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DETECTION OF DAMAGE DUE TO THE 2001 EL SALVADOR EARTHQUAKE USING LANDSAT IMAGES

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ABSTRACT: A strong earthquake hit El Salvador on January 13, 2001. The earthquake with a magnitude of 7.6 caused huge damage in the urbanized areas as well as numerous landslides. In case of large scale earthquakes, the identification of hard hit areas is important and necessary information for decision-makers to handle the disaster relief process. In this study, remote sensing images taken before and after the earthquake by Landsat 7 (ETM+) satellite are compared to identify the location of landslides and hard hit urban areas. The proposed method uses the rationing between bands in the visible range as well as the sharpening of the multi-spectral bands by merging with the panchromatic band. It is expected that with the help of this additional band the identification of landslides and damaged areas will be improved.

1. INTRODUCTION

Recently remote sensing satellite images have become a tool for damage detection. Thanks to their capacity of covering large area of land, the temporal changes that natural events, i.e. earthquakes, floods, landslides, etc., cause can be monitored. This information is vital for decision-makers to understand the extent of damage and thus to conduct the response/recovery activities. In case of El Salvador 2001 Earthquake many landslides were triggered due to the earthquake, as consequence many houses were buried and roads were blocked with the debris.

In order to identify the location of landslides, pre- and post-event sharpened images of Landsat-7 are visually compared. The sharpness is obtained by merging the first three visible bands of 30m pixel-resolution (taken as the low-resolution color image) with the eighth band, the panchromatic band, of 15m pixel-resolution (taken as the high-resolution grayscale image). As a result an RGB image of 15m pixel-resolution is obtained. The detection of heavily damaged areas has been carried out by comparison and rationing between different bands in the visible range.

2. THE JANUARY 13, 2001 EL SALVADOR EARTHQUAKE

On January 13, 2001 at 11:33 am (local time) a strong earthquake with a magnitude Mw=7.6 hit the Republic of El Salvador. It was a subduction zone earthquake off the coast of El Salvador. According to USGS the epicenter was located at 12.83°N and 88.79°W about 110 km south-southeast of San Salvador city (Figure 1). The earthquake was also felt in Mexico, Guatemala, Honduras and Nicaragua. The most affected departments were La Libertad, La Paz, San Vicente and Usulutan in the central part of El Salvador. Officially the toll of the earthquake was 944 deaths and 5,565 injured people, and 1,155 public buildings and 169,692 dwellings were damaged while 108,261 dwellings were destroyed and there were 445 landslides that buried 688 houses. The most affected cities were those located in rural areas where the majority of dwellings are made of adobe or bajareque. Adobe is a kind of hand-made brick, made of unbaked soil (sand, silt, straw and clay) and it's widely used because its low cost. As we can understand the adobe houses have very poor bear capacity against dynamics loads due to quakes. The bajareque houses are made with wooden studs to which cane are attached forming the walls of the house. The walls are filled with mud made of a mix of sand, clay and vegetable fibers. In large cities, where reinforced concrete building and masonry houses are the common, the damage due to the earthquake was limited only to cracks in infill walls and in some cases structural damage were observed, but they did not collapse.

Figure 1. Map of the Republic of El Salvador and the location of the epicenter.

3. DATA

The data used in this study are remotely sensed images taken before and after the earthquake. The pre-event image was taken on November 15, 2000 and the post-event image was taken on February 19, 2001 (Figure 2). The images were acquired by Landsat 7 satellite, which carries the Enhanced Thematic Mapper Plus (ETM+) sensor. This satellite is operated since April 1999. Unlike the previous Landsat missions, this satellite carries an additional panchromatic band of 15 m resolution and the thermal band with 60 m resolution. The image covers an area of 183 km x 170 km, the satellite has a repeat interval of 16 days and its Altitude is 699 km.

Figure 2. Landsat 7 pre-event image (RGB 751).

