Singularity Mitigation in Automated DEM Extraction from IKONOS Images

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Abstract: Extraction of a digital elevation model from high resolution satellite images such as IKONOS is important for many applications. One of the most popular techniques hired for automated DEM extraction is stereo matching. However, high resolution satellite images possess some properties that make automated stereo matching difficult. They present edges of individual buildings, building facades and shadows. The effects of height discontinuity and the presence of occluded regions are significant. They often possess very homogenous areas in urban regions and very noisy patterns on vegetated regions. We will first review the characteristics of high resolution images that make automated DEM generation difficult and analyzed their effects with one IKONOS stereo pair. We will discuss the ideas to mitigate these problems. We will show that the problems of occlusions and building facades can partly be solved by using two way stereo matching, once with the left image as the reference and once with the right image as the references and by merging the two results. We will also show that the problems of noisy patterns and building facades can partly be solved by using pyramid approach.

Keywords: DEM Extraction, IKONOS

1. Introduction

Digital Elevation Models (DEMs) can represent the topography of land surface that can be applied in many fields. There are several methods of generating DEMs, most popular ones being the manual digitization of existing maps and the manual photogrammetric measurements. As manual generation requires significant resources, a study on automated DEM generation has been an active research issue. One of the most popular techniques hired for automated DEM extraction is stereo matching. From a given template, stereo matching determines the conjugate point by searching for the position of best similarity. A number of algorithms have been proposed for stereo matching aerial or satellite images to generate DEMs automatically [1-4].

This paper will deal with the issue of automated DEM generation from satellite images. In particular we will consider DEM generation using high resolution satellite images. As there are several spaceborne platforms acquiring high resolution images it seems possible to create high resolution spaceborne DEMs. This possibility can offer many advantages over DEMs generated from aerial images (or airborne DEMs) as spaceborne DEMs do not affect by the limitation of aviation control.

However, high resolution satellite images have distinctive characteristics that make automated DEM generation difficult. Many stereo matching algorithms often assume smoothness of height changes. High resolution satellite images are fine enough to see edges of individual buildings, building facades and shadows. Due to them the effects of height discontinuity and the presence of occluded regions are significant. High resolution images often possess very homogenous areas, in particular, in urban regions and, conversely, very noisy patterns on vegetated regions. (See the next section for explanation). These characteristics make most of techniques that are developed for mid or low resolution images difficult to be applied to high resolution images.

This paper will first review the characteristics of high resolution images that make automated DEM generation difficult (we name them “singularity”). We will show their effects with an automated DEM generation algorithm developed for SPOT images [3]. This algorithm uses the epipolar geometry of linear pushbroom sensors and intelligent matching strategy. This algorithm is published elsewhere and will not be repeated here. We will then discuss the approach we tried to reduce the effects of singularity. Among many possible approaches we tried two way stereo matching and pyramidal stereo matching. We will show the (visual) improvement of the approaches tried.

2. Singularities of high resolution satellite images in automated DEM generation

1) Test data used for analysis and experiments

In order to discuss the singularity and analyze their effects on DEM generation, we choose to use one IKONOS stereo pair over Daejeon area. Properties of the stereo pair are summarized below. Two images were taken on the same day by tilting the spacecraft for- and backwards along its orbital pass. 13 ground control points were obtained through differential GPS measurements. These were used for establishing sensor models for the stereo pair.

Figure 1 shows a sub-scene extracted from the left image of the stereo pair. The image contains mountains, apartment complex, residential houses, rivers, and agricultural fields. This sub-scene and the corresponding sub-scene extracted from the right image were used for analysis and tests.

Table 1. Characteristics of the IKONOS stereo pair used

Scene ID	Left	Right
Date of Acquisition	19 Nov., 2001	19 Nov., 2001
Time of Acquisition	02:18:46.7 UTC	02:19:44.2 UTC
Satellite Azimuth Angle	46.0°	151.8°
Satellite Elevation Angle	66.5°	69.6°
Sun Azimuth Angle	163.88°	164.14°
Sun Elevation Angle	32.75°	32.81°
No of GCPs	13	13

Figure 1. A sub-scene extracted from the left image of the IKONOS stereo pair (Courtesy of WIA Co. Ltd, formerly e-HD.com, Ltd)

2) Singularity due to building facades and occlusions

Figure 2 presents the appearance of apartment buildings in the left and right images. The location of this sub-scene is indicated as a circle in figure 1. As shown in the figure, the same apartment buildings appear quite different. In the left sub-scene, building facades that are facing upwards are shown whereas in the right, building facades facing downwards are so. This is due to the different viewing geometry of the left and right images (see the difference in satellite azimuth angles). This difference is prerequisite for being stereo pairs and hence is inevitable. On the other hands, the appearance of building facades occludes the surfaces at the ground level on the other side of buildings. Over the areas containing these singularities any automated DEM generation techniques would suffer.

