Rapid Damage eXplorer (RDX): A Probabilistic Framework for Learning Changes From Bitemporal Images

(ICDM Demo Paper)

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***Abstract*—Recent decade has witnessed major changes on the Earth, for example, deforestation, varying cropping and human settlement patterns, and crippling damages due to disasters. Accurate damage assessment caused by major natural and anthropogenic disasters is becoming critical due to increases in human and economic loss. This increase in loss of life and severe damages can be attributed to the growing population, as well as human migration to the disaster prone regions of the world. Rapid assessment of these changes and dissemination of accurate information is critical for creating an effective emergency response. Change detection using high-resolution satellite images is a primary tool in assessing damages, monitoring biomass and critical infrastructures, and identifying new settlements. In this demo, we present a novel supervised probabilistic framework for identifying changes using very high-resolution multispectral, and bitemporal remote sensing images. Our demo shows that the rapid damage explorer (RDX) system is resilient to registration errors and differing sensor characteristics.**

I. Introduction

The Federal Emergency Management Agency (FEMA) defines several types of disasters [1] that can cause severe damage to humans, as well as man-made structures and the environment. A few of the common major disasters include landslides, earthquakes, and hurricanes. Figure 1 shows the damages induced by these types of catastrophic events. Remote sensing data plays a key role in disaster mapping of human settlements. The contributions of these types of data range from delineation of affected population areas to the assessment of structural damages to buildings and critical infrastructures. The study reported in [7], shows that remote sensing technology has been most widely utilized in mapping and monitoring of hazards, identification of damages, and effects of disasters. Remote sensing is also useful in (near) real time assessment of damages caused by floods, forest fires, and other temporal phenomena. The integration of remote sensing, and GIS technologies with data mining systems can provide valuable foundation for building comprehensive decision support systems.

Change detection plays an important role in delineating the affected areas due to natural and anthropogenic disasters discussed in the previous section. Several organizations specifically created, or mandated, to deal with disasters are using remote sensing and GIS technologies to provide detailed information on the affected regions around the globe. One such organization, the International Charter [2] provides a unified system for space data acquisition and delivery of information about the regions affected by natural or man-made disasters. For example, activations map (see Figure 1(e)) created by the International Charter, shows different disasters in 2010. This interactive map provides links to the available image data products to authorized users. Similarly, the United Nations Institute for Training and Research (UNITAR) [4] through its UNOSAT delivers satellite solutions and geographic information on the communities exposed to poverty, hazards, and other crises. Accurate and timely generation of change (or damage) data products is critical for such efforts. In this demo, we present RDX system designed to detect changes from high-resolution bitemporal remote sensing images. RDX is based on the key algorithm presented in [9].

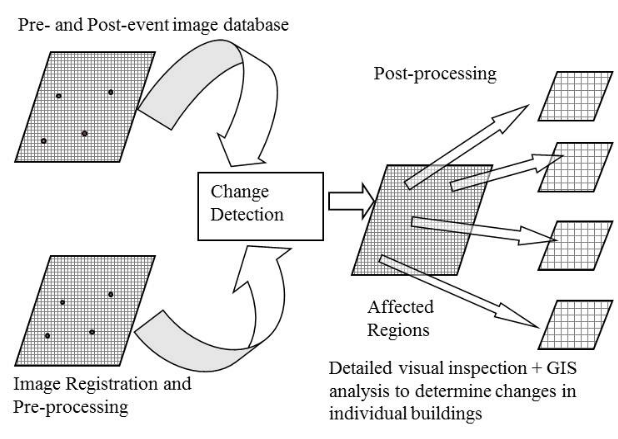


Figure 2. Change detection framework

II. Motivation

Traditionally, damage assessment to the individual buildings and other critical infrastructures has been carried out manually by visual interpretation of pre- and post-event aerial photos. Manual photo interpretation is still used, for example, in a recent study by the Government of Haiti

(a) Major California landslide damage sites 1997-1998 (Source: USGS)

(b) Damaged buildings due to 1998 Laguna Niguel landslides (Source: USGS)

(c) Submerged village near Sumatra after the 2004 Indian ocean earthquake (Source: US Navy)

(d) New Orleans after Katrina, 2005 (Source: US Coast Guard)

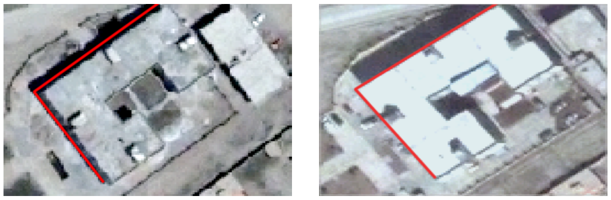
(e) Activations map showing major disaster events in 2010 (Source: International Charter)

