DATA FUSION AND INTEGRATION FOR MULTI-RESOLUTION ONLINE 3D ENVIRONMENTAL MONITORING

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ABSTRACT:

With the advancement of remote sensing sensor technologies, images of the earth's surface have been collected at different spatial resolutions, in different spectral wavelengths (panchromatic, multispectral, hyperspectral), and with mono or stereoscopic views. The advancement of the technologies for geospatial information acquisition and extraction has allowed the generation of digital elevation models (DEMs) with different precisions for global coverage. And, the advancement of the Internet technologies has demonstrated a great potential for fast image data transfer and effective online mapping. This paper presents an automatic system for generating multi-scale colour 3D satellite images and dynamic visualization of 3D images online for environmental monitoring. Medium-resolution satellite images such as Landsat 7, high-resolution satellite images such as Ikonos or QuickBird, and commonly available DEMs are the primary data sources of the system. New image fusion, colour enhancement and stereoscopy algorithms are developed for the generation of multi-scale colour 3D satellite images. Latest Internet technologies are integrated into the system for fast and dynamic visualization of colour 3D images at different scales. State-of-the-art 3D displays present a great potential for 3D visualization of the colour satellite images without using 3D glasses.

1. INTRODUCTION

Three-dimensional (3D) information of the earth's surface is important for environmental monitoring. Colour images with 3D information can provide geo-scientists and environment planners with easy-to-understand geographic information for more effective environmental analyses compared to 2D maps and images. The height information is, sometimes, even crucial for the success of certain applications.

With the advancement of remote sensing sensor technologies, images of the earth's surface can be collected at different spatial resolutions, in different spectral wavelengths (panchromatic, multispectral, hyperspectral), and with mono or stereoscopic views. The advancement of the technologies for geospatial information acquisition and extraction has allowed the generation of digital elevation models (DEMs) at different precisions. And, the advancement of the Internet technologies has demonstrated a great potential for fast image data transfer and effective online mapping.

Currently, new technologies are quickly developed to integrate the available earth images and DEM data for online mapping. The enormous success of Google Earth in integrating 2D satellite imagery into online mapping has demonstrated a massive impact of remote sensing on online mapping and brought remote sensing applications into our daily life. End users can see earth images online in a variety of scales, from the overview of a region to individual houses, trees and even cars. Recently, Microsoft's Virtual Earth has unveiled a new online mapping system with 3D capacity. Google Earth has also started the campaign to extend its 2D image mapping with 3D features. However, the 3D generation technologies involved require manual extraction of 3D models of selected 3D objects (such as buildings and large constructions) and collection and paste of ground images onto the 3D models. Such a 3D process is costly, time consuming, difficult to update, and not practical for generating 3D images of small objects (such as trees and family houses). It is also difficult for the application to environmental monitoring of the earth's surface.

As panchromatic, multispectral, monoscopic and stereoscopic images as well as DEMs at different scales have been made available for global applications. A great potential exists to develop an alternative technology for 3D visualization of the earth's surface in a fast and cost-effective fashion, i.e. using stereoscopic technology to generate colour 3D images. Low resolution colour 3D images can be generated using monosopic low resolution images (such as Landsat) and existing DEMs, while high resolution colour 3D images can be generated using Ikonos or QuickBird stereo pairs.

This paper presents an automatic system for generating multi-scale colour 3D satellite images and dynamic visualization of 3D images online for effective monitoring of the environment of the earth's surface. Medium-resolution satellite images such as Landsat 7 and high-resolution satellite images such as Ikonos or QuickBird are the main data sources for the multi-scale 3D online mapping. New image fusion, colour enhancement and stereoscopy algorithms are developed for the generation of multi-scale colour 3D satellite images. Latest Internet technologies are integrated into the system for fast and dynamic visualization of colour 3D images at different scales. The recently emerging, state-of-the-art 3D displays present a great alternative for 3D visualization of the colour satellite images without using 3D glasses.

The concept of the 3D satellite image generation and the on-line dynamic visualization are presented in this paper. Since Landsat imagery has a global coverage and the Ikonos and QuickBird images can be acquired quickly for the areas of interest, the generation and online visualization of colour 3D satellite images at different scales is possible with this new system. Different 3D objects on the earth's surface from mountain ranges to individual family houses and trees can be dynamically visualized and analyzed through the Internet across the world. Due to its capability of near-real time and low cost, the new automatic system also presents a great potential to monitor the environment of the earth's surface in colour 3D through the Internet.

