Korean Journal of Remote Sensing, Vol.23, No.5, 2007, pp.439~445

Occlusion Restoration of Synthetic Stereomate for Remote Sensing Imagery

Hye Jin Kim, Jae Wan Choi, Ho Wook Chang, and Ki Yun Ryu †

Department of Civil and Environmental Engineering, Seoul National University

Abstract : Stereoscopic viewing is an efficient technique for not only computer vision but also remote sensing applications. Generally, stereo pair obtained at the same time is necessary for 3D viewing, but it is possible to synthesize a stereomate suitable for stereo view with a single image and disparity-map. There have been researches concerning the generation of the synthetic stereomate from remote sensing imagery. However it is hard to find researches concerning the restoration of occlusion in stereomate. In this paper, we generated synthetic stereomates from remote sensing images, focused on the occlusion restoration. In order to figure out proper restoration methods depending on the spatial resolution of remote sensing imagery, we tested several methods including general interpolation and inpainting technique, then evaluated the results.

Key Words : Anaglyph, Occlusion restoration, Remote sensing imagery, Synthetic stereomate.

1. Introduction

Stereoscopic viewing is effective for various remote sensing applications such as image interpretation, tectonic analysis, landscape analysis, and sightseeing. Sometimes, there are problems to get efficient stereography from stereo pair of remote sensing data. Between stereo pair images from satellite or aircraft, the differences of occlusion area and atmosphere are existed because the different acquisition angle and time delay. Moreover it is hard to adjust disparity according to viewer's binocular disparity or viewing scale. Therefore the synthesis of stereomate with a single image and disparity information can be suitable for 3D viewing. In computer vision, there have been a lot of research about synthesizing stereomate from disparity-map (Fehn, 2003; Fehn, 2004; Scharstein, 1996; Usery, 1993). For remote sensing images with large scale, the Digital Elevation Model (DEM), or Digital Surface Model (DSM) can be used as disparity-map (Batson and Edwards, 1976; Bethel., 1991; Chang, *et al.*, 2006; O'Neill, and Dowman, 1998). Through synthesizing new view-point with disparity, the synthetic image has occlusion pixels. Nevertheless there have not been many researches of the occlusion restoration, whereas the generation of synthetic stereomate technique is an active topic. The occlusion

Received 8 October 2007; Accepted 17 October 2007.

† Corresponding Author: Ki Yun Ryu (kiyun@snu.ac.kr)

has different shape by the disparity, image resolution, and scale. Therefore it is necessary to select the appropriate gap-filling method depending on the shape of occlusion. In this paper, we focused on the occlusion restoration, of the synthesized stereomates from remote sensing images. Three methods of the nearest neighbor interpolation, Triangular Irregular Network (TIN) interpolation, and inpainting method were applied respectively to evaluate the occlusion restoration techniques. Because the shape of occlusion depends on the image resolution and scale of disparity-map, we tested two different data, Landsat satellite image as middle resolution image and aerial photo as high resolution image.

2. Synthetic Stereomate Generation

It is possible to make a number of stereomate from the different points of view with the fusion of a disparity-map and a single image generating the synthetic stereo. The method of stereo synthesis should be chosen differently as the resolution of the remote sensing imagery because the effects by relief displacement are different.

1) Stereomate Synthesis for Middle-resolution Image

The simplest way to synthesize the stereo is to assign pixel intensity to the synthetic image by shifting each of pixels of original image by its corresponding disparity. With the middle-resolution satellite image such as Landsat, the synthetic stereomate can be generated easily using DEM (Batson and Edwards, 1976; Salvi, 1995). Because the Landsat Thematic Mapper (TM) imagery has the spatial resolution of 30m per pixel and vertical elevation angle, the relief displacement can be ignored and the image can be considered as ortho-image. Therefore the disparity of each pixel can be calculated from the elevation of terrain. There are two techniques to calculate the disparity. In general the disparity Δd is defined as (1), when Δh is the elevation and K is a constant that determine the strength of the stereoscopic illusion. The selection of the constant is arbitrary.

$$\Delta d = \Delta h \cdot K \qquad (1)$$

The other way to determine the disparity is compressing the rangy by Pth law transformation (Ideses and Yaroslavsky, 2005). In this transformation, each disparity is calculated by following equation:

$$\Delta d = a \cdot \Delta h^P \qquad (2)$$

Where a is a normalizing constant, $0 < P < 1$. In this manner, it is possible to retain the elevation-ordering information in even small value of elevation. If you determine the constant K or P is large value, both of the stereoscopic effect and the occlusion area are exaggerated.

