DETECTION OF THE EARTHQUAKE DAMAGED BUILDINGS FROM POST-EVENT AERIAL PHOTOGRAPHS USING PERCEPTUAL GROUPING

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ABSTRACT:

The collapsed buildings due to Izmit, Turkey earthquake that occurred on 17 August 1999 were detected from post-event aerial photographs using the shadow analysis and the perceptual grouping procedure. The selected area of study is a part of the city of Golcuk, which is one of the urban areas most strongly hit by the earthquake. The area contains a total of 282 buildings, of which 79 are collapsed and 203 are un-collapsed. First, the Canny edge detector was applied to detect the edges between the cast shadows and the surroundings. Second, the output edge image was converted into vector line segments through a raster-to-vector conversion process. These line segments were then grouped together using a two-level hierarchical perceptual grouping procedure. The boundaries of the buildings were available and stored in a GIS as vector polygons. Therefore, after the perceptual grouping procedure, the damage conditions of the buildings were assessed on a building-by-building basis by measuring the aggreement between the detected line segments and the vector building boundaries. The results obtained is satisfactory. The overall accuracy was found to be 72.6%. Of the total 79 collapsed buildings, 63 were detected correctly by the proposed approach, giving 79.7% producer's accuracy.

1. INTRODUCTION

On 17 August 1999, a strong earthquake (magnitude 7.4) occurred in north-west of Turkey. This devastating seismic activity proved to be one of the most deadly earthquakes to strike Turkey in recorded history. According to Turkish Government figures, about 17000 people lost their lives. There were more than 48000 people injured and thousands of buildings were totally or partially damaged. The region is in the first degree earthquake zone. Approximately, 20% of the total population live in this region. In addition, most of the industrial complexes and power plants are also established in this region.

The identification of damaged buildings after such a destructive event is a vital issue to get information about the extent and the location of the hard hit areas. Of course, the assessment of the damaged buildings can be carried out accurately through a field survey. However, this would require a lot of resources and time. Therefore, a rapid assessment of the damaged buildings is required for dispatching resque teams and emergency services to hard-hit areas. The post event aerial and space images have become important data sources for the identification of the damaged areas. Using pre- and post-event SPOT HRV images, Turker and San (2003) detected the Izmit earthquake induced changes. The change areas were detected by subtracting the near-infrared channel of the merged pre-event image from that of the post-event image. The overall accuracy for the change areas was found to be 83%. In a recent study, Turker and Cetinkaya (in press), detected the collapsed buildings caused by the 1999 Izmit, Turkey earthquake using digital elevation models (DEMs) created from the aerial photographs taken before (1994) and after (1999) the earthquake. The DEMs created from two epochs were differenced and the difference DEM was analyzed on a building-by-building basis for detecting the collapsed buildings. The producer's accuracy for collapsed buildings was computed as 84%. Further, Turker and San (in press) utilized the cast shadows to detect the collapsed buildings due to Izmit, Turkey earthquake. The available vector building boundaries were used to match the shadow casting edges of the buildings with their corresponding shadows and to perform analysis in a building specific manner. Of the 80 collapsed buildings, 74 were detected correctly, providing 92.50% producer's accuracy.

This study presents a different approach for detecting the collapsed buildings due to earthquake. The proposed approach is based on perceptual grouping and utilizes the relationship between the buildings and the cast shadows. It is assumed that if a building is fully damaged and collapsed due to earthquake, it will not have corresponding shadows. The digital processing of the shadow producing edges of the buildings can therefore provide very useful cues for detecting the collapsed buildings. The building boundaries are available and stored in a GIS as vector polygons. The agreement is measured between the shadow casting edges of the buildings and the corresponding vector boundaries through perceptual grouping. The decision about the condition of a building assessed is taken based on the degree of the agreement between the two data sets.

2. STUDY AREA AND DATA

The selected study area is the part of the city of Golcuk, which is one of the areas most strongly hit by the earthquake. It is located on south coast of Izmit Bay, which is east-west elongated structural basin situated along the North Anatolian Fault (NAF) at the eastern margin of the sea of Marmara. The study area contains a total of 282 buildings. Of these buildings, 79 were fully damaged and collapsed and the remaining 203 buildings were un-collapsed. The post-event aerial imagery dated September 1999 (1:16,000-scale) was used for the analysis (Figure 1). The imagery was supplied by the General Command of Mapping (GCM) of Turkey.

Figure 1. Study Area.

3. THE METHODOLOGY

3.1 Edge Detection and Vectorization

First, the Canny edge detection operator was applied to the post-event aerial imagery in order to extract the edge pixels between the buildings and their surroundings. The reason for choosing the Canny edge detector was its efficiency and the output it provides as one pixel wide edges. The one-pixel wide edges are used in turn as the input for the vectorization process. To apply the Canny edge detector algorithm, a built-in function of Matlab 6.1.0 was used. The output of the Canny edge detector is given in Figure 2.

