COMPARISON OF BINGHAM MINE LANDSLIDE DSMs USING PLEIADES TRI-STEREO SATELLITE DATA

Philip Cheng

PCI Geomatics, 90 Allstate Pkwy #501, Markham, Ontario, Canada, L3R 6H3
Email: cheng@pcigeomatics.com

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ABSTRACT: The Bingham Canyon Mine is an open-pit mining operation extracting a large porphyry copper deposit in Utah, USA. The mine is the largest man-made excavation in the world and is considered to have produced more copper than any other mine in history. On April 10, 2013 two landslides occurred at the mine with approximately 2.5 billion cubic feet (71 million cubic meters) of dirt and rock thundered down the side of the pit. Pleiades tri-stereo satellite data can be used to compare the differences before and after the landslides. In this paper we will show how to use two Pleiades tri-stereo datasets, acquired before and after the landslides, to extract Digital Surface Models (DSMs) using the Semi-Global Mapping (SGM) method, and compare the differences.

1. INTRODUCTION

The Bingham Canyon Mine, more commonly known as Kennecott Copper Mine among locals, is an open-pit mining operation extracting a large porphyry copper deposit southwest of Salt Lake City, Utah, in the Oquirrh Mountains. The mine is the largest man-made excavation in the world and is considered to have produced more copper than any other mine in history at more than 19 million tons. The mine has been in production since 1906 and has resulted in the creation of a pit over 0.6 miles (970 m) deep and 2.5 miles (4 km) wide, and covering 1,900 acres (3.0 sq mi; 7.7 km^2). It was designated a National Historic Landmark in 1966 under the name Bingham Canyon Open Pit Copper Mine.

On April 10, 2013, two massive landslides carried about 145 million tons of waste rock into the bottom of the open pit at Bingham Canyon. These are the largest mining-induced landslides in history. The two slides, named the Manefay landslides by Kennecott Utah Copper (KUC), started in the northeast corner of the open pit. The first landslide, starting at 9:30 p.m., was the largest at nearly 100 million tons. The second landslide followed a little over an hour-and-a-half later. The second slide was followed 11 minutes later by a small, shallow earthquake (approximate magnitude 2.5) beneath the mine, induced by the rapid shifting weight of the slides. Notably, the Manefay slides resulted in no injuries or deaths, but they significantly changed the face of the mine and caused hundreds of millions of dollars of damage to the operation.

One method to evaluate the changes due to the landslides is to extract high resolution DSMs using satellite data captured before and after the landslides to compute the differences in elevation values throughout the site. The DSMs can also be used to generate ortho images of the area. In this paper we will show the steps in using satellite data to perform such task.

2. SATELLITE DATA

Many satellite data with differing resolutions are currently available. To generate DSMs either stereo or tri-stereo data must be used. Tri-stereo satellite data is preferable because it composes of three nearly simultaneously acquired images - one backward looking, one forward looking, and a third near-nadir image. This configuration, in particular the use of the near-nadir image, allows a better retrieval of heights over terrains where the performance of classic photogrammetry with forward backward looking stereo pairs may be limited (e.g. high roughness, steep slopes, and shadows). Although there are many satellites capable of acquiring sub-metre resolution data, most of them do not acquire tri-stereo data. Pleiades satellite data is the best choice in this case because it provides tri-stereo data with a panchromatic resolution of 50cm. Two Pleiades tri-stereo datasets were chosen for this test. The first dataset was acquired by Pleiades-1A on April 8, 2012, with along-track acquisition angles of 6.82, 0.16 and -4.67 degrees, respectively. The second dataset was acquired by Pleiades-1B on Oct 24, 2013, with along-track acquisition angles of 10.29, -1.01 and -10.25 degrees, respectively. Figure 1 and 2 show the multispectral nadir images before and after the landslides, respectively.

Figure 1: Pleiades-1A image acquired before the landslides

Figure 2: Pleiades-1B image acquired after the landslides

3. SOFTWARE

PCI Geomatics' 2019 OrthoEngine software was used for this testing. This software supports reading and pansharpening of the data, manual or automatic ground control point (GCP) and tie point (TP) collection, geometric modeling using the rational polynomial coefficient (RPC) model, automatic DSM generation using the Normalized Cross-Correlation (NCC) as well as the Semi-Global Mapping (SGM) method, DSM editing, orthorectification, and both manual and automatic mosaicking including automatic cutline generation and colour balancing.

