Automated Point Cloud Analysis
for 3D Topographic Change Detection

THOMAS BAHR[1], NICOLAI HOLZER[1] & REBECCA LASICA[2]

Zusammenfassung: Eine Hangrutschung am 30. Juli 2014 führte zu großflächigen Massenbewegungen, welche Teile des Dorfes Malin in Maharashtra in Indien begruben. In dieser vorläufigen Studie wurde durch Differenzbildung zweier multi-temporaler Geländemodelle Oberflächenänderungen von bis zu 10 m als Folge der Hangrutschung bestimmt. Die ursprüngliche Geländesituation repräsentiert das Airbus DS WorldDEM^{TM} Produkt. Ein aus Pléiades Stereo-Satellitendaten abgeleitetes Geländemodell beschreibt die Situation nach dem Ereignis. Die operationelle Umsetzung der Analytik basiert auf ENVI 5.3 und dem in IDL entwickelten, objektorientierten ENVITask-System. Diese modulare und erweiterungsfähige Implementierung zeigt die Potentiale einer vollautomatisierten Integration, z. B. in webgestützte, servicebasierte Umgebungen wie ArcGIS Server$^{®}$.

1 Introduction

The fusion of stereo photogrammetric point clouds with LiDAR data or terrain information derived from SAR interferometry has significant potentials for 3D topographic change detection. In the present, preliminary case study latest point cloud generation and analysis capabilities are used to examine a landslide that occurred in the village of Malin in Maharashtra, India, on 30 July 2014, and affected an area of approximately 44.000 m^2. The landslide was triggered by heavy rainfall in the area (ERING et al. 2015; RAMASAMY et al. 2015).

The point cloud analysis focuses on Pléiades high resolution satellite imagery and the Airbus DS WorldDEM^{TM} as a product of the TanDEM-X mission. The pre-event topography is represented by the WorldDEM^{TM} product (called pre-DSM, Digital Surface Model), delivered with a raster of 12 m x 12 m and based on the EGM2008 geoid. For the post-event situation a Pléiades 1A/1B stereo image pair was obtained (Figure 1) with a stereo aperture of 19.7°, containing rational polynomial coefficients (RPCs). The panchromatic bands have a ground sample distance (GSD) of 0.5 m and serve for the generation of a photogrammetric point cloud, from which a so-called post-DSM is derived.

For the operation of the various processing steps in service-based production environments an automated workflow was designed. It can be embedded in virtually any existing geospatial workflow for operational applications.

This case study was performed using the Commercial of the Shelf (COTS) software package ENVI 5.3. Integration of custom processes and automation is supported by IDL (Interactive Data Language). Thus, ENVI analytics is running via the object-oriented and IDL-based ENVITask API.

---

[1] Harris Corporation, Talhofstraße 32a, D-82205 Gilching,
E-Mail: [Thomas.Bahr, Nicolai.Holzer]@harris.com
[2] Harris Corporation, 4990 Pearl East Circle, Boulder, Colorado 80301, U.S.A.,
E-Mail: rebecca.lasica@harris.com

Fig. 1: Pléiades panchromatic stereo pair of the Malin landslide area, used to run the photogrammetric generation of a point cloud from optical imagery (subset, GSD 0.5 m).
Left: Pléiades 1A, acquired 8 Feb 2015, incidence angle 21.6°.
Right: Pléiades 1B, acquired 9 Feb 2015, incidence angle 1.9°.

2   3D Topographic Change Detection

2.1   Key Components

For the application of the 3D topographic change detection we compiled the following processing steps:

- Photogrammetric extraction of a passive point cloud from the panchromatic Pléiades stereo dataset (Figure 2). For details on the algorithm see section 3.2. The point cloud is generated with one 3D point per pixel, resulting in a point density of 3-4 points / m^2, according to the 0.5 m GSD of the panchromatic bands.
- Derivation of a post-event digital surface model from the photogrammetric point clouds (called post-DSM) with a raster of 1 m x 1 m, referred to the ellipsoid. For details on the algorithm see section 3.2.
- Adding the geoid component (EGM 2008) to the previously generated post-DSM to get the real geoidal height, as the Airbus DS WorldDEM^{TM} (pre-DSM) is referred to this geoid (RIEGLER et al. 2015).
- Pre-DSM reprojection to a common coordinate system (UTM Zone 43N, WGS-84) and resizing to the 1 m x 1 m grid size of the post-DSM.
- Subtraction of the pre-DSM from the post-DSM.
- Filtering of the DSM difference with a convolution, as the resolution difference between the two elevation datasets has caused some anomalies in the resulting raster grid.
- Creation of a classification raster by thresholding on selected data ranges of the DSM difference (Figures 3, 4).
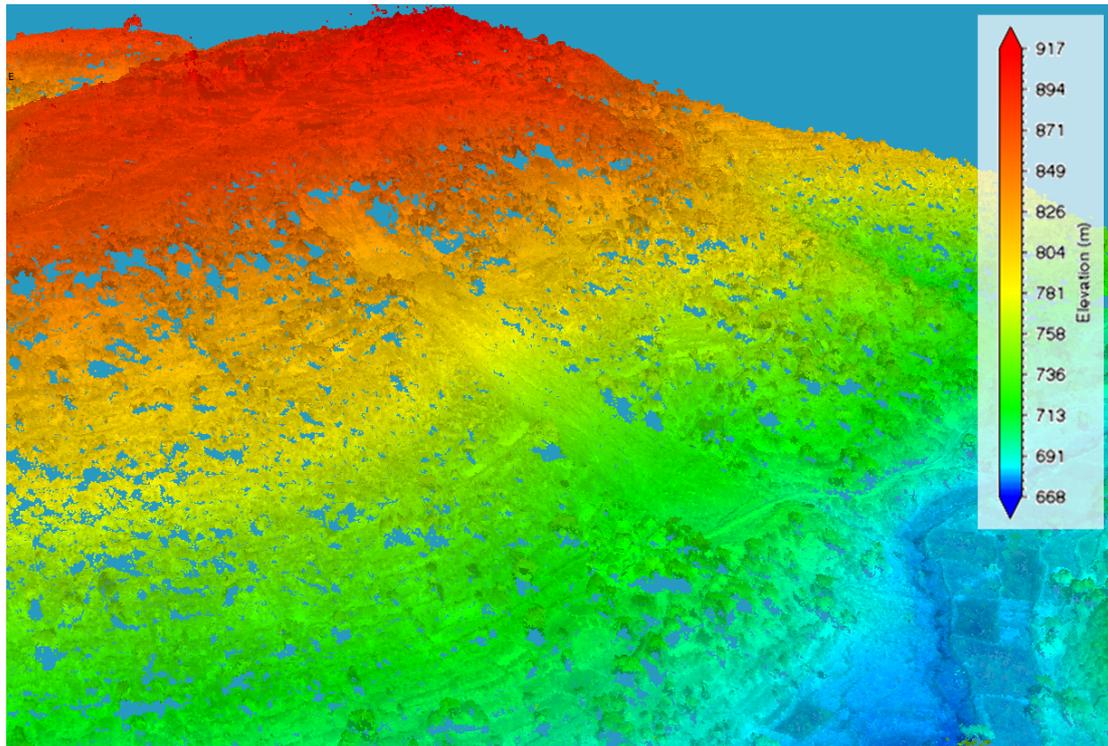
Fig. 2: Point cloud, composed of 158 *.las files, extracted from the panchromatic stereo datasets (subset). The Malin landslide with a length of 514 m is located in the center.
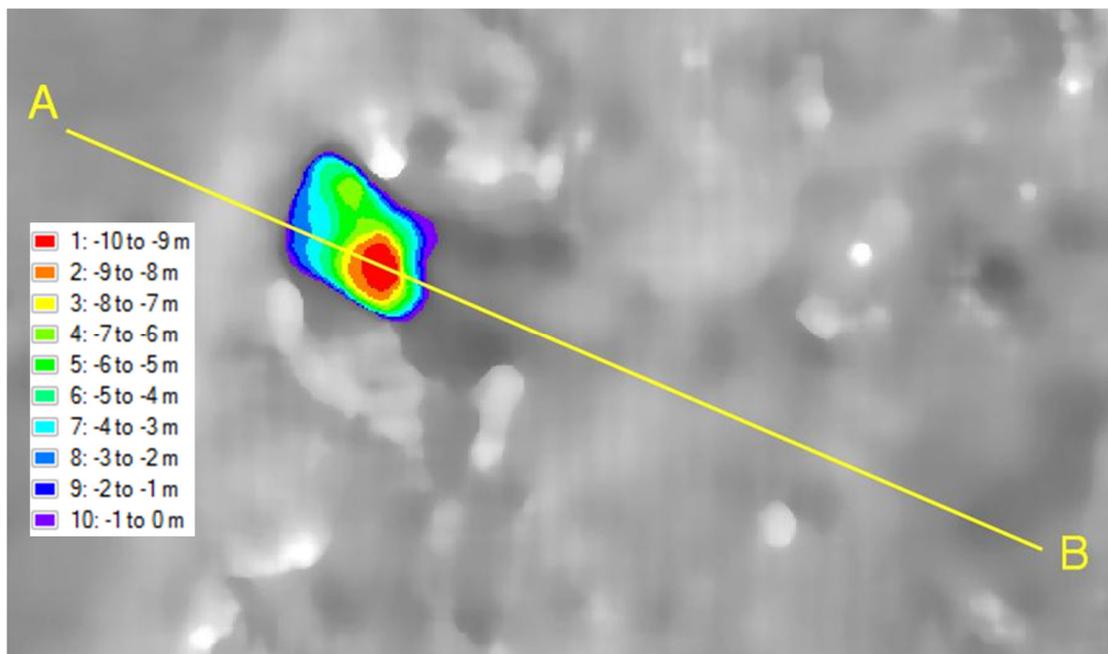
Fig. 3: DSM difference (post-DSM minus pre-DSM) with threshold based classification of the DSM difference (subset), scaled to a range from 0 to -10 m.
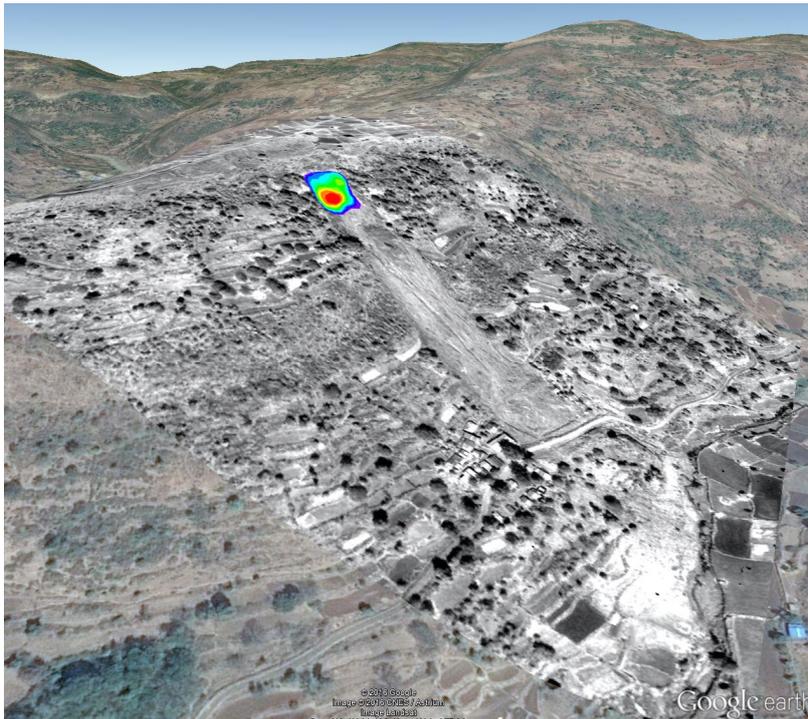
Fig. 4: 3D view of the Malin landslide area with point cloud density image and threshold based classification of the DSM difference overlaid.