4. IMAGE ENHANCEMENT

Colors are formed by the combination of different amounts of red, green and blue lights. Figure 3(a) shows a geometrical representation of the RGB model color cube. The origin of this cube is black and the coordinates are given for values over the axes red, green and blue. Notice that white light is formed by the addition of maximum red, green and blue. The HSI model uses the concepts of hue (H), saturation (S) and intensity (I) to explain the idea of color. Hue refers to the dominant or average wavelength of light contributing to a color. Saturation specifies the purity of color relative to gray. Intensity relates to the total brightness of color. Figure 3(b) shows a 3D geometrical representation (hexcone) of the HSI model. Hue, the dominant wavelength of the perceived color, is represented by angular position around the top of the hexcone (e.g. red at 0°, Green at 120°, and blue at 240°). The saturation or purity is given by the distance from the center, vertical axis of the hexcone, to the border. The intensity or value, is defined by the distance along the gray line, from black to any given hexagonal projection. Any pixel in the RGB color space can be transformed into its HSI counterpart and vice versa.

The hue, saturation and intensity transform is useful in two ways: (i) as a method of image enhancement and (ii) as a means of combining co-registered images from different resolution or sources. Figure 4 illustrates this process. First RGB bands (i.e. Bands 3, 2 and 1) are converted into HSI; this process is called Encode. Afterwards, the spatial resolution is changed to match the image with high resolution and the intensity component is replaced by the high-resolution data, in case of Landsat 7 the high resolution band is Band 8; this process is called Manipulate (Figure 4). Finally, this new H', S', I' is converted back to R', G', B'; this process is called Decode.

(a) (b)

Figure 3. The color space. (a) Red-green-blue color cube. (b) Hue-saturation-intensity hexcone.

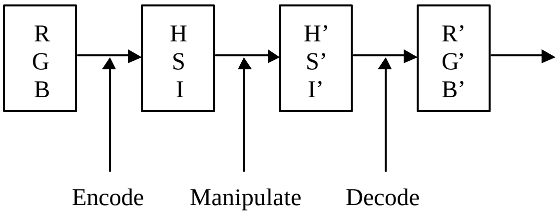


Figure 4. RGB/HSI encoding and decoding for image enhancement.

4.1 RGB to HSI transformation

First the RGB values have to be normalized by their maximum values, so that the range of RGB is [0, 1]. The ranges of S and I are also [0, 1] and the range of H is [0, 2π] (Japan Association on Remote Sensing, 1996).

$I=\max(R, G, B)$

If $I=0$; then $S=0$ and H=indeterminate

If $I\neq 0$, Let $i=\min(R, G, B)$
Then $S=(I-i)/I$
Let $r=(I-R)/(I-i)$, $g=(I-G)/(I-i)$, $b=(I-B)/(I-i)$
Then: if $R=I$ then $H=(g-b)\pi/3$
if $G=I$ then $H=(2+r-b)\pi/3$
if $B=I$ then $H=(4+g-r)\pi/3$

4.2 HSI to RGB transformation

Once the image has been manipulated, it must be transformed back into the RGB so that the image can be displayed. The transformation from HSI to RGB is as follows:

If $S=0$, $R=G=B=I$ regardless of value of H

If $I\neq 0$, let: $H'=3H/\pi$, $h=\mathrm{floor}(H')$, $P=I(1-S)$,
$Q=I\{1-S(H'-h)\}$ and $T=I\{1-S(1-H'+h)\}$
(floor(x): function of getting the truncated value of x)
Then:
If $h=0$ then: $R=I$, $G=T$, $B=P$
If $h=1$ then: $R=Q$, $G=I$, $B=P$
If $h=2$ then: $R=P$, $G=I$, $B=T$
If $h=3$ then: $R=P$, $G=Q$, $B=I$
If $h=4$ then: $R=T$, $G=P$, $B=I$
If $h=5$ then: $R=I$, $G=P$, $B=Q$

Figure 5 shows an example of this image enhancement.