2. THE NEW 3D SYSTEM

Based on the general concept of Zhang (2002a), an automatic system has been developed to automatically generate colour 3D images and dynamically visualize natural colour 3D images on the Web. The system consists of the major components:

(1) automatic image fusion to
  a. producing 0.7-m pan-sharpened high resolution QuickBird (or 1-m Ikonos) natural colour image pairs; and
  b. producing 15-m pan-sharpened medium resolution Landsat natural colour images.
(2) automatic colour enhancement for better colour 3D visualization;
(3) automatic matching points extraction for automatic matching of the stereo pairs;
(4) automatic generation of high resolution epipolar images and colour 3D satellite images using Ikonos or QuickBird image pairs;
(5) automatic reconstruction of medium resolution stereo image pairs using Landsat natural colour images and digital elevation models (DEMs);
(6) fast data transfer through the Internet for effective visualization of large coverage 3D images on the client end; and
(7) automatic refinement for effective colour 3D viewing on the client end.

Figure 1 illustrates the general components of the developed 3D generation and online visualization system. For the generation of medium resolution colour 3D images, Landsat ETM+ images are the ideal image data source, and commonly available medium resolution DEMs are the ideal data source for the height information of the 3D images, because Landsat does not collect stereo images. For the generation of high resolution colour 3D images, however, the QuickBird and Ikonos stereo image pairs, as well as aerial photo stereo pairs, can be directly employed to generate high resolution colour 3D images.

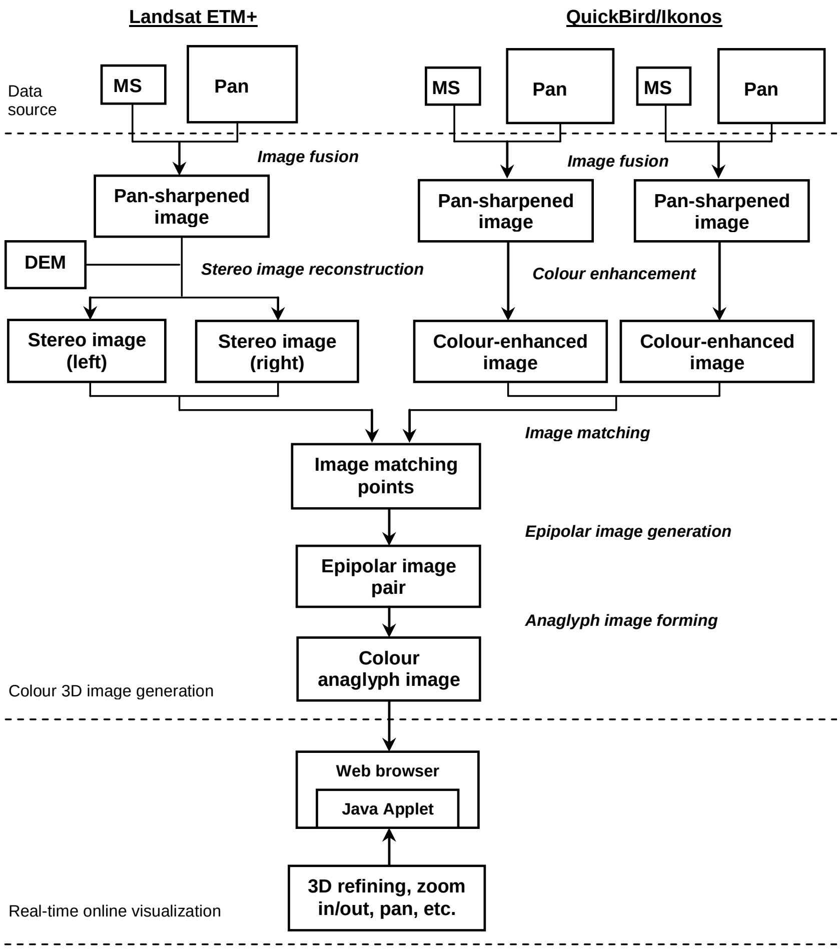


Figure 1. Processing flowchart of the developed system for colour 3D image generation and online visualization using medium resolution monoscopic Landsat images and high resolution QuickBird/Ikonos image pairs

Figure 2. Automatic image fusion of Ikonos Pan and MS images, University of New Brunswick, Canada.
Left: Original panchromatic image (1 m); Center: Original natural colour image (4 m); Right: Fused natural colour image (1 m).

