Mansouri, B. and Houshmand, B., 2004. Methodologies for Post-earthquake Building Damage Detection Using SAR and Optical Remote Sensing: Application to the August 17, 1999 Marmara, Turkey

Earthquake, MCEER-04-0004 Technical Report, MCEER: Buffalo.

Klang, D., 1998. Automatic Detection of Changes in Road Databases Using Satellite Imagery. IAPRS, Vol. 32, Part 4 "GIS-Between Visions and Applications", Stuttgart, 1998,pp.293-298.

Valadan Zoej, M.J., Mokhtarzadeh, M., 2004. Road Detection from High Resolution Satellite Images Using Artificial Neural Networks, Proceedings of ISPRS XXth Congress, Istanbul, Turkey, July 12- 23, 2004.