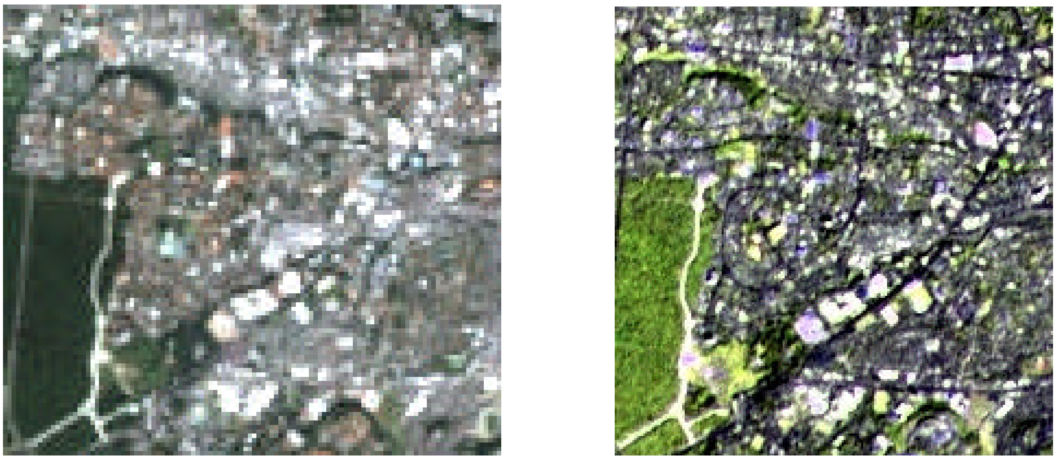

(a) (b)

Figure 5: San Salvador city. (a) RGB (321) composite color image. (b) Sharpened image by HSI transformation and merged with the panchromatic band.

5. LANDSLIDE DETECTION

Once the pre - and post-images have been enhanced, they are compared to identify the location of major landslides. To carry out the visual comparison, the two images are linked to each other, so that visualization area is the same. Afterwards their histograms are matched so that we obtain an apparent distribution of the brightness values in certain range and make the brightness distribution of the two images as close as possible. As a result we achieve two images in which the differences due to landslide are highlighted. Figure 6 (a) and (b) show the pre - and post-event enhanced images via HSI method for one of the major landslides detected. .

(1) Loss Estimation

Geographic Information Systems (GIS) are computer-based systems that can deal with virtually any type of information about features that are referenced by the geographical location. Overlaying a GIS map over a satellite image, we can combine the information kept in the GIS with the visual information given by the remotely sensed image and conduct queries about extension of damage, number of deaths, economic loss, etc.

As mentioned before, a huge landslide occurred at Nueva San Salvador (Figure 6) burying around 600 houses and causing death of 585 people. By overlaying a GIS map over the satellite image (Figure 6(c)) it is possible to estimate how many blocks were buried and then looking in the database kept in the GIS system give some numbers about how many houses were buried, how many people might be killed and so on. Notice in Figure 6(b), there is a white spot at the toe of the landslide. This very high reflection area is due to the spreading of lime over the buried houses to avoid any outbreak of infection.