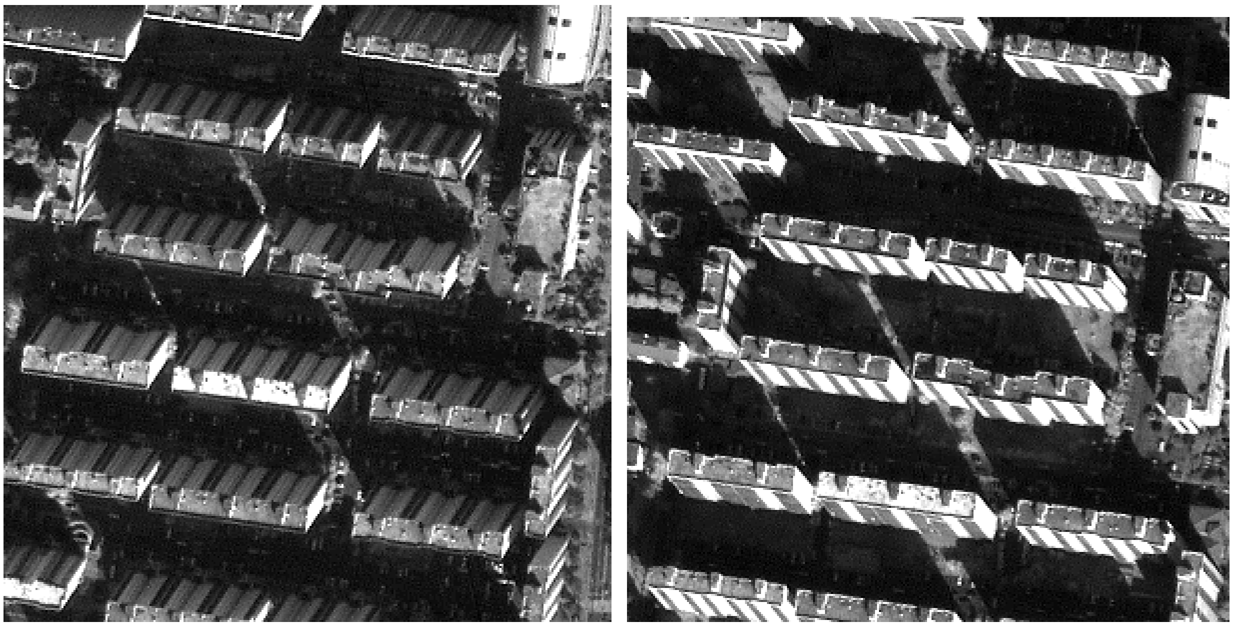

Figure 2. Appearance of apartment complex in the left and right images

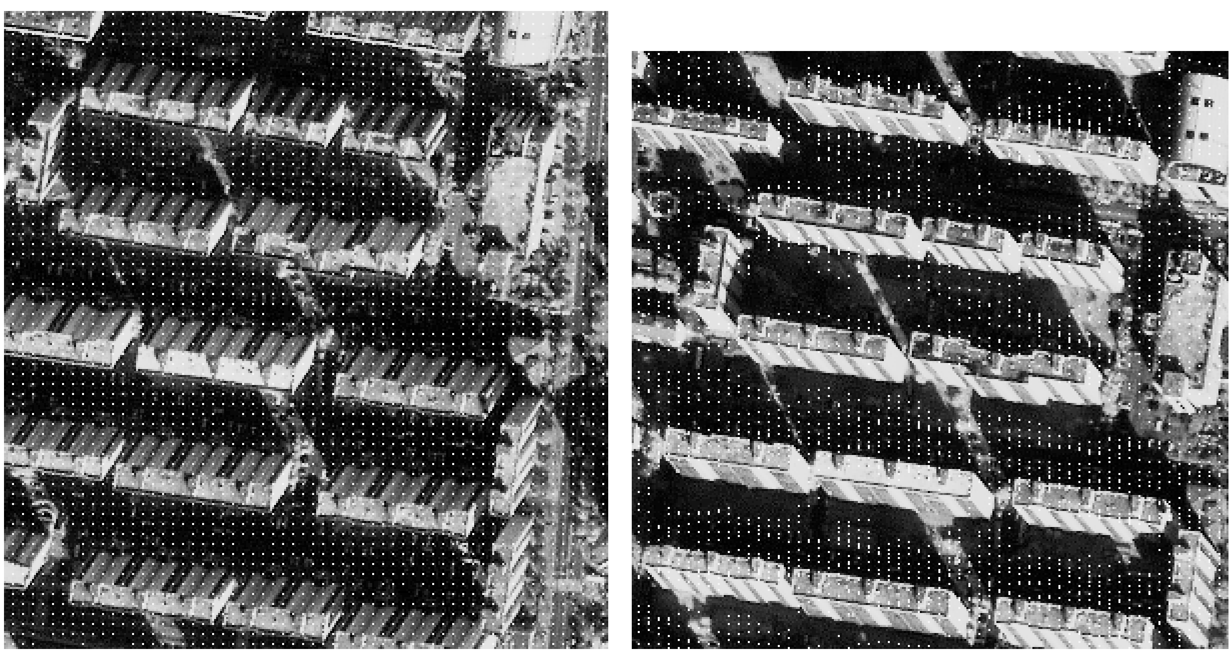

Figure 3. Results of stereo matching over apartment buildings

Figure 3 shows the results of stereo matching applied to the sub-scenes in figure 2. White dots indicate the locations of match results in the left and right images. After providing ground control points for the left and right images, the whole stereo matching process was performed automatically. We used the left image as the reference and the right image as the target and applied stereo matching on points in the reference images with five-pixel spacing. (This is the reason why the dots in the left image are regular spaced and dots in the right are not.)

The stereo matching results show that the points on building facades in the left image have been (falsely) matched even though there are no corresponding points in the right image. On the other hands, the building facades in the right images and their vicinities are not matched because these areas are occluded in the left image and therefore no reference points on these areas are defined. (This is good news). Figure 6 shows a DEM generated from these stereo matching results (indicated as a circle).