2) Stereomate Synthesis for High-resolution Image

The method we mentioned above is not appropriate to the high resolution satellite image or aerial photo except when they are ortho-rectified because of large relief displacement. Therefore reprojection method using sensor model have been worked by H. Chang *et al.* (Chang, *et al.*, 2006; O'Neill and Dowman, 1998). In this way, a single image is projected onto the DEM or DSM and reprojected onto new view image plane along epipolar line. In order to synthesize the high resolution stereomate, it needs to get DSM that includes not only topographic elevation but also artificial height. In the synthetic stereomate generated by the reprojection method, there can be large unfilled gaps by occluded area or side wall of tall buildings. Accordingly, the selection of gap-filling technique is important for high resolution stereomate.

3. Occlusion Restoration

There are several interpolation method generally used such as bilinear interpolation, cubic convolution, but these methods can not applied to fill the gaps that exist continuously. Within a steep slope area or building sidewall in a stereomate, the occlusion area can be much larger than several pixels. For that reason, we tested the gap-filling algorithms that can be used regardless of the gap size.

1) Nearest Neighbor Interpolation

Nearest neighbor is the most basic and requires the least processing time of all the interpolation algorithms because it only considers on pixel that the closest one to the interpolated point.

2) TIN Linear Interpolation

TIN based linear interpolation is commonly used for surface interpolation of 3D coordinate. When it is applied to gap-filling, the brightness value can be regard as Z value. TIN interpolation is computationally very efficient, utilizing a Delaunay triangulation algorithm and simple mathematical function.

3) Inpainting Method by Fields of Experts (FoE) Model

Image inpainting is the algorithm to remove certain parts of an image, scratches on a photo or unwanted occluding objects (Criminisi *et al.*, 2003; Criminisi *et al.*, 2004) . In our approach, the inpainting method using FoE model is used (Roth and Black, 2005). The FoE model which consist inpainting algorithm extends traditional Markov Random Field (MRF) models by learning potential functions, which are modeled using a Products of Experts (PoE) framework that exploits nonlinear functions of many linear filter responses. This algorithm has some advantages over other inpainting method because it preserved more continuity of edge than other algorithm.

4. Experimental Results

In order to evaluate the occlusion restoration methods, we performed experiments with two different resolution remote sensing data, Landsat TM image and aerial photo. Each of the original single images was regarded as a left image, and the synthetic stereomates were generated as a right image. We synthesized the Landsat stereomate image using DEM, and aerial photo stereomate using LiDAR (Light Detection and Ranging) DSM. Then the occlusion area in the synthetic stereomates was restored by three gap-filling methods respectively.

1) Data and Implementation

The Landsat imagery has 30m ground resolution with seven bands. As shown in Fig. 1, the test area of Landsat image is about 48km48km covering around Seoul, Korea. DEM with 1km resolution was used as disparity map for Landsat data, and resampled to 30m per pixel to have same resolution with Landsat data. After that left image was rectified to DEM by polynomial transform, the right synthetic stereomate was produced from compressed DEM.

Fig. 2 shows the second test data which is color aerial photo with 24cm ground resolution, in Daejeon, Korea. There are a number of high buildings and rolling hill in the test area which is about 300m by 300m. To get the DSM at the test area, we generated raster DSM having same scale as aerial photo, from LiDAR point data. Using a

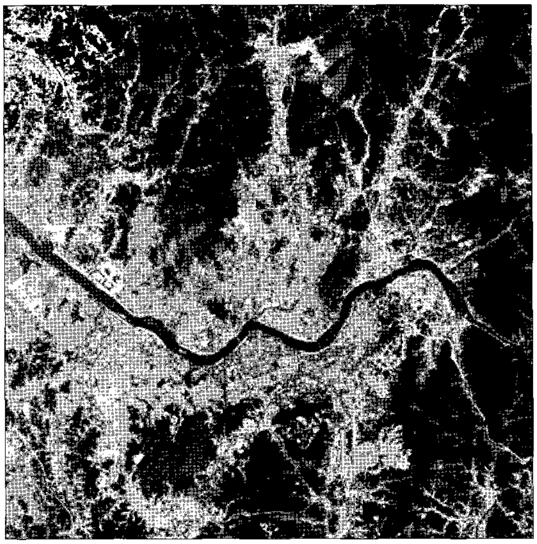


Fig. 1. Landsat test image of Seoul area in Korea.

