Damage Detection using High Resolution TerraSAR-X Imagery in the 2009 L’Aquila Earthquake

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ABSTRACT: The L’Aquila earthquake of magnitude 5.8 occurred on April 6, 2009 in the central Abruzzo region of Italy, causing widespread damage. More than 300 people lost their lives and property worth more than 2,500 million dollars was damaged. We analyze the high-resolution Synthetic Radar Aperture (SAR) imageries from TerraSAR-X along with high-resolution QuickBird optical images for the building damage detection of L’Aquila city center where the damage was mostly concentrated.

Key Words: The 2009 L’Aquila earthquake, SAR imagery, Damage detection.

I. INTRODUCTION

International Disaster Risk Reduction (ISDR) has defined disaster as a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses, which exceed the ability of the affected community, or society to cope using its own resources [1]. Of the various kinds of disasters, natural disasters like earthquakes, floods, landslides are the most prominent in terms of casualty around the world. Timely action in disaster situation is very important. For this purpose, satellite remote sensing can help a lot by providing the data of a large region of affected areas without being there physically. Remote sensing can be defined as a science of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation [2]. Broadly, satellite systems can be divided into two types based on the sensor type viz., optical and microwave sensors. Optical sensors are affected by solar radiation and local weather condition whereas a radar system like synthetic aperture radar (SAR) is independent of weather condition and sunlight. SAR is extraordinary for its capability of recording the surface condition of target regardless of weather or solar illumination. Because of all weather capability, SAR has emerged as a powerful tool in the disaster situations including earthquakes, wildfires and so on [3-4]. With the advancement of the technology, the spatial resolution of SAR has considerably improved and now in the order of 1 meter is possible. In this paper, we utilize the SAR imagery from TerraSAR-X to detect the building damage during the 2009 L’Aquila earthquake.

II. THE 2009 L’AQUILA EARTHQUAKE

Italy has been experiencing different kinds of natural disasters like volcanoes and earthquakes from the historical time. L’Aquila area (Fig. 1) lying in the central Abruzzo region has experienced severe earthquakes in the past, notable events include that of 1315, 1349, 1461, 1703, 1706, 1915, and 1958 [5]. The 2009 L’Aquila earthquake of magnitude 5.8 on the Richter scale (6.3 on moment
magnitude scale) occurred on 6th April at 3.32 am local time causing widespread damage throughout the region. This earthquake took more than 300 lives, caused more than 1,500 people injured and made about 65,000 people homeless. It was the deadliest earthquake in Italy after the Irpinia earthquake in 1980. Figure 2 is the shake map [6] of the earthquake-affected region.

**III. DATA SET AND SAR DATA**

We use TerraSAR-X (X-band, wavelength of 3.1 centimeter) SAR data from Infoterra, Germany. Two sets of data: one pre-seismic (February 6, 2009) and other post-seismic (April 13, 2009) were employed as shown in Fig. 3. These images have incidence angle of 39.2 degree, strip-map acquisition mode with polarization HH (single). The path of satellite is ascending with right look. These images have spatial resolution of 1.25 meter. Figure 4 shows the intensity images of the study area. Similarly, we also use two QuickBird(QB) satellite data from DigitalGlobe. Data include one pre-seismic (September 4, 2006) and other post-seismic (April 8, 2009). These images have spatial resolution of 0.6m for panchromatic mode and 2.4m for multispectral (4 bands) mode.
IV. DAMAGE DETECTION METHODOLOGY

The fundamental idea behind damage detection using microwave radar technology is that man-made structures including buildings in urban areas give strong backscatter returns to the satellite receiver compared to the damaged buildings, as shown in Fig. 5. It is to be noted that the images of urban structures like buildings are affected by layover, double bounce and shadowing effects. Regarding the image processing, we changed the spatial resolution of two SAR images from 1.25 m to 0.6 m to make comparable to 0.6 m pan-sharpened QuickBird images. We remove speckle noise in the SAR images using Lee adaptive filter [7] with a 21×21 pixel window.
Fig. 5: Schematic figure of the geometry of repeat pass satellite observation and backscattering characteristics of the objects on earth’s surface

Radiometric calibration of intensity images was done utilizing equations (1) and (2) after Fritz [8]. The difference \( d \) and the correlation coefficients \( r \) derived from the pre- and post-event SAR images have been used in extracting the changes/damages caused by an event [3], [9-11]. We also calculate these two parameters of backscattering difference value \( d \) and correlation coefficient \( r \) within a 51×51 pixel window from the pre- and post-event SAR images using equations (3) and (4) for change extraction.

\[
\sigma_0 \text{ (dB)} = 10 \log_{10}(\text{Cal Factor} \times DN^2) + 10 \log_{10}(\sin(\Theta_{loc}))
\]

\[
\theta_a = \frac{GIM - (GIM \mod 10)}{100}
\]

where, \( \sigma_0 \) is the backscattering coefficient of a pixel, \( DN \) is the digital number and \( \text{Cal Factor} \) is the calibration coefficient which varies from \( 10^{-6} \) to \( 10^{-4} \) depending upon the radar incidence angle. Geocoded incidence angle mask (\( GIM \)) gives the local incidence angle and it is the angle between the radar beam and the normal to the illuminated surface. \( GIM \mod 10 \) represents the remainder of the division of \( GIM \) by 10.

\[
d = \bar{I}_a - \bar{I}_b
\]

\[
r = \frac{N \sum_{i=1}^{N} I_{a_i} I_{b_i} - \sum_{i=1}^{N} I_{a_i} \sum_{i=1}^{N} I_{b_i}}{\sqrt{\left(N \sum_{i=1}^{N} I_{a_i}^2 - \left(\sum_{i=1}^{N} I_{a_i}\right)^2\right) \left(N \sum_{i=1}^{N} I_{b_i}^2 - \left(\sum_{i=1}^{N} I_{b_i}\right)^2\right)}}
\]
where, $I_{ai}$, $I_{bi}$ represent the $i$-th pixel values of the post-event and pre-event images respectively, and $\bar{I_{ai}}$, $\bar{I_{bi}}$ are the average values of $51 \times 51$ pixels surrounding the $i$-th pixel.