2.1 Automatic Image Fusion

A new automatic image fusion approach has been developed (Zhang, 2002b; Zhang, 2004) and integrated into the automatic system for colour 3D image generation. The fusion technique can automatically fuse panchromatic and multispectral images from Landsat, QuickBird, Ikonos, or any other sensors without losing spatial detail or altering colour information, through a one-step process. Figure 2 shows an example of the images before and after the automatic image fusion.

2.2 Automatic Colour Enhancement

Compared to ordinary natural colour photos, colour aerial photos or Landsat natural colour images, the colour of the natural colour QuickBird or Ikonos images usually appears unnatural or distorted (Figure 3, top and middle), which affects the visualization effect of colour 3D images. A colour enhancement algorithm has, therefore, been developed and integrated into the system for automatic colour enhancement to improve the colour 3D visualization. The bottom image of Figure 3 shows an example of a colour enhanced Ikonos image.

Figure 3. Colour enhancement of Ikonos natural colour image. Top: original Ikonos colour image; Middle: pan-sharpened Ikonos colour image; Bottom: pan-sharpened and colour enhanced Ikonos image.

2.3 Automatic Image Matching

Much work on automatic image matching has been done in aerial and satellite stereo image applications such as DEM generations. Feature-based and area-based approaches are two commonly used techniques. The automatic image matching technique presented in this paper integrates both matching techniques. An epipolar constraint was applied to the process of the eliminating outliers. The overview of the matching algorithm is illustrated in Figure 4. An image tiling technique is employed to effectively process big images piece by piece.

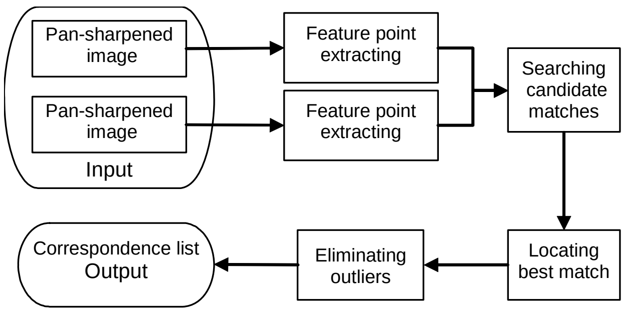


Figure 4. Overview of the image matching process involved in the colour 3D system

2.4 Epipolar Resampling and Colour 3D Image Generation

According to the matching points found from the image matching step and the epipolar geometry of the stereo pair from QuickBird or Ikonos, an epipolar image resampling was applied. It includes:

(1) Carrying out the affine transformation from the right image to the left image.
(2) Rotating both the left and the transformed right images by the angles of the epipolar line.

Figure 5 shows a pair of Ikonos images before and after epipolar resampling.

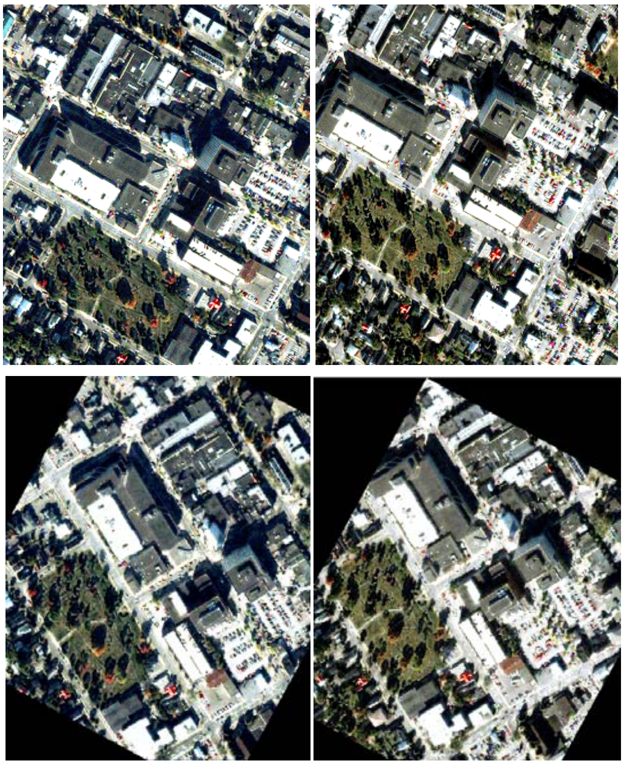


Figure 5. Epipolar geometry resampling. Top: Ikonos image pair before epipolar resampling; Bottom: epipolar images.