2.2 Result Evaluation

ERING et al. 2015 examined the landslide using the finite difference program FLAC 2D (Fast Lagrangian analysis of continua). As a result, Figure 5 (right) shows the displacement contours [dm] of the slope. Accordingly, ERING et al. 2015 calculated a maximum slip surface thickness of 10 m and were able to confirm that by ground truth. This magnitude corresponds to our threshold based classification of the DSM difference, visualized in Figures 3 and 4 with a range from 0 m to -10 m. The pre-DSM and post-DSM transects in Figure 5 (left) clearly reveal the erosion within the slip zone. The analysis of ERING et al. 2015 demonstrates that the slope failure occurred due to the loss of suction strength at the interface between rock and local soil.
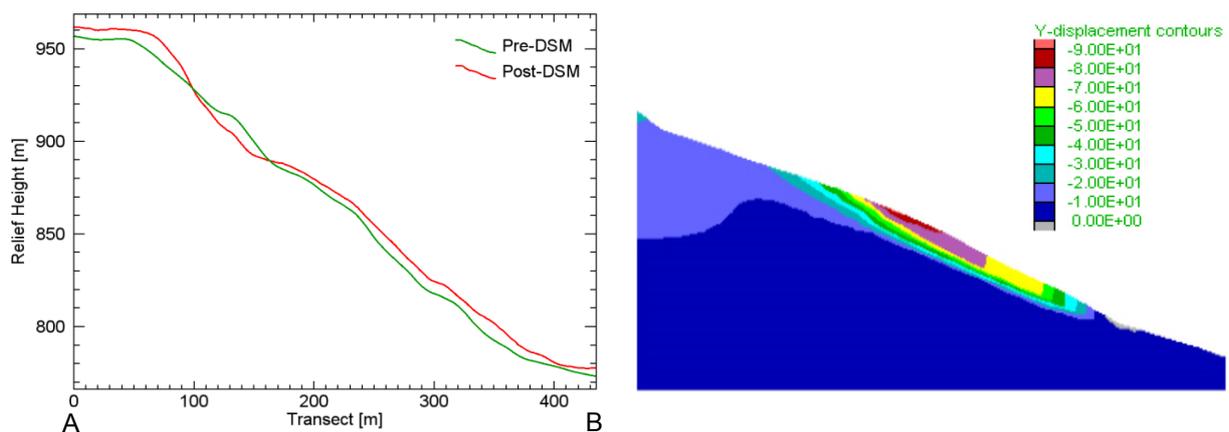
Fig. 5: Left: Terrain profiles along the transect A-B (see Figure 3) reveal the slip surface of the Malin landslide. Right: Modeled displacement contours of the slope at the time of failure after ERING et al. 2015. Maximum thickness of the slip surface is approximately 10 m.

