High-Resolution Satellite Image Sources for Disaster Management in Urban Areas

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Abstract

With the rapid development of Earth observation technology and geospatial information technology, disaster managers (in the broadest sense) now have power tools capable of collecting and integrating data from various sources in an efficient and cost-effective manner. These properties make it particularly attractive to disaster management support activities. This paper examines the problems of geospatial data acquisition for disaster management with a focus, in particular, on urban environments from two perspectives: geospatial data requirements and the role which high-resolution satellite imagery (0.6 – 5 m) can play in satisfying these geospatial information requirements, and effective image exploitation methods. We focus on the potential of available very high-resolution commercial satellite image data for rapid urban mapping and discuss the example of automated building and road extraction from pan-sharpened IKONOS and QuickBird images.

1 Introduction

The summer flood of 1998 in Yangtze River region, China, the 9-11 terrorist attack of 2001 in New York, USA, the disastrous earthquake of 2003 in the historic city of Bam, Iran, have tragically demonstrated that the whole disaster management sector is under pressure for better, more sophisticated and appropriate means for facing natural and man-made disasters. One of the key issues in disaster management is to effectively monitor and analyze hazards and risks, which is a very complex and challenging task, as many factors can play important role in the occurrence of the disastrous event. Therefore, analysis requires a large number of input parameters, and techniques of monitoring and analysis may be very costly and time consuming. The increase availability of high-resolution satellite image data an innovative development of geographic information systems (GIS) have created opportunities for a more detailed and rapid monitoring and analysis of disasters (Li and Chapman, 2004; Johnson, 2000; Lu et al., 2004; Banger, 2004; Cova, 1999). The proper structure of an information system for disaster management should be presented to tackle the disaster and to manage it. Geospatial information technology can be used to create an elaborate and effective disaster management information system. An integrated approach using scientific and technological advances should be adopted to mitigate and to manage disasters. Moreover there should be a national policy for disaster management.

The application of geospatial information technology begins with the acquisition of data about disasters and culminates in the effective communication of information to those concerned with the outcomes of decisions, which here are disaster managers. In between, there are technologies relating to information manipulation, modeling, analysis, and management. Our work on disaster management concentrates on three levels of this process: information extraction from remote sensing data using digital photogrammetric and image analysis techniques, information management and exploitation using GIS, and information communication using environmental visualization tools. We are seeking to put these into a large context of information management for interactive spatial decision support. In considering both information extraction and visualization, we go beyond the concepts of two-dimensional (2D) mapping and consider the importance of three-dimensional (3D) modeling for disaster management.

For technologies to be effective in disaster management support activities they must be fast but reliable, cost effective, and simple to use by disaster managers, and as far as possible based on the off-the-shelf software components, such as desktop/laptop/pocket GIS. Among these requirements, fast and effective imaging sources and mapping techniques are most critical. This paper principally explores the role of both satellite-based geospatial data collection and touches upon the exploitation of these data in a desktop environment for disaster management. The needs for geospatial data cover a broad range of spatial scales, from regional to local, and thus encompass different imaging sources from Earth observation satellites with different spatial and temporal resolutions. Pan-sharpened imagery is invaluable in land use and land coverr classification for generating map products for disaster managers. This imagery can also provide cues (e.g., color) in the process of feature extraction for automated mapping. A significant goal in this regard is the extraction of buildings and roads to support change detection between pre- and post-disaster for damage assessment.

Initially, we discuss the geospatial information requirements and roles for high-resolution satellite imagery in disaster management. We then consider present sources and future options for the provision of image-based geospatial data products. Finally, the example of building and road extraction is discussed to illustrate the potential of automated spatial information collection.