After spipolar images are generated, colour 3D (or anaglyph) images can be produced by superimposing one colour band from one colour image with two colour bands from another colour image of the epipolar stereo pair. The criterion of superimposing in a horizontal direction is to compel the smallest horizontal disparity of the matching points to zero. Figure 6 shows the colour 3D image automatically generated using the epipolar image pair of Figure 5.

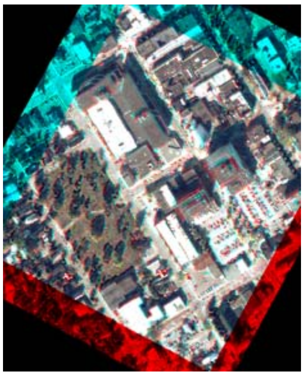


Figure 6. Colour 3D image generated using an epipolar image pair

2.5 Automatic Stereo Image Reconstruction

To produce medium resolution colour 3D satellite images for global 3D visualization, Landsat imagery is an ideal data course because of its high image quality, global availability, and low cost. However, Landsat series does not collect stereo images and a direct generation of colour 3D images using Landsat imagery is not possible. An alternative solution has been found for producing colour stereo image pairs, i.e. reconstructing colour stereo image pairs using available monoscopic Landsat images and corresponding DEMs. An automatic software tool has been developed for this process. Figure 7 shows a Landsat image before and after the stereoscopic reconstruction.

2.6 Fast Data Transfer

Most Internet users access to the Internet through relatively low speed modems. The problem of bandwidth constraint exists for ordinary users to effectively view large volume colour images online. To overcome this problem, a technique was developed to divides high-resolution images into bite-size tiles and deliver "pixels on demand". Therefore, the data transmission is done only when there is a downloading demand, which allows high resolution images to be transferred over all bandwidth environments.

2.7 Automatic 3D Refinement

In stereoscopic 3D visualization, a larger horizontal parallax will cause difficulties in depth perception and stereo fusion. Therefore, the overall horizontal parallaxes should be maintained in a limited range for an acceptable stereo fusion (Carr 1993). Since satellite images cover a larger area, some areas may have larger horizontal parallaxes, as illustrated in Figure 8 (left), causing stereo fusion problems. A tool for automatic 3D refinement is therefore necessary to reduce the overall horizontal parallaxes to maintain an acceptable parallax range for effective 3D viewing (Figure 8, right).

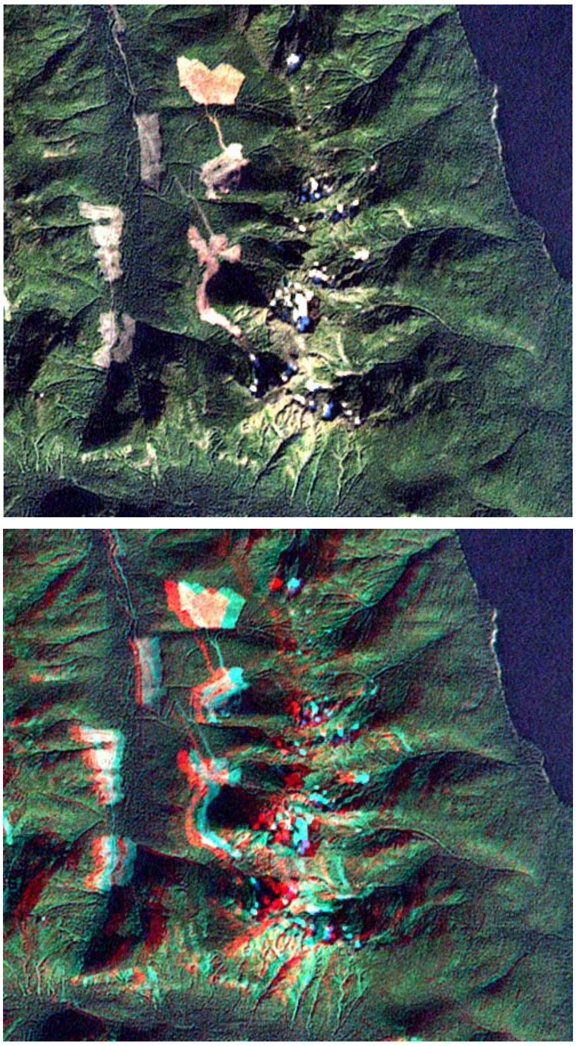


Figure 7. Reconstruction of Landsat colour 3D images. Top: 2D colour image collected by Landsat; Bottom: Reconstructed colour 3D image from the 2D image and a corresponding DEM.