In the past NCC was the most common method for extracting DSMs. The major problems with this method are blurred object borders, and the loss of small features due to matching using square windows. Heiko Hirschmueller (2008) from the DLR developed the SGM method. It uses a pixelwise, mutual information (MI)-based matching cost for compensating radiometric differences of the input images. SGM is currently among the top-ranked algorithms for DSM generation, and is the best if subpixel accuracy is considered. This paper will use the SGM method to extract DSMs.

4. DATA PROCESSING

Pleiades panchromatic images were used in order to obtain the highest resolution DSMs. Since GCPs were not available, a total of 198 TPs were collected automatically across all images. Using TPs ensures all results are perfectly aligned with each other for comparisons before and after the landslides. All Pleiades data come with RPCs, hence the RPC geometric model can be used in this case. TP RMS residuals of approximately 10cm in X and Y, and 2cm in Z, were obtained.

4.1 DSMs

To generate DSMs before and after the landslides, the nadir-forward and nadir-backward scenes were used. DSMs were generated at 1m spacing and the results were combined together to generate the final DSM. Figures 3 and 4 show the DSMs before and after the landslides, and figure 5 shows the difference between the two DSMs.

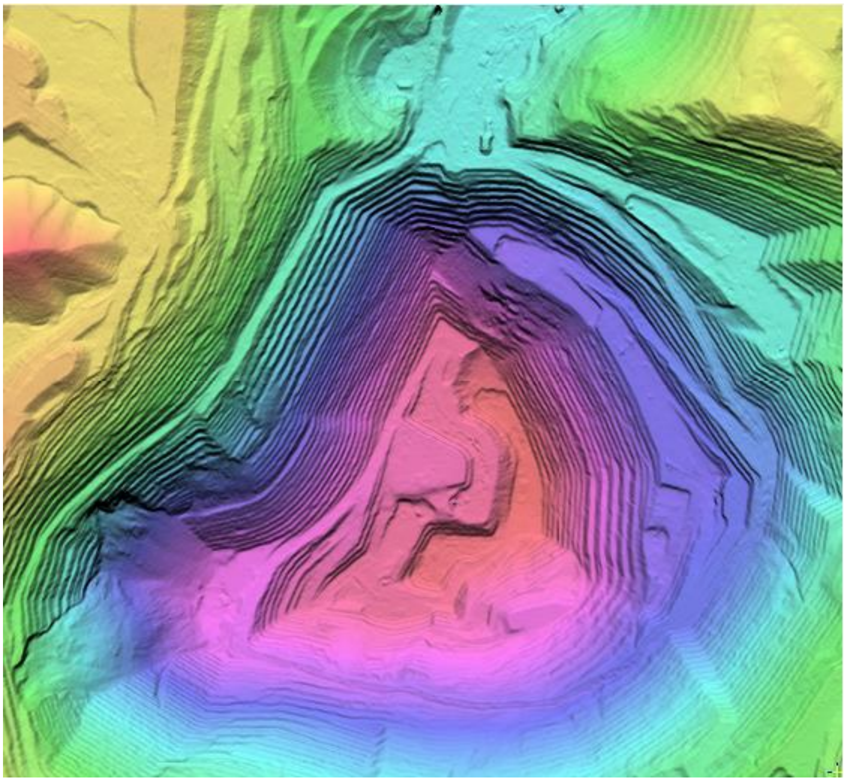

Figure 3 Pleiades extracted DSM before the landslides

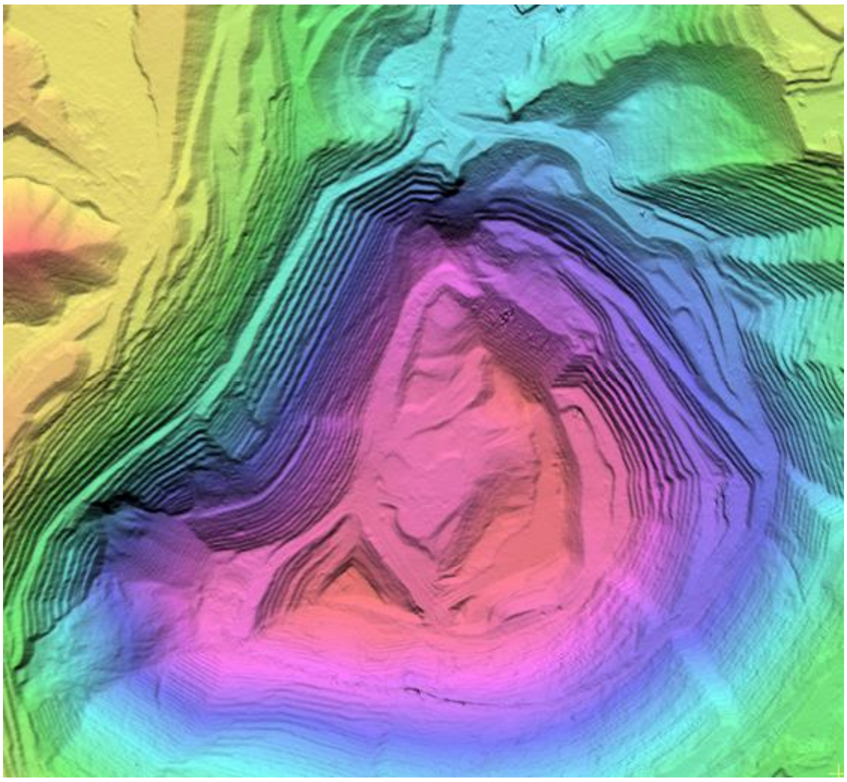

Figure 4 Pleiades extracted DSM after the landslides

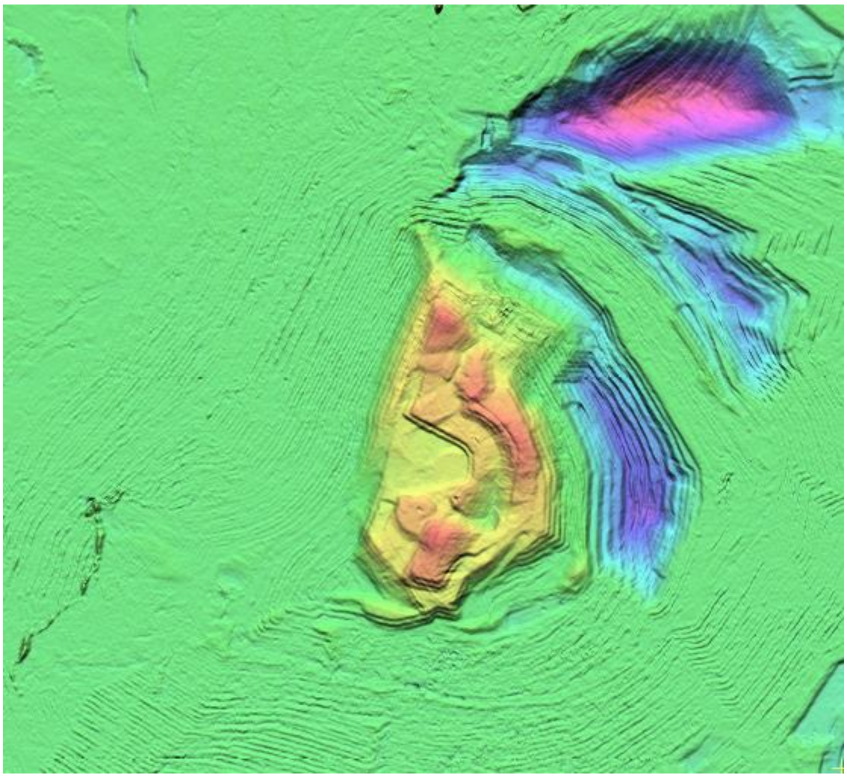

Figure 5: DSM difference before and after the landslides

4.2 Ortho Images

Prior to the generation of ortho images, pansharpening was applied to each nadir looking panchromatic and multispectral image to generate high resolution multispectral images at 0.5m resolution. Nadir looking images were chosen because they are less sensitive to any errors in the DSM. The pansharpened images together with the extracted DSMs were then used to generate ortho images. Figure 6 to 9 show the ortho images and the corresponding DSMs before and after the landslides.