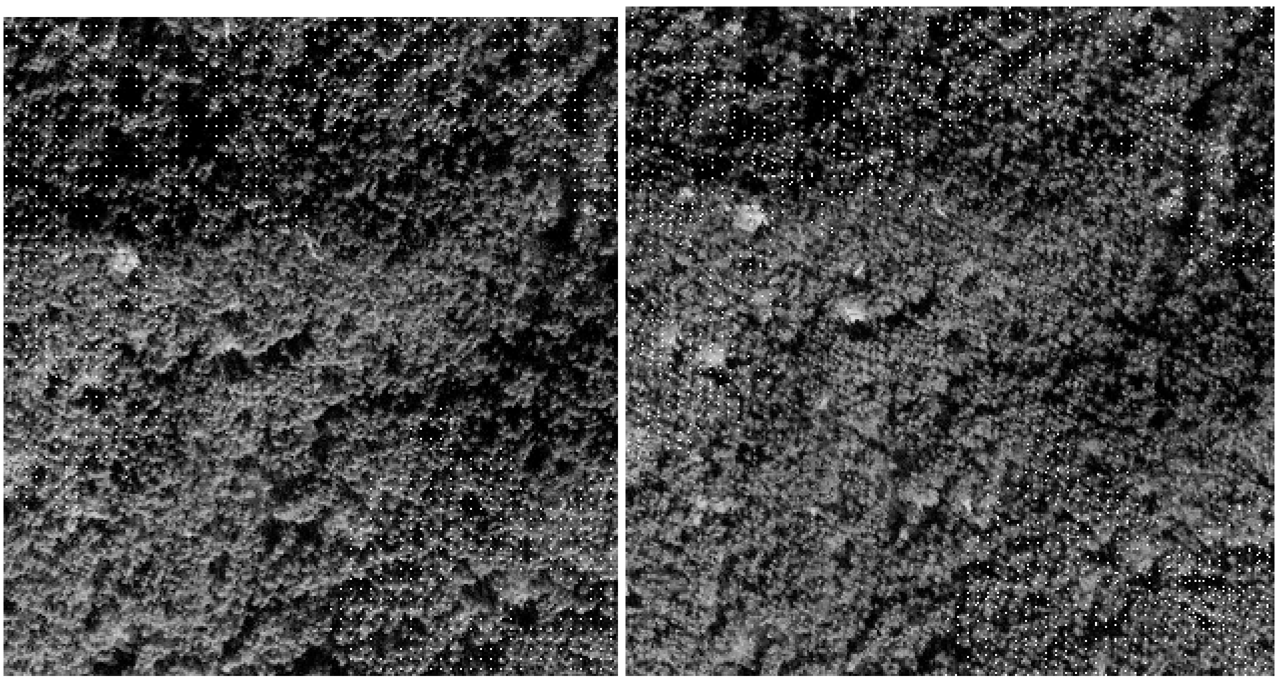

Figure 4. Stereo matching results over pseudo-random noisy patterns

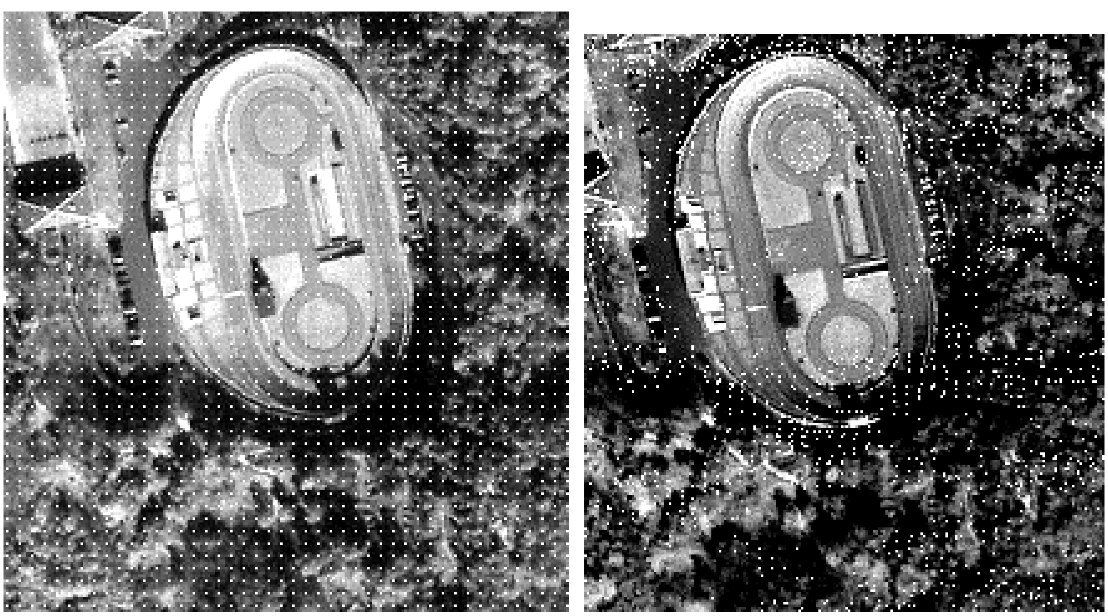

Figure 5. Stereo matching failures over homogenous patterns

3) Singularities due to low texture and homogeneity

Figure 4 shows the example of stereo matching failure over the mountain. The region without dots indicates the area where stereo matching failed. Although naked eyes can identify conjugates points in the stereo pair, the trees and their shadows generate pseudo-random noise patterns or patterns of low texture. Since the stereo matching algorithm used was based on cross-correlation of gray values these patterns forced stereo matching failures. For low or mid resolution images these patterns may not be so distinctive. Due to high resolution trees appear noisy in the image. Another stereo matching failure occurs on homogenous regions, as shown in figure 5. This singularity is common in all level of resolution. However, problems due to homogeneity can be severe in high resolution images. Those regions that appear in-homogenous in low or mid resolution images often appear locally homogenous in high resolution images.