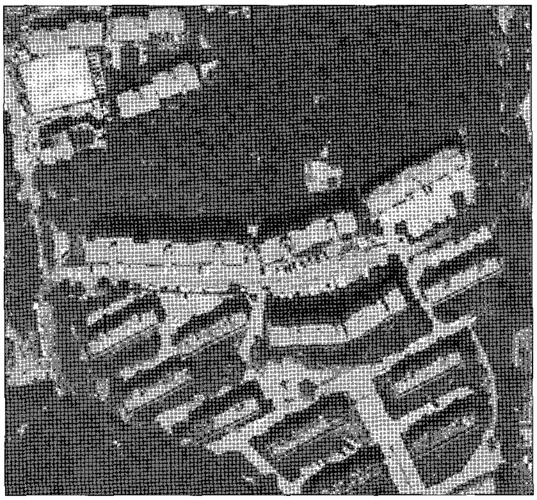


Fig. 2. Aerial photo of Daejeon area in Korea.

collinearity condition equation, we defined a new view image plane satisfying the epipolar geometry. Then the original image projected onto DSM was reprojected onto synthetic image plane.

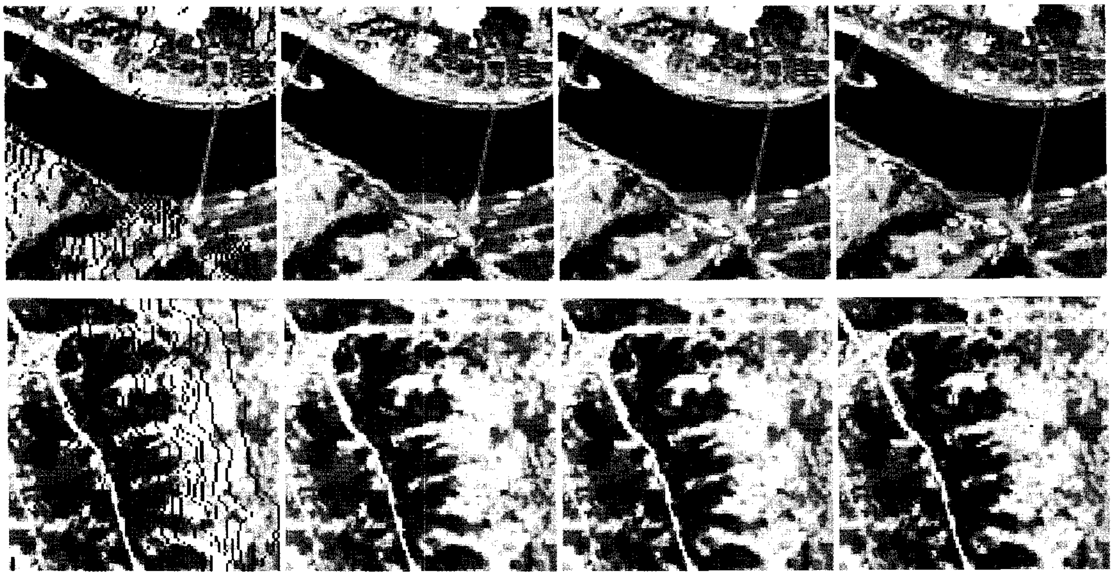
2) Result Evaluation

We compared the result of three occlusion restoration methods visually. The methods are nearest neighbor, TIN linear interpolation, and inpainting using FoE model. Fig. 3 shows the parts of result applied to the Landsat image. As shown in Fig. 3 (a), most of occlusions in Landsat stereomate are distributed with linear shape irregularly. The size of each occlusion area is not large because the disparity of each pixel is decided by topographic altitude changed continuously. The result showed that nearest neighbor and TIN interpolation were acceptable to fill gap area. However noises occurred in the result of inpainting method, especially in small occlusions which is one or two pixel wide.