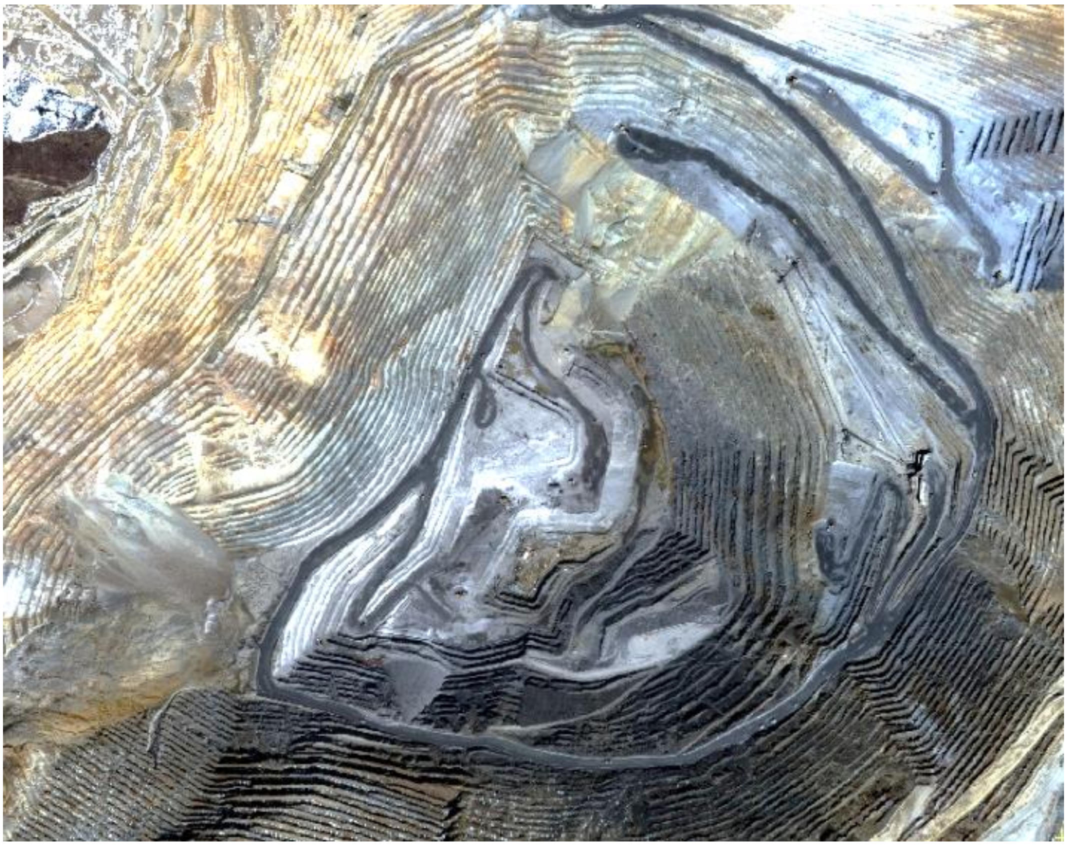
Figure 6: Pansharpened Pleiades ortho before the landslides

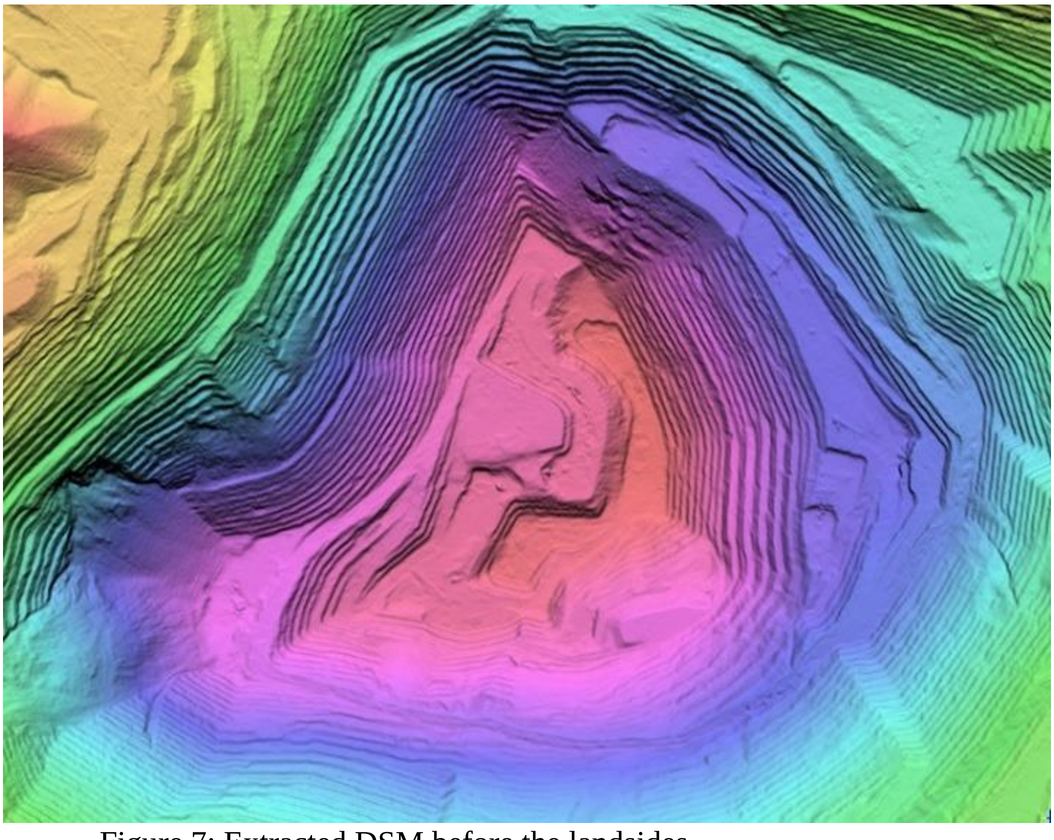
Figure 7: Extracted DSM before the landsides