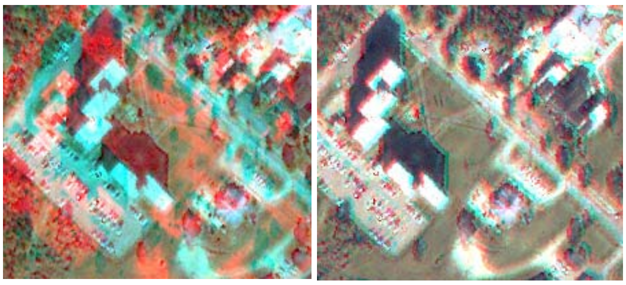


Figure 8. Influence of overall horizontal parallaxes for effective colour 3D viewing. Left: larger overall horizontal parallaxes cause stereo fusion problems; Right: small overall horizontal parallaxes are more comfortable for colour 3D viewing.

A quadtree-based approach was developed to allow 3D refinement being performed in real time. To refine 3D image effetely, only those quadrants crossing the refining area (Figure 9) are searched.

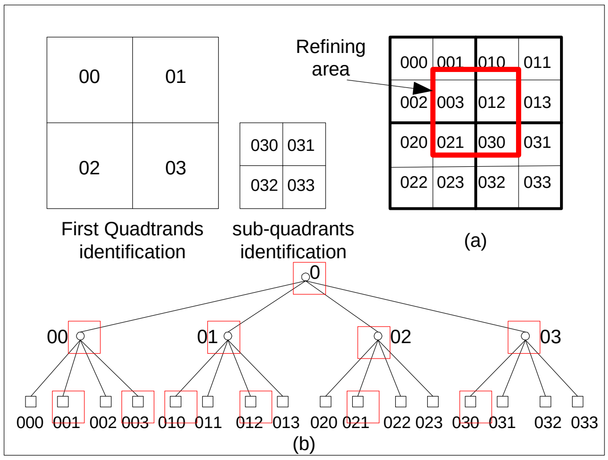


Figure 9. Quadtree method for parallax refining. (a) decomposition of an image, and (b) quadtree representation of the image.

3. RESULTS

A website for colour 3D image online visualization and analysis was developed using the new 3D system. A pair of Ikonos images of Fredericton, New Brunswick, Canada, a full scene of Landsat 7 image covering the southeast territory of the Province of New Brunswick, and a full scene of Landsat 7 image of the Rocky Mountains in the Province of British Columbia, Canada, were acquired and processed for testing the new 3D system. All of the colour 3D images were processed automatically. Figure 10 shows the home page of the 3D Website: http://studio2.gge.unb.ca/3dSatelliteImage/.