4) A DEM generated before singularity mitigation

Figure 6 shows the DEM automatically generated from the stereo pair shown in figure 1. The singularities explained above are present in the DEM. The area with a circle indicates the singularities due to building facades and occlusions as explained in figure 3. The holes on the mountains are due to the noisy patterns on trees, as shown in figure 4. The problem of homogeneity has been minimized by defining a very small search range.

It is notable that the DEM below was generated purely from stereo matching results without any interpolation and that we tried stereo matching several times in order to get optimum match parameters. Although the DEM contains singularities, it still represents real surface patterns well. (Quality assessments are to be performed later.)

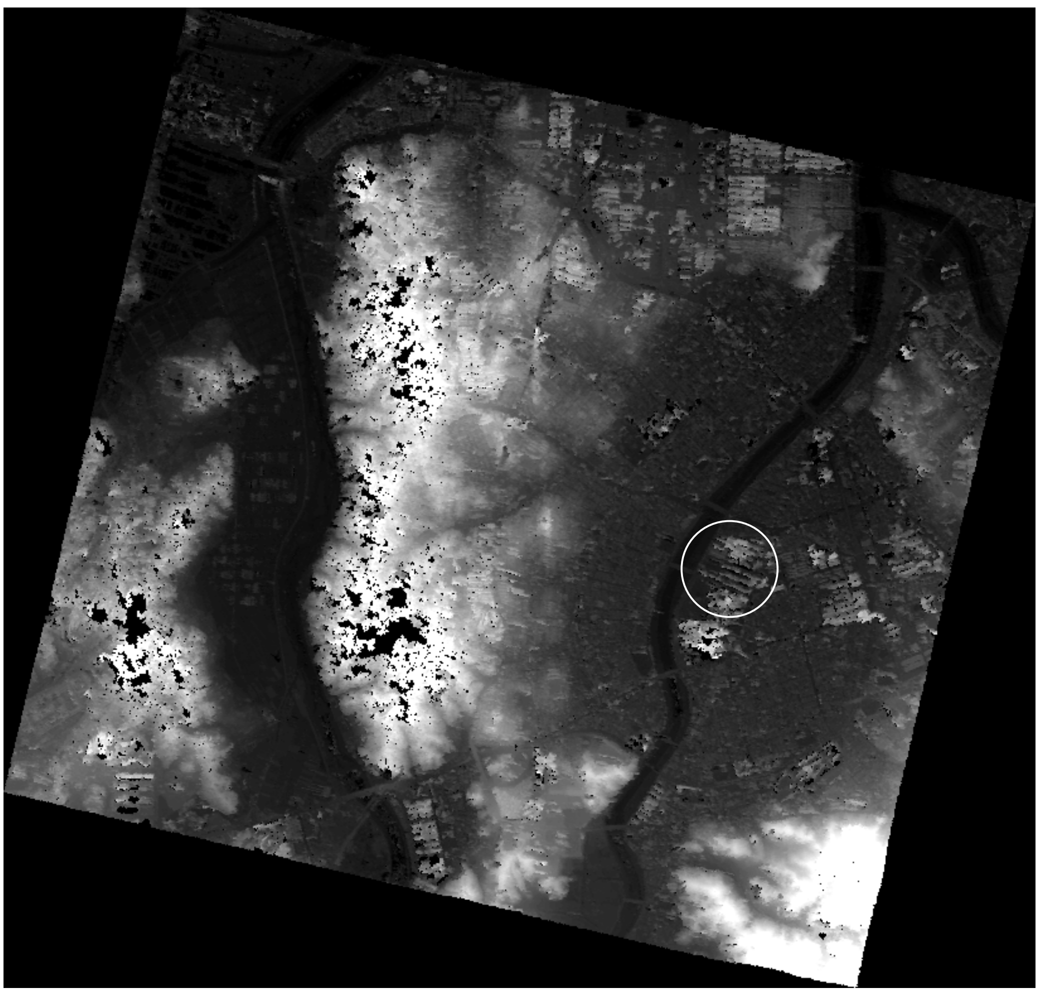

Figure 6. An example of a DEM without singularity mitigation

3. Strategies to mitigate singularities

1) The merge of left-to-right and right-to-left stereo matching

In figure 2, we observed that due to the occlusion made by buildings in the left image the building facades and their vicinities in the right images have been left out correctly for stereo matching. Following this observation, we may try to easy the problems due to building facades and occlusions by applying stereo matching twice, once with the left image as the reference and once with the right image as the reference and by merging the results of individual matching.