Then, the output edge image was converted into vector line segments using a raster-to-vector conversion process. During the vectorization process, the locations of the vertexes on the edge pixel segment were found. Two vertexes represent a line segment, which may be a candidate for an edge of a building. In other words, each vertex defines a terminal point of a line segment. Therefore, it is important to find the locations of the vertexes.

Figure 2. The output of the Canny edge detector.

To run the vectorization algorithm, two parameters were used: (i) tolerance value (ε) and (ii) the number of pixels to recognize a vertex (N). The first parameter is required to decide if an edge pixel is a vertex or not. The second parameter is used to define the minimum number of pixels to search a vertex. A line is drawn between the first and the N^{th} pixels. Then, a pixel that violates the straight line by means of the tolerance value is searched for on the edge pixel segments. This process continues from first to the last pixel of the edge pixel segments and therefore, the line segments are generated. In the present case, 1.5 m and 13 pixels were used for ε and N respectively.

3.2 Perceptual Grouping

The line segments generated above through the vectorization process were available for perceptual algorithm. To group the line segments, a two-level hierarchical method was used. First, the colinear line segments were grouped together to see if they are closely located. This process was carried out to construct a full line, which might have been fragmented somehow during the edge detection and the vectorization steps. Then, the lines were grouped together to find a corner. Finally, the conditions of the buildings were assessed.

3.2.1 First Level Grouping

In the first level grouping, those line segments belonging to an edge of a building were combined. To do that two parameters were used: (i) proximity and (ii) collinearity. While the proximity refers to the distance between the line segments, the collinearity measures the orientation between them. In the present case the proximity value was selected to be less than the minimum distance between the buildings present in the study area. Otherwise, two line segments that belong to different buildings would be erroneously combined. The first level grouping is illustrated in Figure 3.

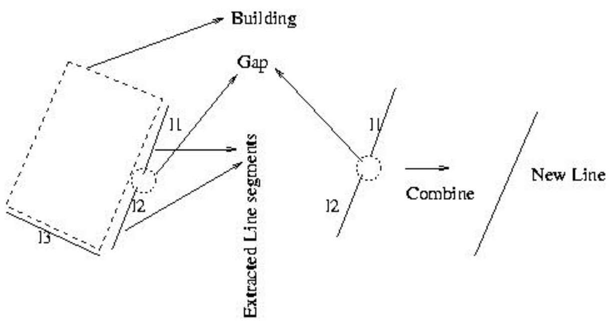

Figure 3. The first level perceptual grouping.

3.2.2 Second Level Grouping

The study area contains usually the rectangular shaped buildings. As can be known, the edges of a rectangular shaped building intersect at the corners with an angle around 90^0. Therefore, in the second level grouping, the corners were used as an indication of a building and the line segments were grouped according to the principles of the perpendicularity and the proximity. For each couple of line segments, these two principles were checked whether they were satisfied or not. When a couple of line segments were detected then, these two line segments were grouped together. The second level grouping is illustrated in Figure 4.

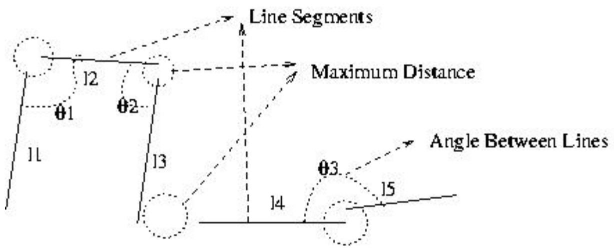

Figure 4. The second level perceptual grouping.

3.3 Assessing the Conditions of the Buildings

After grouping the line segments through the perceptual grouping procedure, the conditions of the buildings were assessed on a building-by-building basis. For each building, the assessment was carried out based on the measurement of the agreement between the above detected line segments and the vector building boundaries. This is based on an assumption that if the vector building boundaries match with the detected line segments then, the building under consideration is declared to be un-collapsed. To measure the degree of the match between the line segments and the vector building boundaries, three parameters were used: (i) the orientation, (ii) the distance between the line segments and the edges of the building polygons, and (iii) the length of the line segments.

Of these parameters, the orientation was used to measure the degree of parallelism between the detected line segments and the edges of the vector building polygons. In the present case, the value for the orientation was set to 10^0. The distance between the detected line segments and an edge of a vector building polygon shows how close the line segments are to the edge of the vector building polygon. The closer the line segments to an edge of the building polygon the higher the chance that they belong to that building. The third parameter measures the degree of the coincidence between the line segments and the edges of the building polygons. If a building is collapsed then, the degree of the coincidence will be low. On the other hand, the un-collapsed buildings are expected to show a high degree of coincidence.

This is illustrated in figure 5 where, l1, l2, l3, l4, and l5 represent the line segments detected through perceptual grouping procedure. The broken lines illustrate the boundaries of the vector building polygon. As can be seen in the figure, there is a full overlap between the line segment l1 and the left edge of the building polygon. The overlap between l2, l3, and l4 and the upper edge of the building polygon is about 75%. On the other hand, approximately 50% overlap is measured betwen l5 and the right edge of the building polygon. In the present case the threshold value was taken as 75%.