6. BUILDING DAMAGE DETECTION

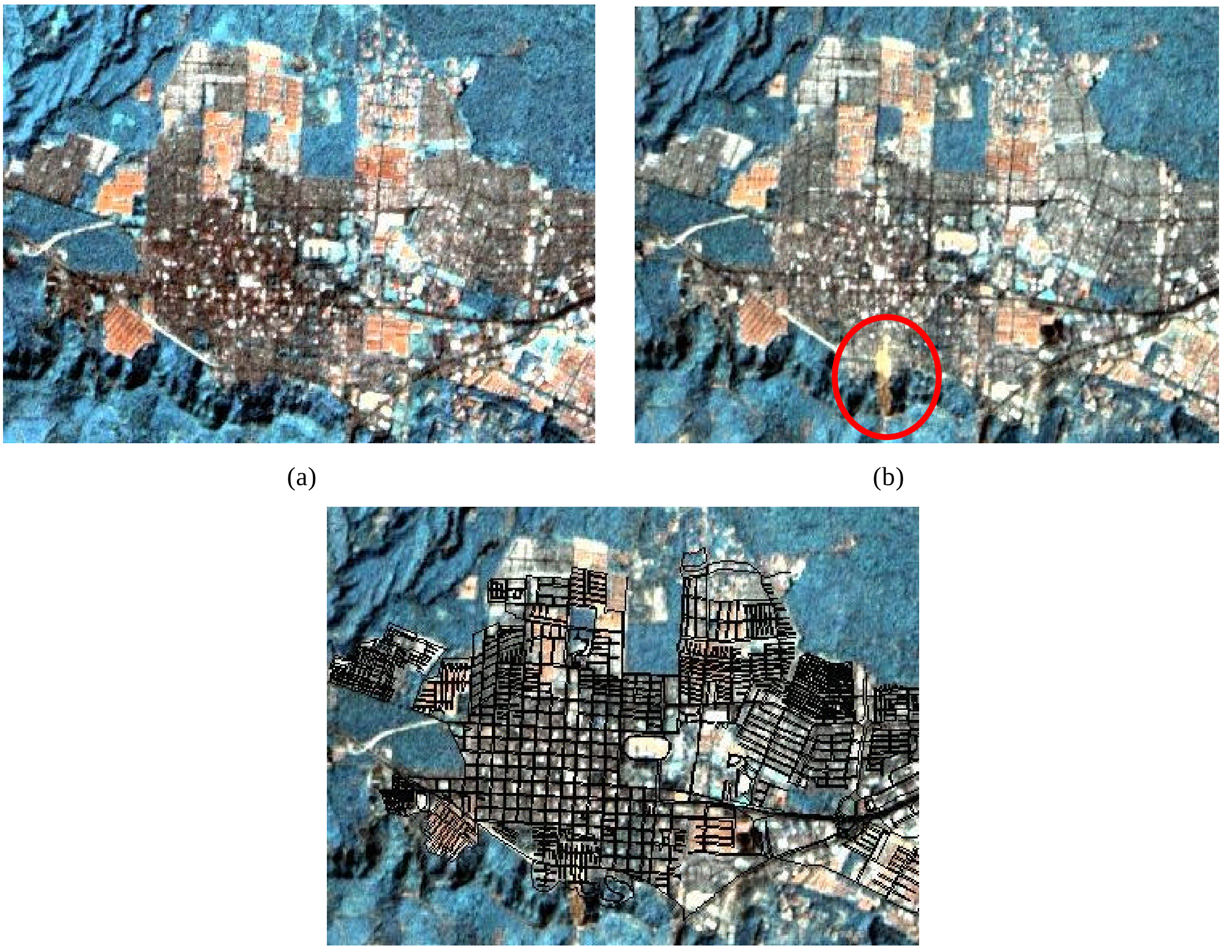
As a method for building damage detection, we conducted the comparison of the data in the visible range. For Landsat, Bands 1, 2 and 3 are within this range. First we calculate the average of these three bands by

$$BR_{avg}(i,j) = \sum_{k=1}^{3} BB_k(i,j) \Big/ 3 \qquad (1)$$

where $BB_k(i, j)$ is the digital number of the pixel (i, j) of the band k of the pre-event image. $BR_{avg}(i, j)$ is the averaged value of the pixel (i, j) of the pre -event image. This same formula is also applied to the post-event image. Then, we calculate the ratio between these two averaged images by Equation 2, where AR represents the averaged image after the event and R the ratio:

$$R(i, j) = AR_{avg}(i, j) \big/ BR_{avg}(i, j) \qquad (2)$$

As a result we obtain a ratio image that is shown in Figure 7.



(a)

(b)

(c)

Figure 6: Enhanced image of Nueva San Salvador. (a) Enhanced pre-event image. (b) Enhanced post-image and location of the landslide. (c) GIS map overlaid on the satellite-enhanced image.