2 Geospatial Information Requirements

The term “disaster management” encompasses a wide range of activities which can be grouped into five phases that are related by time and function to all types of emergencies and disasters. These phases are planning, mitigation, preparedness, response, and recovery. All phases of disaster management are related to each other and depend on data from a variety of sources (Johnson, 2000). During an actual emergency it is critical to have the right data, at the right time, displayed logically, to respond and take appropriate action. Each phase has different requirements in terms of data types, and specifications (positional accuracy, completeness, currency). Different scales of disaster management can be distinguished, for example, the regional and the local level, mach differing with respect to the granularity of the geospatial data required.

2.1 Mapping Scales

Natural hazard information should be included routinely in developmental planning and investment projects preparation. Development and investment projects should include a cost/benefit analysis of investing in hazard mitigation measures, and weigh them against the losses that are likely to occur if these measures are not taken. According to Banger (2004), satellite remote sensing can play a role at the following levels:

At national level, the objective is to give an inventory of disasters and the areas affected or threatened for an entire country and create disaster awareness with politicians and the public. Mapping scales will be in order of 1:1,000,000 or smaller. The following types of information should be included:

- Hazard free regions for development.

- Regions with severe hazards where most development should be avoided.
- Hazardous regions where development already has taken place and where measures are needed to reduce the venerability.
- Regions where more hazards investigations are required.
- National scale information is as required for these disaster that affect and entire country (drought, major hurricanes, floods, etc.)

At regional level (typical mapping scales between 1:10,000 and 1:1,000,000) and at **all inter-municipal or district level** (mapping scales ranging from 1:25,000 to 1:100,000)**,** the objective is to investigate where hazards can be a constraint and to provide the pre-feasibility study of the development of urban or infrastructural projects. The areas to be investigated range from several thousands to a few hundreds of square kilometers, and the required details of the input data are sometimes up to considerable higher. Slope information at this scale may be sufficiently detailed to generate Digital Elevation Models (DEMs), and derivative products such as slope maps. Spatial analysis capabilities for hazard zonation could be utilized extensively.

At local level, the objective is to generate hazard and risk map for existing settlements and cities, and in the planning of disaster preparedness and disaster relief activities, which are typically that of a municipality. Typical mapping scales are 1:5,000 - 1:25,000. The details of information will be high, including for example cadastral information. The hazard assessment techniques will be more quantitative and based on deterministic/probabilistic models. The size of area under study is in the order of several tenths of square kilometers and the hazards classes on such maps should be absolute, indicating the probability of occurrence for mapping units, with areas down to one hectare or less. At site investigation scale GIS is used in the planning and design of engineering structure and in detail engineering measures to mitigate natural hazards. Typical mapping scale is 1:2,000 or larger. Nearly all of the data is of a quantitative nature. GIS is basically used for the data management, and not for data analysis, since mostly external deterministic models are used for that. A 3D GIS can be of great use at this level.

2.2 Roles of Satellite Imagery

The impacts of floods, forest fires, tornado, and tropical storms, earthquakes, and other natural disasters around the globe in recent years are forcing us to seek new prevention and mitigation methods. This task involves improving predictive models and monitoring tools, drawing up regulatory requirements and planning emergency response. For this purpose, we need to acquire regularly updated, reliable and objective spatially referenced information in a timely fashion.

The roles of satellite image and image analysis in supporting disaster management are many and here are only two examples: (1) Preventing floods. The only way to prevent flooding is through effective land-use planning and a detailed knowledge of land occupancy and the natural phenomena likely to affect a region. In this respect, high- and very-high resolution Earth observation data are a valuable aid for producing and maintaining maps to provide information about flood-prone areas. Such imagery has the potential to improve our understanding of land use, land cover, and flood extents. It also can be combined with cadastral maps for flood risk prevention planning. (2) Evaluating earthquake damage. Optical and radar satellite imagery has already shown its potential for detecting damage caused by natural disasters. High- and very-high resolution satellite imagery makes it possible to interpret earthquake damage zones in sufficient detail and map earthquake damage quickly. By comparing two satellite images (one acquired before and one immediately after the event) within less than 48 hours of image reception could may urban zones affected by the earthquake. Such imagery is able to detect changes to large buildings and determine the probability that they have been damaged.