Figure 1. Various types of damage events

(2010) in the aftermath of magnitude 7.0 earthquake on 12 January 2010. Image analysts at UNITAR/UNOSAT categorized buildings into destroyed, severely damaged, moderately damaged, and no visible damage based on European Macroseismic Scale - 98 definition [5]. Such detailed studies are required for accurate assessment of damages; however, it takes much time and effort. More timely damage assessment and delineation of disaster affected areas can be achieved with high-resolution satellite imagery and automated change detection techniques. One of the more important functions of disaster assessment of human settlements includes rapid estimates of affected regions so that rescue and recovery operations can be carried out in an effective manner. This is the main motivation behind our RDX system. Figure 2 shows a generic change detection framework. First, suitable high-resolution imagery from pre- and post-event dates must be obtained. These images should then be geo-registered so that one to one (pixel) correspondence may be established between the set of images. Once the images have been registered, change detection techniques can be applied to obtain a map that shows possible changes (affected regions). Typically, further analysis is needed to accurately identify damages to individual structures.

III. Design and Development of RDX System

The first major drawback of widely used change detection techniques is that they are all point based, that is, the comparison (difference, ratio, etc.) is done at the individual pixel. Despite good image registration techniques available, it is very difficult to establish a pixel to pixel correspondence in very high-resolution images. Figure 3 illustrates the practical difficulties in establishing the image to image (pixel level) correspondence. From the figure, one can notice two types of problems, first there is a registration error (look at the red colored line - which is drawn at same geolocation and superimposed on both images) of roughly 3 pixel wide between 2004 and 2009 images, secondly, look at the shadow orientation. Even though both images were acquired by same satellite, they were acquired at slightly different angles. Therefore, pixel-wise comparison methods perform poorly on these kind of images.



(a) (b)

Figure 3. Registration Errors (left: 2004, and right: 2009)

A second drawback of change detection techniques is that they are mostly univariate, and multivariate techniques like MAD [6] produces multi-band change detection maps. Those multi-band images then required to be fused which is another complex task. Another relevant limitation is that most of these techniques produce a continuous change detection map, which requires further processing like thresholding the change map into various change categories. To overcome these limitations, we developed a novel probabilistic framework [9] to identify changes. This framework has following important features/improvements:

- works with image blocks instead of pixels, so the negative effects of registration errors are minimized
- works with both panchromatic (single band) and multispectral images, but produces single band discrete change map
- computed changes are automatically grouped into different change categories

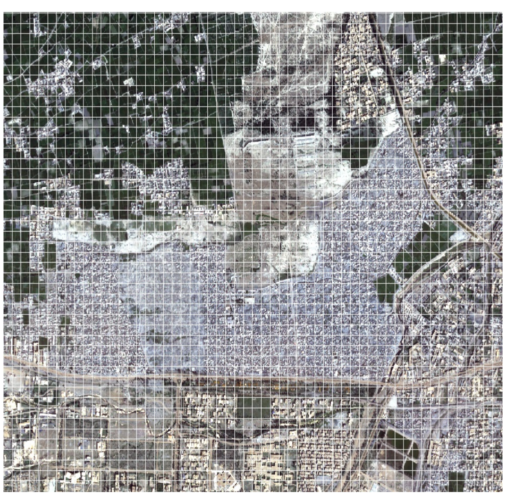
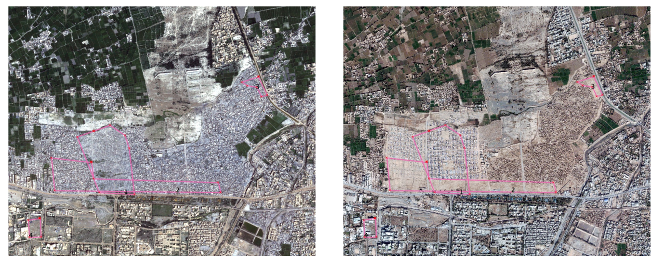


Figure 4. User Defined Grids Superimposed on a High-resolution Image

The RDX system consists of following four key steps:

1) Divide the image into grids (or blocks) of equal size (see Figure 4)
2) Model the data from each grid as a Gaussian distribution. Therefore, at each grid i we have two Gaussian distributions $G_{t1}(i), G_{t2}(i)$ for time $t1$ and $t2$ respectively.
3) For each grid i, compute the distance between Gaussian distributions $G_{t1}(i), G_{t2}(i)$. Most notable distances are: the Kullback-Leibler (KL) divergence, Bhattacharyya distance, and Mahalanobis distance. We implemented all these three measures, but experimentally found that KL divergence is slightly better than other two distances.
4) Cluster the distance data by modeling it as a statistical distribution (e.g., GMM [10]), where different clusters correspond to various degrees of change.