Figure 8: Pansharpened Pleiades ortho after the landslides

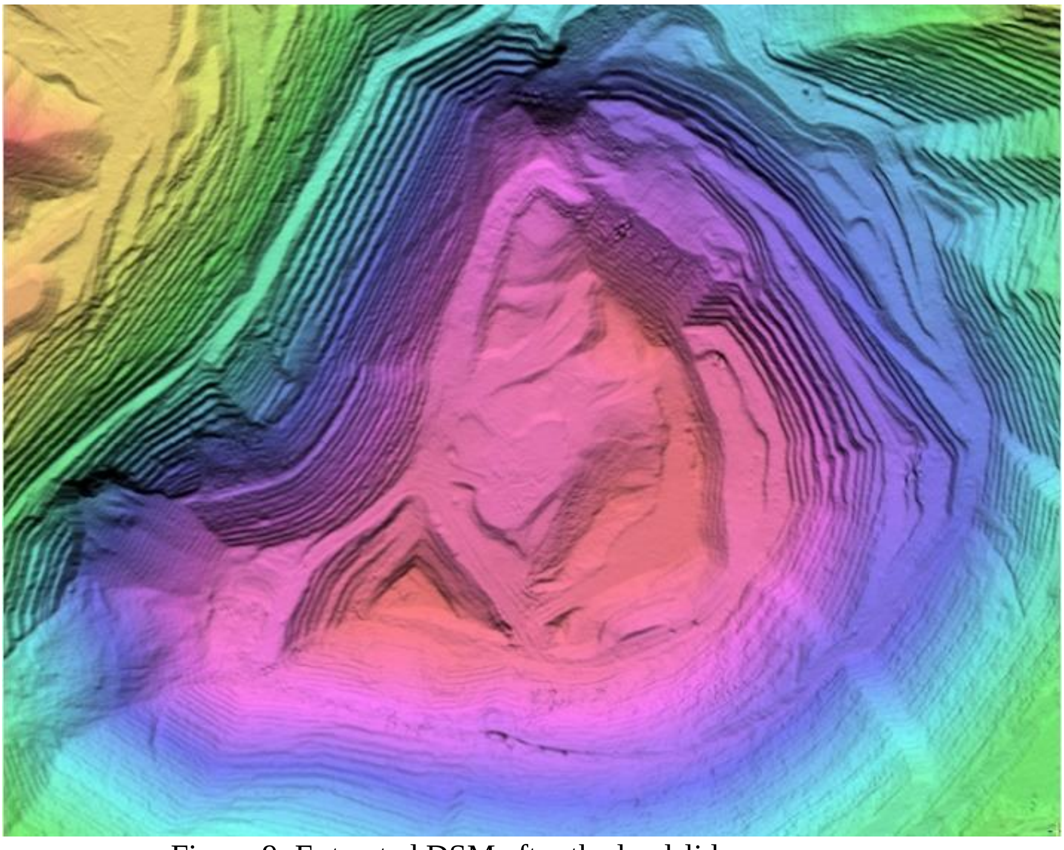

Figure 9: Extracted DSM after the landslides

5. CONCLUSIONS

In this paper we have shown the steps in using Pleiades tri-stereo data to generate DSMs and pansharpened orthos for evaluating the differences before and after landslides. This method can be extended to other applications to monitor changes in elevations.

6 ACKNOWLEDGMENT

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7 REFERENCES

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