3 Image Sources

A number of new spaceborne imaging satellites present interesting and viable options for the acquisition of spatial data in disaster management support activities. We will now present a brief summary of the primary characteristics of these high-resolution spaceborne imaging sensors as they relate to disaster management in urban areas.

Investigations are conducted in this section to demonstrate how high-resolution satellite imagery data can assist emergency management and disaster response teams in urban areas. High-resolution satellite images with spatial resolution ranging from 0.6 m to 5 m have a number of advantages over and provide additional applications to aerial photography. These include:

- Normally having four spectral bands from visible blue to near infrared, providing the equivalent of both color and color infrared photography.
- Their digital radiometric characteristics providing the ability to undertake spectral classification and semantic modeling of the data.
- Allowing multi-date analysis of radiometrically calibrated data.

- Capability of radiometric calibration and allowing the compilation of large area mosaics.
- Being captured as 11 bits (e.g., IKONOS and QuickBird) rather than 8 bits giving better dynamic range than aerial photography and airborne scanners.
- With no variable brightness within a single image that is usually associated with aerial photographs.
- Normally already having data in archive over your area or can commence capture within 7 days of placing an order.

Here we group the satellite images with spatial resolution ranging from 2.5 m to 5 m into high-resolution satellite imagery, while those with spatial resolutions between 0.6 m and 1 m are grouped into very-high-resolution satellite imagery.

3.1 High-Resolution Satellite Imagery

High-resolution Earth observation satellites with ground resolution of 2.5 m to 5 m currently in operation are French SPOT 5 and Indian IRS-1D. SPOT 5 carries a High Resolution Geometric (HRG) instrument and has a multi-resolution, wide-swath imaging capability offering the finer resolution of 2.5 m and 5 m (instead of 10 m by SPOT 4) in black-and-white mode, and 10 m (instead of 20 m by SPOT 4) in color mode for studying vegetation. Like all their predecessors, each SPOT instrument covers a 60-km swath, making it possible to image large conurbations in a single pass. In addition, SPOT 5 also carries a (High Resolution Stereoscopic (HRS) instrument, which provides stereoscopic imaging capability along the satellite track, designed specially to acquire wide-area DEMs.

The Indian Remote Sensing (IRS) satellite system collecting 5-m resolution panchromatic imagery, with a pushbroom configuration (much akin to SPOT system), is ideal for urban planning, disaster management, mapping and other applications requiring the unique combination of high-resolution imagery, high revisit frequency (5 days), and broad area coverage (70 km by 70 km). These satellites have stereo imaging capability, adjustable gain and cross-track imaging capability. The elevation accuracy of 5 to 10 m (relative) and 10 to 15 m (absolute) can be expected for the DEMs generated from HRS images. This would support urban mapping up to 1:10,000 scale. It is also seen feasible for mapping to 1:15,000 scale from IRS-1D data, at least in terms of planimetric accuracy (Ravichandran et al. 2002; Raju et al., 2002).

From the disaster management perspective, however, it is not so much the metric quality of the data from satellite platforms which is of prime importance, but the semantic content of the imagery since both the national and the regional level mapping focus upon land use. So-called pan-sharpened imagery "colors" the high-resolution panchromatic image with fused multispectral image at lower resolution to achieve the impression of a high resolution color image. This imagery provides a very useful tool for both land use and land coverr mapping and the collection of basic road networks and other cultural data. In cases where optimal metric quality is sought, both ortho rectified imagery and even stereoscopic analysis can be employed.

Nevertheless, because the spatial resolution of the multispectral bands is relatively coarse and those bands are broad spectrally and only cover the visible to near infrared range of the electromagnetic spectrum, 5 m satellite imagery is unlikely to be a complete source of data for disaster management at the local level mapping, mainly of municipality.