Figure 7 shows the results of stereo matching with the right image as the reference. In this result, we can observe that the number of the falsely matched points on building facades in the left image has been reduced (although there are still some false matches). Conversely, there are additional false matches on the building facades of the right image. Figure 8 shows the differences between the DEM created from the conventional one-way stereo matching using the left image as the reference (the left image of figure 8) and the DEM created by merging the two stereo matching results (the right image of figure 8). One can observe that the edge of building are represented better in the latter DEM.

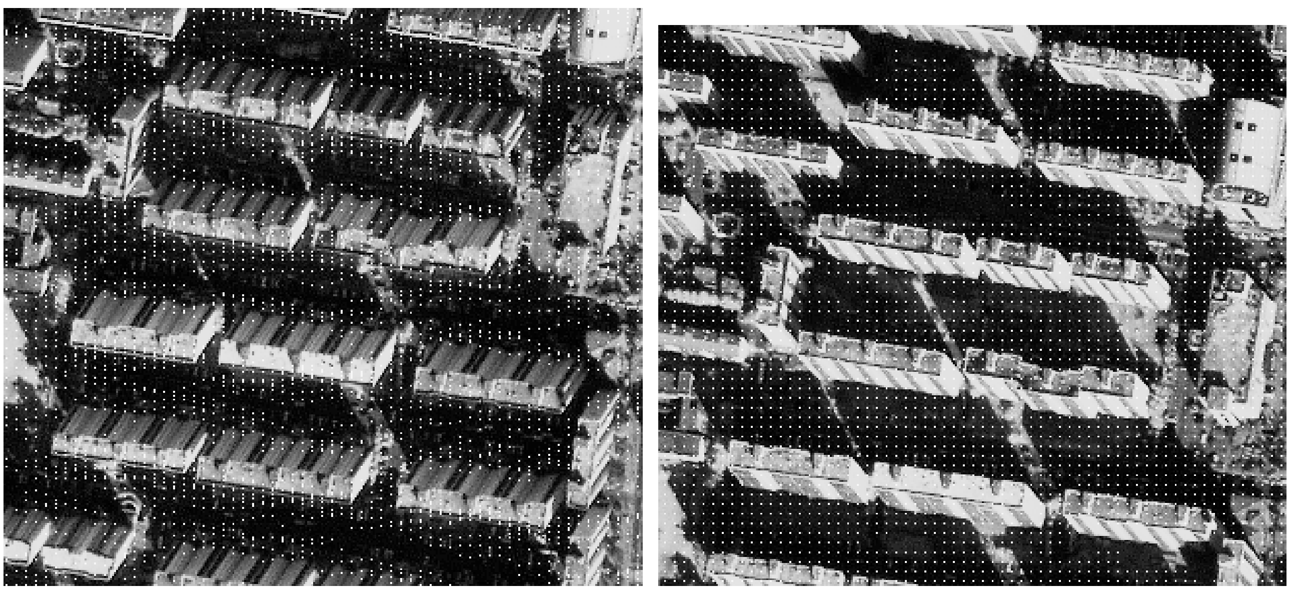

Figure 7. Results of stereo matching using the right image as the reference

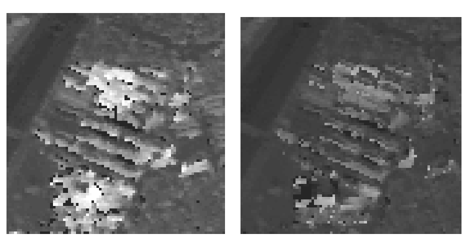

Figure 8. DEMs over apartment buildings from one-way and two-way stereo matching

2) Pyramidal approach

In the previous section, we discussed the singularities due to noisy patterns, low texture and homogeneity and we mentioned that high spatial resolution was one main source of these singularities. Following this discussion, we may try to reduce such singularities by reducing the spatial resolution of the original image until the level where noisy patterns, low texture and homogeneity due to high resolution become negligible.