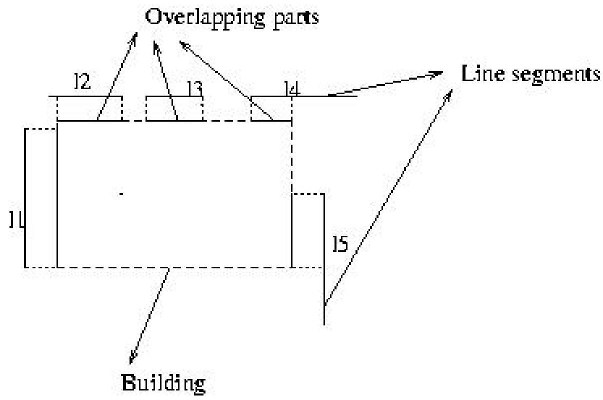

Figure 5. The overlaps between the line segments and a building polygon.

The final decision about the damage condition of a building was made based on the degree of overlap between the edges of the vector building polygon and the above detected line segments. If at least three edges of the building polygon show an overlap above the pre-set threshold of 75% with the line segments then, the polygon is declared to be un-collapsed. However, due to the illumination effect and the type of the roof material, the contrast between the roofs and the surroundings may not be high and therefore, those edges of the buildings located in the opposite direction of the illumination may not be detected by the Canny edge detector. As a consequence, because of the misdetected edges, the un-collapsed buildings can be labeled wrongly as collapsed. To overcome this problem, the shadow producing edges of the buildings were tested. If the shadow producing edges of a building show an overlap of above the pre-set threshold value with the line segments and if there is a shadow corner formed by these edges then, the building is labeled un-collapsed.

4. RESULTS

The assessment results of the proposed damage detection approach is given in table 1. The results show that the proposed approach for detecting the collapsed buildings due to earthquake is satisfactory. A high degree of aggreement is evident between the assessment results and the reference data. A total of 282 buildings falling within the selected area of study were assessed. Of these buildings, 205 were correctly labeled as collapsed and un-collapsed, providing an overall accuracy of 72.6%. Of the total 79 collapsed buildings, 63 were correctly detected. The producer's and the user's accuracies were computed, for collapsed buildings, as 79.5% and 50.8% respectively. Compared with the producer's accuracy, the user's accuracy is significantly low. It appears that sixteen buildings were omitted from the collapsed category.

For un-collapsed buildings, the user's accuracy was found to be remarkably higher than that of collapsed buildings. The producer's and user's accuracies of un-collapsed buildings were computed as 70.0% and 89.9% respectively. Of the total 203 un-collapsed buildings, 61 were omitted from this category while 142 were labeled correctly. The assessment results are also illustrated graphically in figure 6. In the figure, the green colored buildings represent the un-collapsed buildings. The red colored buildings represent the collapsed buildings. The yellow and the blue colored buildings represent the omisssion error for collapsed and un-collapsed buildings, respectively.

	Reference		
	Collapsed	Un-collapsed	Total
Collapsed	63	61	124
Un-collapsed	16	142	158
Total	79	203	282
Producer's (%)	79.7	70.0	
User's (%)	50.8	89.9	
Overall (%)	72.6		

Table 1. The error matrix.

The erroneously categorized buildings were further investigated to find out what might have caused them to deviate from reference data. It appears that the main reason for 16 collapsed buildings to be wrongly categorized as un-collapsed is the spacing between the buildings. The rather short distance between the buildings caused the line segments detected through perceptual grouping to match with the wrong buildings. Therefore, 16 collapsed buildings were wrongly labeled as un-collapsed. Similarly, 61 un-collapsed buildings were wrongly categorized as collapsed. There seems to be two main reasons that cause these false negatives. The first one was the absence of the edges on the boundaries of the buildings. It was therefore, impossible to find a line segment corresponding to the edges of the buildings. Of the 61 un-collapsed buildings, 38 were found to be erroneously labeled due to this reason. The second reason was the vectorization process, through which the line segments were detected and smoothed. The smoothing process might have changed the orientations of the line segments. Therefore, the difference between the orientations of the line segments and the edges of vector building polygons might have stayed above the pre-set threshold level. Therefore, because the rule of orientation does not work in such a case the un-collapsed buildings are wrongly labeled as collapsed, therefore.

Figure 6. The results of the assessments.

5. CONCLUSIONS

In this study, an approach was presented for detecting the collapsed buildings due to earthquake. The proposed approach is based on the perceptual grouping and utilizes the relationship between the buildings and the cast shadows. The results of the analysis reveal that cast shadows can provide very useful cues for detecting the collapsed buildings. The results achieved in this study are satisfactory. The overall accuracy was computed as 72.7%. Of the 79 collapsed buildings, 63 were detected correctly, providing 79.7% producer's accuracy. Compared with the collapsed buildings, a lower degree of agreement is evident between the assessment results and the reference data for un-collapsed buildings. Of the total 203 un-collapsed buildings, 142 were labeled correctly, providing 70.0% producer's accuracy.

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