Likewise, we also calculate the normalized difference vegetation index (NDVI) using equation (5) from the post-event QuickBird optical image (multispectral, four bands) to do comparison with $r$ and $d$.

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

(5)

where NIR and R represent digital numbers of a pixel in the near-infrared band and the red band image, respectively. NDVI ranges from -1 to +1 and gives the amount of biomass within a pixel [12].

V. RESULT AND DISCUSSION

Figure 6 shows the color composite image (the post-event as red while the pre-event as green and blue bands) obtained after the radiometric calibration of the intensity images. Highlighted red color indicates the possible changes after the earthquake. Figure 7 shows the correlation and backscattering difference. Values for correlation differs from -0.5 to 1.0 while for the backscattering coefficient difference it ranges from -11.4 to 12.2. A low correlation value and a large backscattering difference represent a possible damaged area. To check this we investigated several cases and presented one case here as shown in Fig. 8. We can notice that the marked areas with a rectangle show low correlation and large backscattering difference in Fig. 8(b) and 8(c). A QuickBird image of the same area also indicates the building damage during the earthquake in Fig. 8(d).
Fig. 8: Correlation and difference map of a damaged area corresponding to the area (iv) in Fig. 6

(a) Color Composite: R: the post-event, G,B: the pre-event

(b) Correlation

(c) Difference

(d) QB (2009.4.8)

Fig. 9: NDVI and correlation map of the central L’Aquila city

(a) SAR 2009.4.13
\[ r \leq 0.3 \]

(b) 2009.4.8
\[ \text{NDVI} \leq 0.16 \]

(c) Overlay of correlation over NDVI

Fig. 9: NDVI and correlation map of the central L’Aquila city
We also prepared images from low correlation values ($r \leq 0.3$) and low NDVI values ($\leq 0.16$) as seen in Fig. 9(a) and 9(b). After this, we overlaid the low correlation areas over the low NDVI areas as shown in Fig. 9(c).

Fig. 10: Overlay of areas with low NDVI and low $r$ values on the QB image. (a) corresponds to the area (iv) and (b) corresponds to the area (ii) in Fig. 6

Fig. 11: Overlay of intersection between high $d$ and low $r$ and low NDVI over QB image. Here (a) and (b) are from the damaged areas while (c) is the parking area. Note that (a), (b) and (c) correspond to the areas (iv), (i) and (iii) respectively, in Fig. 6

When the values of low correlation ($r \leq 0.3$) are overlaid to the possible manmade land-cover (NDVI $\leq 0.16$) as shown in Fig. 10, it is found that building damaged areas show low NDVI and low correlation values (Fig. 10(a)). However, some green areas with low NDVI also show low correlation as seen in Fig. 10(b). From this, it can be inferred that vegetation is clearly affecting the X-band imagery.

Comparison of high back scattering difference ($d$) with low NDVI areas showed that damaged
building had low NDVI and negatively large backscattering difference as in Fig. 11(a). This is evident for the reason that as the buildings get damaged after an earthquake, less backscatter returns to the radar sensor from damaged buildings compared to undamaged buildings. However, Fig. 11(b) shows a damaged building represents an increase of backscatter. This was the case of the 5-storey student dormitory building, which was totally collapsed killing eight inhabitants. This dormitory was connected to other buildings however, they did not get collapsed [13]. When we look out the plan layout in the area, we can observe clearly that intact buildings enclose the damaged building. When the buildings are damaged, their surface roughness gets increased than before, causing the diffuse scattering from the damaged buildings. This causes increased response arisen from the damaged building to intact building as seen in Fig. 12(b). This may be the reason that might have led to the increased travel path of reflected radar signal from the damaged building causing some shift in the response from the damaged building. High backscatter of damaged buildings is also reported by other researchers [11, 14]. Vehicle parking area is also showing high backscatter in Fig. 11(c) and this may be the caused by vehicle parking after the earthquake event.

![Diagram of backscatter from undamaged and damaged buildings](image)

**Fig. 12: Schematic diagram of backscatter from (a) undamaged buildings (b) a collapsed building in close proximity to undamaged buildings**

**VI. CONCLUSION**

Focusing on the high resolution pre- and post-event TerraSAR-X radar imageries, we conducted building damage analysis for the 2009 L’Aquila earthquake event. Correlation and backscattering difference between two TerraSAR-X images taken in different times were calculated. We also calculated the NDVI value from a post-event QuickBird image and compared with the difference and correlation coefficients from the TerraSAR-X images. Low correlation and large backscattering coefficients difference were seen for damaged areas. We also found that X-band imagery was sensitive to vegetation so it should be taken into consideration while conducting damage detection in urban areas.

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REFERENCES