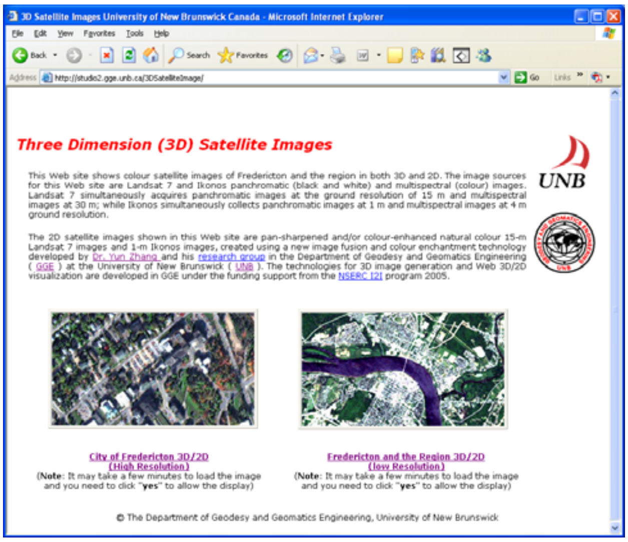


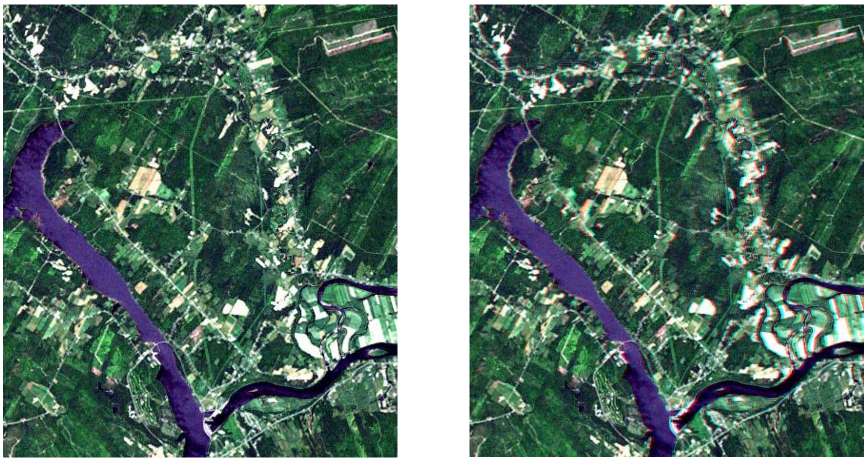
Figure 10. Home page of a colour 3D Website developed using the new 3D system for dynamic visualization of colour 3D and 2D images at different scales

Large scale colour 2D and 3D images can be dynamically visualized using Ikonos (or QuickBird) images, in which individual houses and trees can be viewed in colour 2D and 3D (Figure 11).

Small scale colour 2D and 3D images (Figure 12 and 13) can also be generated and visualized using the new 3D system, for which Landsat images and corresponding DEMs were used.

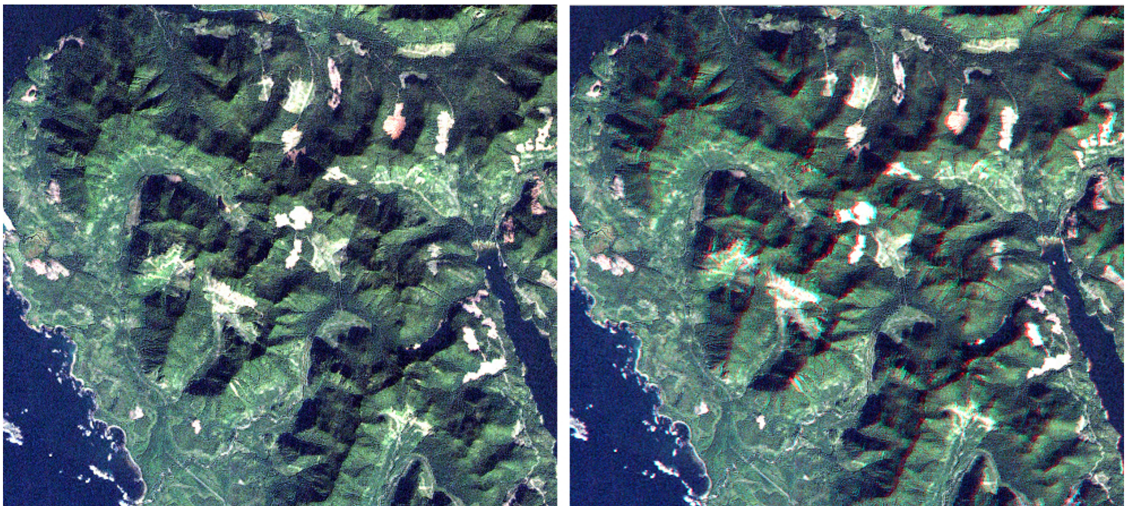
2D image 3D image

Figure 11. Large scale colour 2D and 3D images produced using Ikonos images (Engineering Building, University of New Brunswick)



2D image 3D image

Figure 12. Small scale colour 2D and 3D images generated using the Landsat 7 ETM+ Pan and MS image (Mactaquac Power Station and the reservoir, New Brunswick, Canada)



2D image 3D image

Figure 13. Small scale colour 2D and 3D images generated using the Landsat 7 ETM+ Pan and MS image (Part of Vancouver Island, British Columbia, Canada)

The 2D and 3D colour images can be visualized in a specified window. They can also be displayed and analyzed in full screen (Figure 14, 15 and 16) with specifically signed analysis options, such as displaying at different scales, switching between 2D and 3D, moving from one location to a designated location, and measuring the relative height of an object of interest.

In Figure 11, we can see that detailed ground objects can be observed in both the 2D and 3D images, from individual buildings to individual cars. When the 2D image (Figure 11, left) is viewed, all of the objects appear flat and no information about the terrain variation, building height and tree tallness can be perceived. However, when the image is switched to colour 3D (Figure 11, right), all of the height information becomes visible, like a real 3D model. It can be seen that the buildings are built on a slope and some trees are taller than others.