In fact, pyramidal approach has been proposed previously to solve problems of matching high resolution aerial images over urban areas [2]. In this paper we tested this approach again for generating DEMs from high resolution satellite images. We first established an image pyramid of five levels. At the lowest level we used the original stereo pair. For the next higher level we reduced the spatial resolution of the images by the factor of two subsequently. At the highest level we used the images reduced by the factor of 16. We then applied stereo matching at the highest level. We used the results of matching at higher level as seed points of stereo matching for lower level. We repeated this process until we reached to the lowest level. Figure 9 shows DEMs created from the highest level (reduction factor of 16) to the second lowest level (reduction factor of 2).

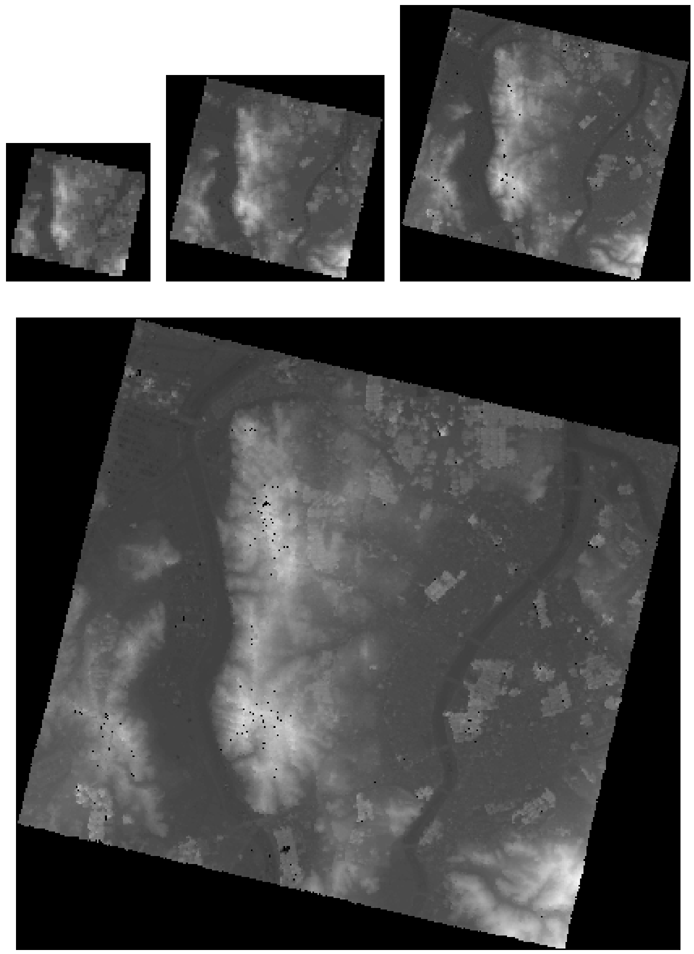

Figure 9. Results of pyramidal approach. The DEMs generated by images reduced by the factor of 16 (the top left DEM), 8 (the top middle DEM), 4 (the top right DEM), and 2 (the bottom DEM).

Figure 10 shows the DEM at the lowest level generated from pyramid approach. Compared with the DEM in figure 6, the DEM in figure 10 shows better coverage, more clear building boundaries and less blunders. There are still some small holes on noisy patterns within mountain areas. However, most of them are small enough to be filled with a simple interpolation technique.

3) Other approaches

There can be other approaches to solve the problem associated with stereo matching high resolution satellite images. One solution can be masking out shadow regions from stereo matching. Usually shadow regions occur in the vicinity of buildings and create areas with low texture. By masking out these regions, one can artificially suppress regions next to buildings to height of ground level. This has been tried previously [5] but need to be verified further. Other possibilities can be the use of voxel-based match [5] instead of the current pixel-based one. Since voxel-based match tries to find the best correspondences for 3D object spaces, it can potentially remove the problems associated with occlusions and building facades.

Combining many approaches may ease the problem further. For example, the DEM in the right of figure 8 has better building boundaries from the two-way approach, whereas the DEM in figure 10 a better coverage. If we merge these two, we should have a DEM with a better quality.

These approaches will be studies in near future.