3.2 Very-High-Resolution Satellite Imagery

While the semantic content of SPOT-5 and IRS-1D imagery by and large limits its stand alone application in the generation of a 1:10,000 scale urban mapping, the new generation of commercial 1 m resolution Earth observation satellites will be capable of fulfilling this demand. Satellite imaging systems such as IKONOS from Space Imaging, QuickBird from DigitalGlobe, and OrbView-3 from ORBIMAGE are providing resolution equal to that of about 1:20,000 scale aerial photography, as well as supplying supplementary multispectral image data. The range of applications envisaged for such imagery goes well beyond the provision of topographic map data to 2 – 3 m accuracy, to include infrastructure planning, land and natural resource management, environmental monitoring and disaster management. The 0.6 – 1 m resolution satellite imagery will be extremely valuable as means of providing the local level and the on-site scale mapping capability in disaster management support activity in urban areas. The moderate size of several tenths of square kilometers, means that a single IKONOS (11 km 11 km), QuickBird (16 km x 16 km), or OrbView-3 (8 km x 8 km) image can provide sufficient coverage to meet most needs for managing disasters at the local level, with a potential of virtually immediate delivery of georeferenced, radiometrically and geometrically corrected digital ortho image map products. Thus, the familiar problems of data currency are overcome and the imagery can support temporal studies of dynamic conditions within urban environments, albeit probably at a scale lower than that required to detect the geometric changes of a single house caused by disaster.

The use of 1m satellite imagery for local level disaster management also becomes viable, at least as far as the planning of utilities and services and the general demarcation of land plots under risk is concerned. Similar to the case of 5 m satellite imagery, however, 1 m satellite imagery is not expected to fully suffice as a source for on-site investigation scale disaster management. For example, it remains to be seen whether water points and power lines can be reliably extracted from this imagery. Under such circumstance, 1 m satellite imagery may be supplemented by higher resolution airborne imagery using a principle of multiresolution coverage.

3.3 Multiresolution Coverage

It is readily apparent from the descriptions of the different satellite imaging options presented that no one sensor system offers stand alone information solution to data acquisition for disaster management. Moreover, the capabilities for semantic information extraction from these satellite images do not fully overlap the information requirements of the different spatial scales employed in disaster management. For example, we can observe that 5 m satellite imagery may fulfill the requirements of a regional level disaster mapping at scales between 1: 25,000 and 1: 100,000 and 2.5 m satellite imagery may provide sufficient cartographic integrity for inter-municipal or district scale mapping to scale as large as 1: 10,000. However, at the local mapping level, which is not smaller than 1:2,000, useful satellite imagery will no double be limited to that with 1 m or higher resolution. Even this satellite imagery will probably insufficient and the semantic content cannot be expected to be sufficient to provide both comprehensive thematic information extraction and automated feature extraction functions such as detecting changes in houses. Here we may have to rely on aerial imagery. The use of conventional aerial photography is by no means precluded, but its role will probably be restricted, due to its high cost, to the creation of initial regional- or local-level disaster mapping. For example, first epoch capture of DTMs, and the mapping of major infrastructure and fixed features. Map or GIS database updating with aerial photography is simply not economically viable option for disaster management. It is also noteworthy that, for regional or municipal scales, provision of all data via 1 m satellite imagery, while certainly conceivable, may not be warranted due to cost factors equivalent to those which limit large-format aerial photograph coverage to 5-10 year cycles. A practical solution is to consider image coverage at multiresolution for each of the levels of spatial data required in disaster management.