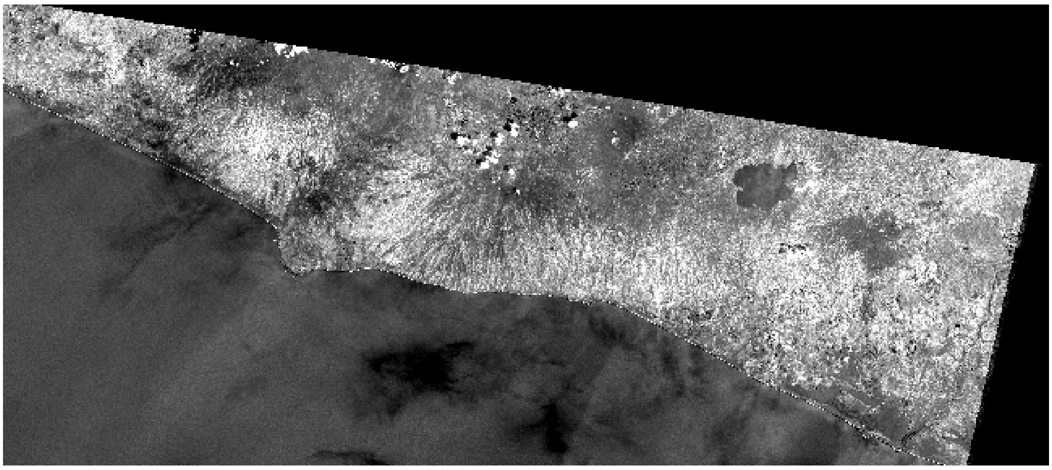


Figure 7: Ratio after/before of the average of the first three visible bands.

Afterwards, we analyzed the values of the modified digital number in this new image for the different levels of damage, to get any typical distribution and we obtained the graph shown in Figure 8. As we can observe the cumulative probability lines that represent the different levels of damage Heavy, Moderate and Minor, are rather close. Due to this proximity between those lines, unfortunately, the identification of different levels of damage is difficult. The most affected cities were those located in the countryside where the common construction material is adobe and the houses are spread in the area. We believe the reflection in the visible range of the spectrum before and after the earthquake hardly has changed due to the material used in the houses. Adobe will remain as it is after the earthquake, and also since the houses are spreading in the countryside the resolution of the satellite image (30 m) is not enough to get the information on the spreading collapsed dwellings.

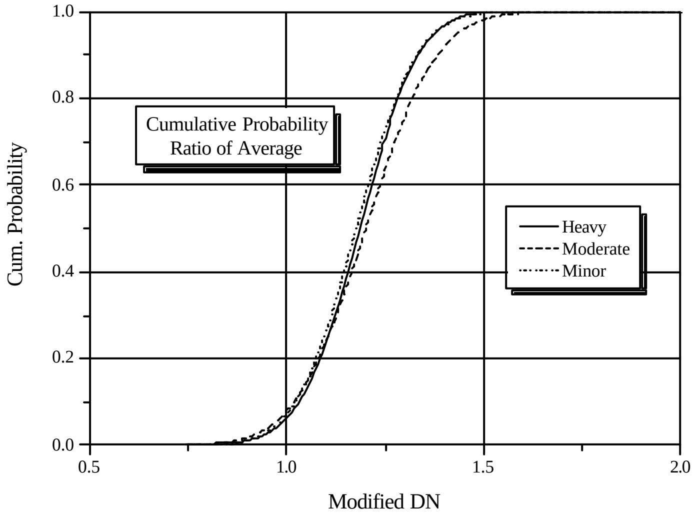


Figure 8: Cumulative probability of the ratio after/before of the averaged images.

7. CONCLUSIONS

Detection of damage due to the January 13, 2001 El Salvador Earthquake has been conducted using satellite images by Landsat-7. By comparing enhanced pre- and post-event images the major landslides were successfully identified. The enhanced method used in this study is the HSI (hue, saturation and intensity) transformation and merging with the high-resolution panchromatic band. In this study, the identification of major landslides was carried out manually. A future study will aim to automate this process.

The identification of different levels of damage through the comparison of the pre- and post-event images in the visible range was not satisfactory. We believe that the changes in the reflection after the earthquake are not detectable due to the construction material of the houses (adobe). A future research on different methods of identification is also necessary

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