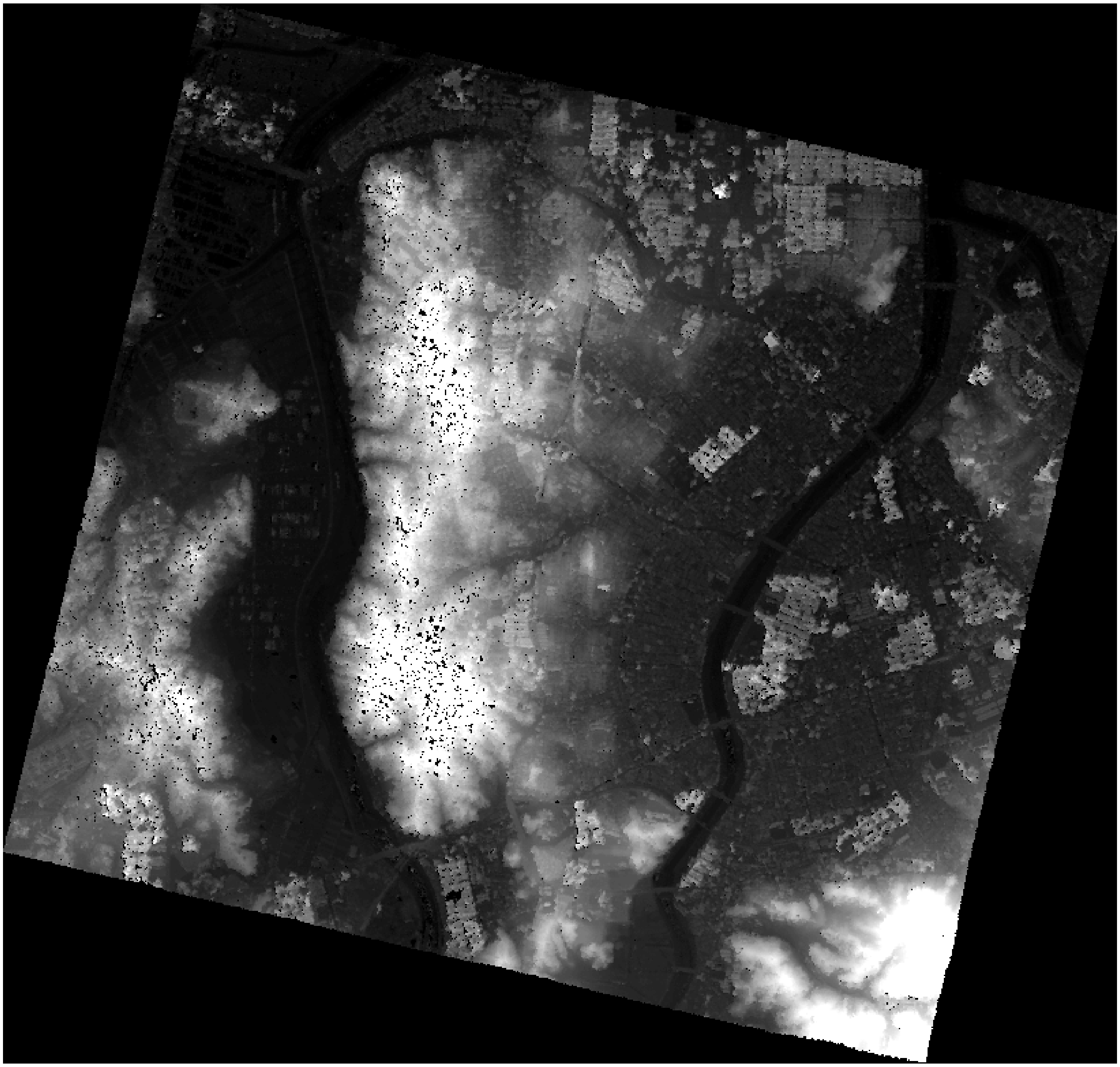

Figure 10. The DEM created from pyramid approach (and processed with the original images)

4. Conclusions

In this paper, we discussed the problems associated with automated DEM generation from high resolution satellite images. We identified two major sources of problems: problems due to occlusions and building facades and the problems due to noisy patterns and homogeneity. We analyzed these problems with one IKONOS stereo pair. We discussed the ideas to mitigate these problems. We showed that the problems of occlusions and building facades could partly be solved by using two way stereo matching, once with the left image as the reference and once with the right image as the references. We also showed that the problems of noisy patterns and building facades could partly be solved by using pyramid approach.

Acknowledgement

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