4 Example of Automatic Image Exploitation: Building and Road Extraction

One of the predominant data requirements in local level disaster management is a spatial inventory of structures. Building data are required for many applications ranging from house counts for residential density analysis to precise building footprint measurement for in situ damage assessment Given the size of many residential areas (many are composed of hundreds of buildings) and the need for quick pre- and post-disaster inventory updating, there is a strong need for automated information extraction tools. Ideally, these tools should be implemented on a desktop/laptop computer and be simple enough to be used by trained emergency managers to exploit their local knowledge in the extraction process. This would also have additional benefits of direct community involvement in disaster management. In the following discussion, we examine development towards automated building and road extraction from high-resolution satellite imagery. We begin by introducing a new fuzzy C-partition method following by presenting a building and road extraction strategy with some promising results.

The section describes a new method for extracting objects from pan-sharpened high-resolution satellite images. This method is based on the fuzzy segmentation algorithm which has been developed in our previous works. The proposed object extraction method consists of three steps: color image segmentation, object detection, and post-processing. The paper also gives practical results from using the proposed method to extract centerlines of road networks and roof outlines of buildings from pan-sharpened QuickBird and IKONOS images.

4.1 Image Segmentation by Fuzzy C-partition Algorithm

Fuzzy c-partition algorithm has been wildly used to solve the clustering problems in pattern recognition (Tou and Gonzalez, 1974; Zeng and Starzyk, 2001), image segmentation (Liew and Yan, 2001), unsupervised learning (Langan et al., 1998), and data compression (Zhong et al., 2000). We are currently developing a man-made object extraction strategy using a fuzzy c-partition-based color segmentation approach (Li et al., 2004). The approach takes full advantages of color cue into the automated feature extraction process. It consists of three steps: segmenting the color image, detecting objects from the segmented image, and post-processing of the extracted objects, for example, delineating road centerlines from the extracted road networks. Here we concentrate our discussion mainly on Steps 2 and 3.

After the color image is segmented by the proposed approach, the binary object image is generated by selecting the pseudo-color corresponding to the object regions. In general, the objects in the binary image are corrupted by noise objects, which have the similar colors to the objects of interest. Then binary morphological operations are applied for filtering the corrupted object image. The appropriate combinations of binary dilation, erosion, opening, and closing are chosen depending on the shapes of noise objects.

In the case of road extraction, an important process for representing the structural shape of the detected road regions is to reduce it to a graph. This work can be accomplished by a thinning algorithm developed by Zhang and Suen (1984) for thinning binary road regions. It is assumed that the road pixels in the binary road network images have value 1 (black), and those background (non-road) pixels have the value 0 (white). The method consists of the successive passes of two basic steps applied to the contour pixels of the given images, where a contour pixel is any pixel with value 1 and has at least one 8-neighour value 0. In the case of building extraction, we develop am.

In the case of building extraction, the building regions are first detected according to the color features of the buildings followed by extracting roof outlines of the detected buildings using the developed boundary extractor (Li, 2004).

Our object extraction method has been tested with pan-sharpened 0.6 m QuickBird and 1 m IKONOS images (see Figure 1). All test images have a size of 150 × 150 pixels, a subset of a typical Toronto residential scene which highlights the residential aspects of an area, including trees, lawns, houses, schools, roads, rivers and parks. This type of imagery could be used to assess and measure damage to buildings, facilities, roads and highways, utility networks and other structures. It could also be used for disaster preparedness, insurance and risk management and disaster mitigation efforts.

4.2 Experimental Results

The segmented images generated from the test images shown in Figure 1 are presented in pseudo-colors and given in Figure 2. The binary images of the objects extracted the segmented images are shown Figure 3. It can be observed in all the four test images shown in Figure 3 that the segmented objects are corrupted by other objects with similar colors to the objects of interest.

Figure 4 illustrates the object regions obtained after filtering the segmented images depicted in Figure 3 by using the binary morphological operators. A visual comparison of the images clearly favors the filtered images (see Figure 4) over the segmented images (see Figure 3). Figure 4a shows the results obtained by filtering Figure 3a using binary dilating with a structuring element of 3×3, followed by eroding with a structuring element of 5×5. Figure 4b shows the results obtained by dilating Figure 3b with a structuring element of 3×3 and eroding with a structuring element of 5×5. Figure 4c shows the results obtained by closing Figure 3c with a structuring element of 4×4. Figure 4d shows the results obtained by eroding Figure 3d with a structuring element of 3×3 followed by closing with a structuring element of 4×4.