In the aerial photo stereomate, large gaps existed because the building sidewall area could not projected from DSM. Mostly the disparity in the high resolution imagery is caused by the ground features, such as buildings or trees. As shown in Fig. 4, nearest neighbor method was not proper to restore large gaps which located around forest and building sidewall. Both of the TIN interpolation and inpainting techniques produced good results. More specifically, inpainting method restored wide occlusion more clearly than TIN interpolation. It also preserved the edge sharply at the building sidewall occlusion, while TIN interpolation blurred the edge.

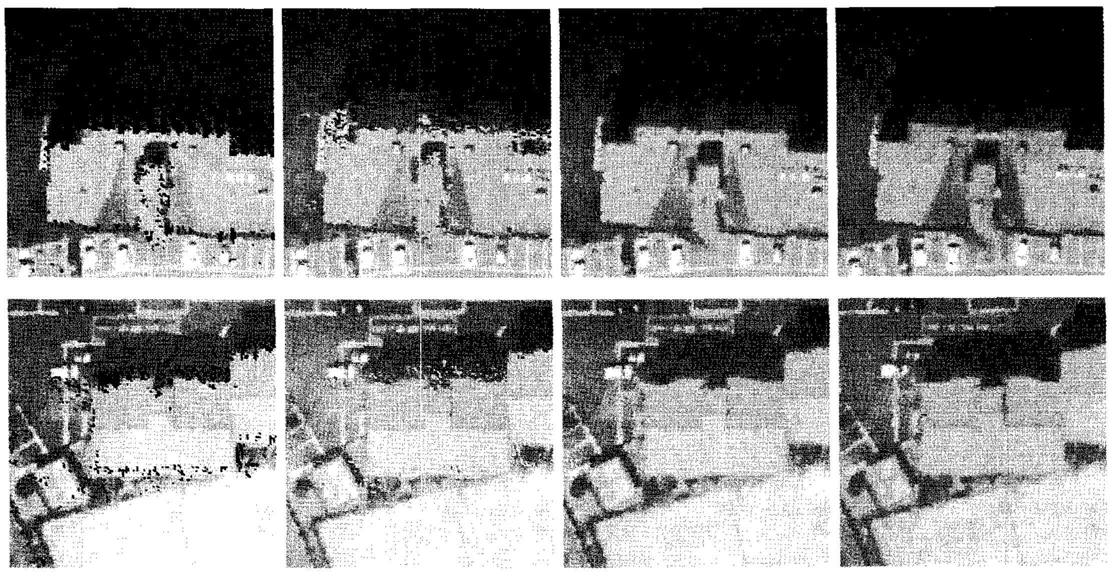
3) Anaglyph Comparison

In order to examine the significance of the results, we created stereoscopic color anaglyphs with the original image and the stereomate restored by each method. The Dubois algorithm was used to generate the color anaglyph (Dubois, 2001). Then we compared the quality of anaglyphs. As the evaluation of the results visually, the anaglyph using the TIN interpolation was the best comfortable and efficient to see 3D view in the case of Landsat stereo pair, and inpainting method provided most natural stereoscopic anaglyph in case of aerial photo's stereo pair. Fig. 5 and Fig. 6 show these anaglyph results.



(a) (b) (c) (d)

Fig. 3. Restoration result of the riverside and hill area in the Landsat stereomate: (a) occluded stereomate, (b) nearest neighbor, (c) TIN interpolation, (d) inpainting.



(a) (b) (c) (d)

Fig. 4. Restoration result of buildings area in the aerial photo: (a) occluded stereomate, (b) nearest neighbor, (c) TIN interpolation, (d) inpainting.

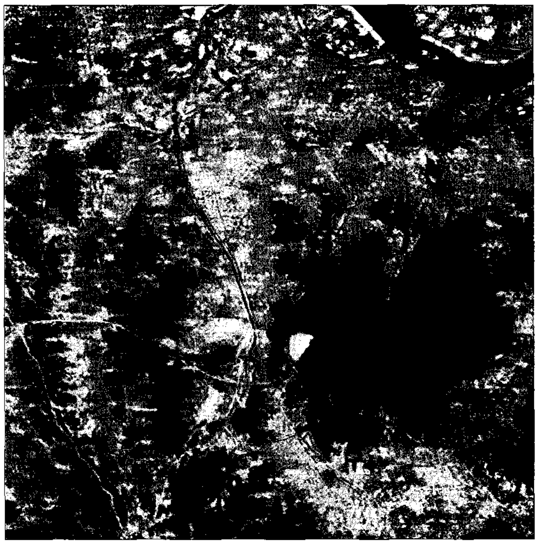


Fig. 5. Anaglyph of the southern Seoul area from Landsat stereomate using TIN interpolation.