(a) 2004 Image (b) 2009 Image

Figure 5. QuickBird images of Kacha Garhi camp. The image also highlights changes in settlement areas generated through human interpretation

The RDX system was implemented in Java using Fork/Join framework. This framework supports the divide-and-conquer parallelization paradigm. The grid-based approach (first step) nicely fits this programming model and our experimental results showed near linear scalability on Intel's hexa-core processor (Xeon X5690).

IV. RESULTS

We applied our probabilistic change detection framework on bitemporal high-resolution multispectral images over Kacha Garhi camp. Kacha Garhi was a camp established in 1980 for Afghan refugees. Located in West Peshawar, Pakistan, it was closed to clear space for urban development, which meant thousands of native Afghans were repatriated. Two QuickBird images acquired circa 2004 and 2009 show the transition in process. The images contain four spectral bands in the visible and near-infrared wavelengths, and resampled to a spatial resolution of 2.4 meters. Image-to-image registration was conducted with a registration error within three pixels. In 2004, before the closing of the camp, mud structures built by refugees constitute the majority of the camp region. In the western portion of the 2009 camp region, one can see the displacement of mud houses by new residential development, clearly of different building materials. Mud structures still exist in 2009, but missing rooftop materials indicate dismantling is still in progress. These two images were shown in Figure 5. These images also show four polygons (red color) highlighting changes (camp distraction and new construction) obtained through expert knowledge. Polygon 1 shows that in 2004, the camp area was already cleared. For the same site, one can find new and better housing facility in 2009. On the other hand, polygon 2 shows old and mud houses in 2004, but destroyed by year 2009. Also, one can notice that eastern part of the camp (just above polygon 2 on the right hand side) is going through the clearing process as roof tops are missing.

Figure 6 shows the results of our change detection algorithm. First, one will notice that algorithm accurately detected all the changes (purple colored grid blocks) that were highlighted by the human expert (4 polygons). The additional changes detected were mostly on croplands. By comparing 2004 and 2009 images (Figure 5), one can easily see that all fields are under cultivation (green) in 2004, while many of the plots are not cultivated in 2009.

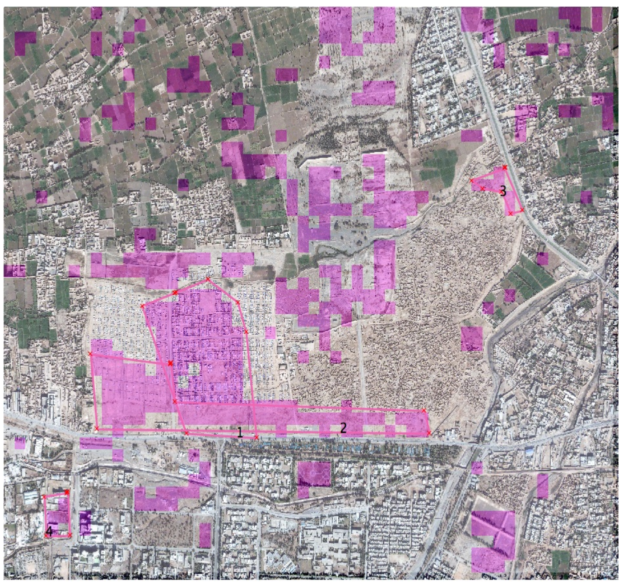


Figure 6. Changes (purple) identified between 2004 and 2009 using RDX

V. Interaction with RDX

RDX system is integrated with the open source Quantum GIS [3]. Users can access the RDX functionality through this integrated framework. QGIS provides various visualization capabilities through which users can interactively explore high-resolution remote sensing imagery and other spatial data products (like maps). It allows exploratory data analysis through which users can get familiar with the study area and visually identify probable change sites. The users can then explore the RDX by varying several parameters, the grid size, the probabilistic distance measures, and the number of components in the mixture model. They can interactively map the clusters into change categories and compare the results against the ground-truth if available. Due to parallel implementation, the RDX allows interactive exploration on big images (3K x 3K). The RDX framework is accurate (as compared to other point-based change detection techniques), and significantly faster, thus allows rapid damage exploration using very high resolution images, which is critical in planning and execution of humanitarian programs in the aftermath of disasters.

VI. Conclusions and Future Directions

RDX system provides an interactive environment through which users can rapidly explore changes/damages using very high-resolution bitemporal images. In near future we are planning to integrate RDX system with web map servers (e.g., MapServer [8]) in order to give a more broader access to this important service.

VII. Acknowledgements

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