Fig.1. Test images: (a) and (c) QuickBird, (b) and (d) IKONOS images

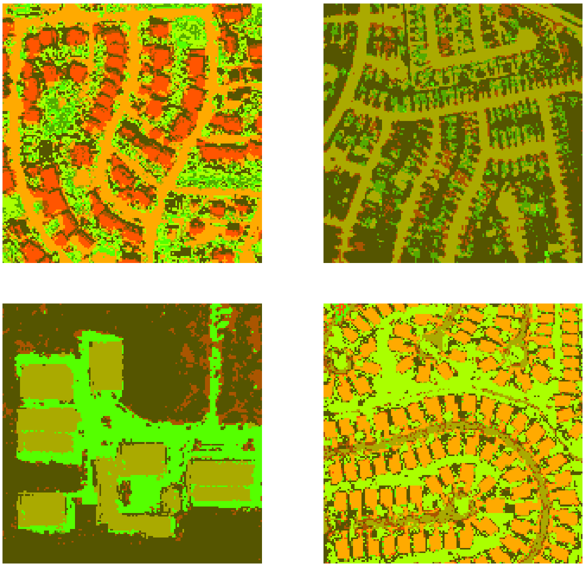

Fig.2. Segmented images: (a) and (c) QuickBird, (b) and (d) IKONOS images

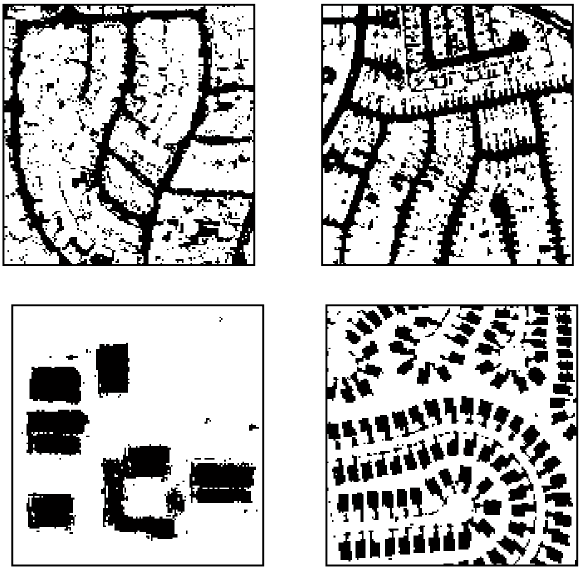

Figure 3. Binary images of object regions: (a) and (c) QuickBird, (b) and (d) IKONOS images

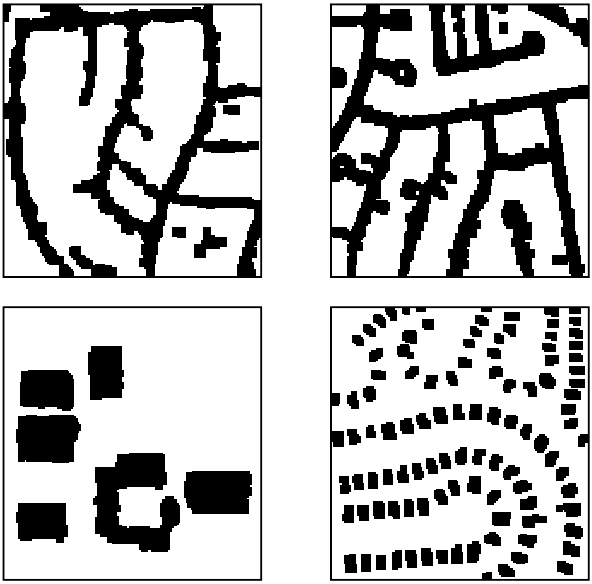

Fig. 4. Object regions after filtering: (a) and (c) QuickBird, (b) and (d) IKONOS images