In Figure 12, when we look at both the 2D and 3D images, we can see a big river and a dam construction located at the joint of the two rivers (bottom). We can also see a horseshoe shaped area combining the big river and an area filled with crop fields. From the 2D image (Figure 12, left) no more information can be further obtained. However, from the 3D image (Figure 12, right) we can clearly see that the fields in the horseshoe shaped area are in a valley and the water levels on the both sides of the dam are significantly different. This tells that the original river must go through the entire horseshoe shaped area, before the power station was built.

The above two comparisons demonstrate that colour 3D online mapping can provide much more information for environmental monitoring than does 2D online mapping. Another example can be seen from the comparison between the two images in Figure 13. In the left image (2D) we can see some white spots linked with some lines. But it is not easy for an ordinary viewer to understand what the spots and lines are. However, when we see the image in colour 3D (Figure 13, right), we can see that all of the white spots are located on the sunny sites of the mountains and the white lines link from the white spots to the valleys. With some general knowledge of this area, we can conclude that the white sports must be forest cut areas and the lines are the roads for timber transportation.

A broader colour 3D view of the three compared areas can be seen in a full screen display in Figure 14, 15 and 16, from which more information can be obtained environmental monitoring.

4. CONCLUSION

This paper presents a new approach and system to generate natural colour 3D images of different scales and to visualize the colour 3D images through the Internet. To effectively utilize the available high resolution and medium resolution satellite multispectral and panchromatic images, an image fusion technique is used to increase the resolution of the multispeectral images by integrating detailed spatial information from the panchromatic images. A colour enhancement technique is also employed to improve the colour of the natural colour images for more effective colour 3D visualization. The quality of the image fusion and colour enhancement plays a crucial role for the quality of the colour 3D visualization.

This study and the results have demonstrated that it is possible to develop an online system for global colour 3D visualization using currently available Landsat images and the corresponding DEMs. For detailed, large scale colour 3D visualization high resolution satellites images, such as QuickBird or Ikonos, can be acquired. By integrating the information from Landsat, DEMs and Ikonos/QuickBird, 3D objects on the earth's surface, from mountain ranges to individual family houses and trees can be dynamically visualized and analyzed through the Internet across the world.

Compared to the current 3D online mapping technologies used by Microsoft Virtual Earth and Google Earth, the new 3D system presents its unique advantages for environmental motoring, i.e. the 3D images can be produced in near real time at an affordable costs, the 3D coverage is complete and real (including small objects and trees), and the 2D and 3D colour images can be instantly switched between each other for more effective analysis.

When the state-of-the-art 3D displays are used for this new 3D system, users can even view colour 3D and 2D images without using 3D glasses (most 3D displays can be switched to a normal 2D display by a button click).

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Figure 14. Full screen view of a large scale colour 3D image showing the campus of the University of New Brunswick, Canada