Fig. 6. Anaglyph from aerial photo stereomate using inpainting.

5. Conclusion

In this paper, we synthesized stereomates and evaluated the three occlusion restoration methods by applying them to synthesized stereomates of different resolution. The proposed application and specifications between the middle resolution image such as Landsat image and the high resolution image such as aerial photo are so different that it need to different way to generate a synthesized stereomate and restore the occlusion. We focused on finding a proper method to restore the occlusion from synthesizing stereomates. Through the experiments, the general interpolation method such as nearest neighbor or TIN interpolation was appropriate to middle resolution satellite imagery. On the other hand, inpainting algorithm was better than interpolation technique on aerial photo because interpolation distorted the spatial information of high resolution image. Therefore we concluded that it is necessary to choose the proper occlusion restoration method in accordance with the kind of the data and occlusion pattern.

Acknowledgment

The authors gratefully acknowledge financial support form Seoul Research and Business Development (10540).

References

Batson, R. M. and Edwards, K., 1976. Synthetic Stereo and LANDSAT Pictures, *Photogrammetric Engineering and Remote Sensing*, 42(10): 1279-1284.

Bethel J. S., 1991. Generation of synthetic stereo views from digital terrain models and digitized photographs, Proc. SPIE Conf. on Stereoscopic Displays and Applications II, San Jose, The USA, 1457: 49-53.

Chang, H., Kim, H, Lee, J., and Yu, K., 2006. Synthesis of stereo-mate through the fusion of a single aerial photo and LiDAR data, Proc. Conf. on ISRS 2006 PORSEC, Busan, Korea, CD-ROM.

Criminisi, A., Perez, P., and Toyama, K., 2003. Object removal by exemplar-based inpainting, Proc. IEEE Conf. on Computer Vision and Pattern Recognition, Madison, The USA, 2: 721-728.

Criminisi, A., Perez, P. and Toyama, K., 2004. Region filling and object removal by exemplar-based inpainting, *IEEE Trans. Image Processing*, 13: 1200-1212.

Dubois, E., 2001. A projection method to generate anaglyph stereo images, Proc. IEEE Conf. on Acoustics. Speech Signal Processing, Salt Lake City, USA, 3: 1661-1664.

Fehn, C., 2003. A 3D-TV Approach Using Depth-Image-Based Rendering (DIBR), Proc. Conf. on Visualization, Imaging, and Image Processing, Benalmádena, Spain, pp. 482-487.

Fehn, C., 2004. Depth-Image-Based Rendering (DIBR), Compression and Transmission for an New Approach on 3D-TV, Proc. SPIE Conf. Stereoscopic Displays and Virtual Reality Systems XI , San Jose, USA, pp. 93-104.

Ideses, I. and Yaroslavsky, L., 2005. Three methods that improve the visual quality of colour anaglyphs, *Journal of Optics A: Pure and Applied Optics*, 7(12): 755-762.

O'Neill, M. A. and Dowman, I. J., 1998. The generation of epipolar synthetic stereo mates for SPOT images using a DEM, Proc. 16th ISPRS Congress, Kyoto, Japan, vol.27, part B3, pp.587-598.

Roth, S. and Black, M. J, 2005. Fields of Experts: A Framework for Learning Image Priors, Proc. IEEE Conf. on Computer Vision and Pattern Recognition, San Diego, USA, pp. 860-867.

Salvi, S., 1995. Analysis and interpretation of Landsat synthetic stereo pair for the detection of active fault zones in the Abruzzi region, *Remote Sensing of Environment*, 53(3): 153-163.

Scharstein, D., 1996. Stereo vision for view synthesis, Proc. IEEE Conf. on Computer Vision and Pattern Recognition, San Francisco, USA, pp852 -858.

Usery, E. L., 1993. Virtual stereo display techniques for three-dimensional geographic data, *Photogrammetric Engineering and Remote Sensing*, 59(12): 1737-1744.