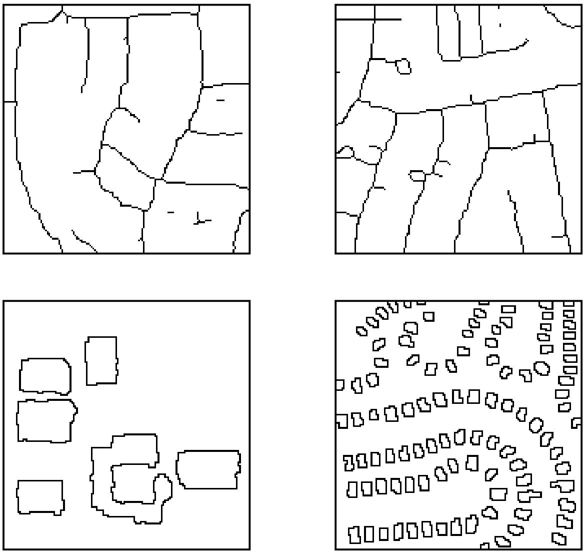

Figure 5. Road centerlines and building roofs: (a) and (c) QuickBird, (b) and (d) IKONOS images.

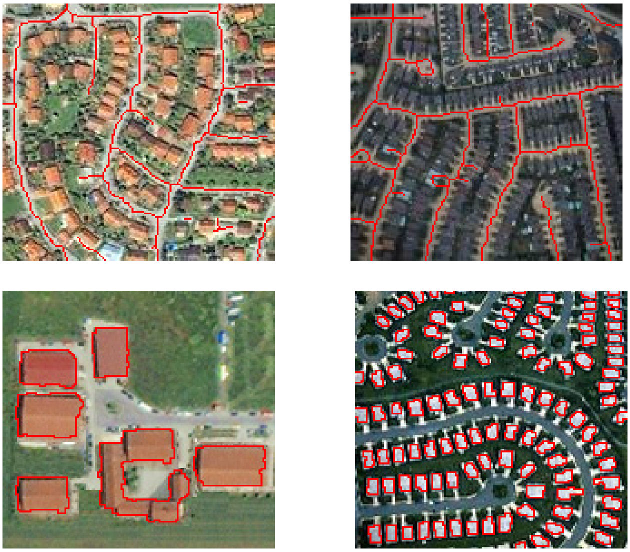

Fig. 6. Extracted road centerlines and building roof outlines (in red) overlaid on test images: (a) and (c) QuickBird, (b) and (d) IKONOS images

The road centerlines and the outlines of the extracted building roofs are delineated using the thinning algorithm and the proposed boundary extractor (The detailed description about it can be found in Li et al., 2005). In order to illustrate the accuracy, the extracted road centerlines and the outlines of the extracted building roofs (both are presented by red lines) are overlaid on the original test image, see Figure 6. The results presented illustrate the potential of the proposed approach.

5 Concluding Remarks

The spatial data requirements have been presented in the context of disaster management at the regional and local scale. In this paper, we have discussed a multiresolution approach whereby information extracted from high-resolution satellite imagery with different spatial and temporal resolutions is complemented from one to another to cover disaster mapping need from the regional to the local scale. The potential of pan-sharpened IKONOS and QuickBird images has been demonstrated through practical applications of our fuzzy segmentation approach to building and road extraction. In the future, our research will continue on a number of fronts, with work on the imagery aspect emphasizing further development of the principle of multiresolution coverage, additional investigation of multispectral classification, fusion of optical and synthetic aperture radar (SAR) satellites (e.g., Canadian 3 m Radarsat-2 and German 1 m TerraSAR-X, to be launched in 2005 and 2006, respectively) data and continuation of automated information extraction tools.

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