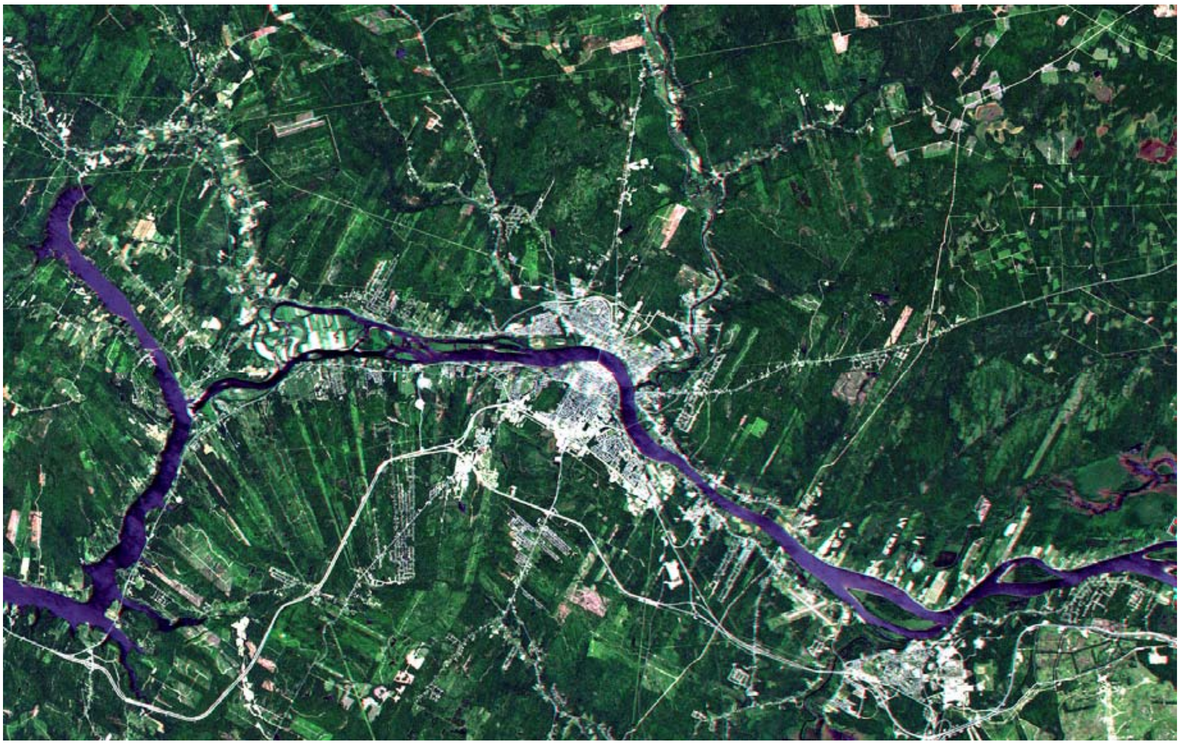

Figure 15. Full screen view of a small scale colour 3D image showing Fredericton and Saint John River valley, Canada

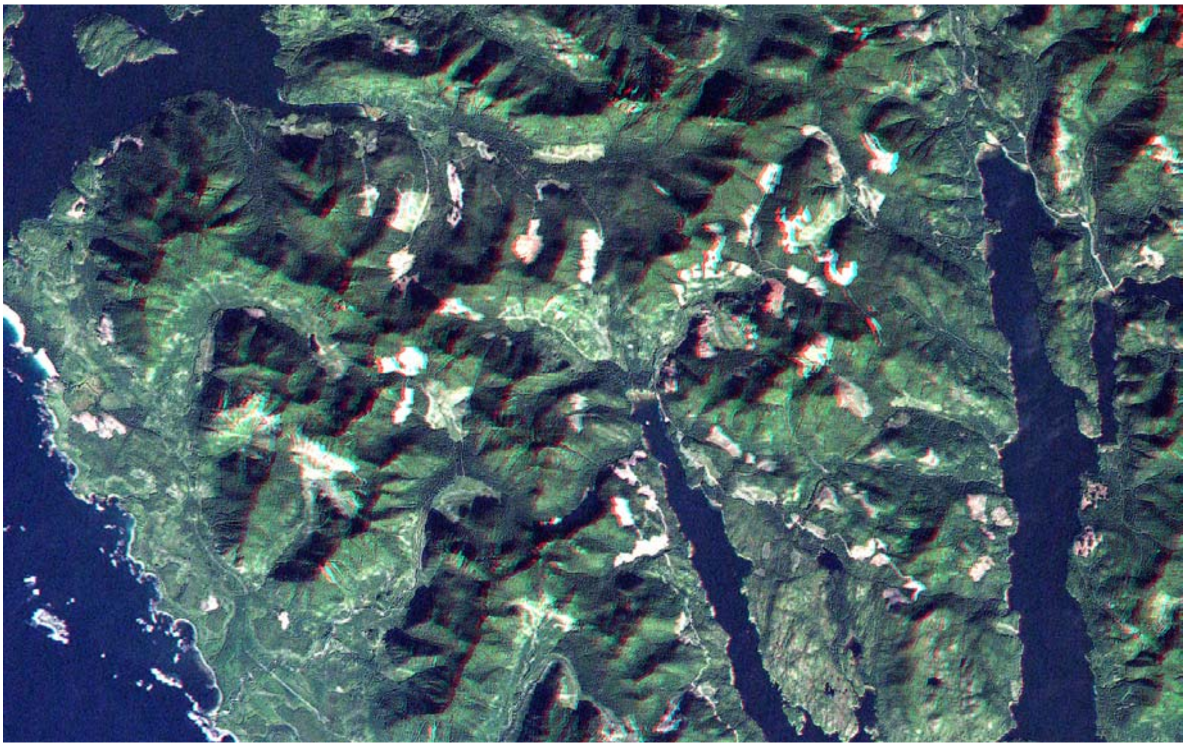

Figure 16. Full screen view of a small scale colour 3D image showing a part of Vancouver Island, British Columbia, Canada