127

3 Automated Change Detection Workflow

3.1 IDL-Based Task System

For the operation of the processing steps (as described in section 2) in service-based production environments we embedded them in an IDL-based Task System. IDL (Interactive Data Language) as the development language of ENVI allows to extend or customize ENVI features and functionality, and to integrate them in existing geospatial workflows.

Based on IDL, ENVI introduced a so-called ENVITask API for processing data. ENVITasks are an object-oriented approach to run ENVI analytics programmatically. ENVITasks are objects with properties and methods. After instantiation, their properties can be manipulated before executing them. An example for predefined ENVITasks is given in Figure 6.

```
PRO generatePointClouds, inStereo1, inStereo2, inDEM, outDIR
  COMPILE_OPT IDL2
  ; Start the application
  e = ENVI(/HEADLESS)
  ; Open input rasters
  rasterStereo1 = e.OpenRaster(inStereo1)
  rasterStereo2 = e.OpenRaster(inStereo2)
  rasterDEM     = e.OpenRaster(inDEM)
  ; Get the point cloud generation task from the catalog of ENVITasks
  Task = ENVITask('GeneratePointCloudsByDenseImageMatching')
  Task.INPUT_RASTERS      = [rasterStereo1, rasterStereo2]
  Task.INPUT_DEM_RASTER   = rasterDEM
  Task.DO_BLOCK_ADJUSTMENT = 55.00   ; default
  Task.MINIMUM_OVERLAP    = 55      ; default
  Task.MATCHING_THRESHOLD = 15      ; default
  Task.EDGE_THRESHOLD     = 5       ; default
  Task.QUALITY_THRESHOLD  = 60      ; default
  Task.OUTPUT_DIRECTORY   = outDIR
  Task.Execute
END
```

Fig. 6: Usage of the corresponding ENVITask to automate the photogrammetric generation of a point cloud from optical stereo imagery.

3.2 Change Detection Workflow in the Task System

The workflow introduced in section 2 contains the following predefined ENVITasks:

The "GeneratePointCloudsByDenseImageMatching" task was implemented to extract passive point clouds in LAS file format from the panchromatic stereo datasets:

- A dense image-matching algorithm is used to identify corresponding points in the stereo pair. For a given point in one image, it searches a two-dimensional grid of points in the second image. By having orientation data, the search is reduced to one dimension: along an epipolar line in the second image.
- Additionally, the WorldDEM^{TM} was input to constrain the range of heights in the matching area, and subsequently the length of the epipolar line. This reduces both the risk of false matches and the time in matching by reducing the search space.

- A bundle adjustment is applied to refine the 3D coordinates that describe the scene geometry. It finds a set of parameters that most accurately predict the locations of the observed points in a set of images, thus minimizing the reprojection error between image locations of observed and predicted image points.

Figure 6 presents a complete application example of the corresponding ENVITask scripted in an IDL procedure. Not shown are optional steps such as error handling, etc., for sake of clarity.

The "PointCloudFeatureExtraction" task was executed to generate the post-DSM from the photogrammetric point clouds. The following parameters were set for the DEM extraction:

- DEM_GRID_RESOLUTION: 1 m (project density 3-4 points / m^2).
- DEM_NEAR_TERRAIN_CLASSIFICATION: 0.5 m. Classifying points as near-terrain is useful to catch low objects that are not part of the terrain and are also not buildings, trees or power lines.
- DEM_FILTER_LOWER_POINTS: Rural Area Filtering. To filter, the area is divided to the grid resolution of 1 m. For each cell in the grid, the points are sorted by height and put into a histogram. Points that are below a multiplier of the standard deviation from the median are filtered out. Rural areas have less false points that need to be filtered; therefore the filtering is applied in a less rigorous way.

4 Implementation in Operational Environments

The presented automated point cloud generation and analysis approach can be embedded in virtually any existing geospatial workflow for operational applications. Three integration options were implemented as part of this case study:

- Integration within any ArcGIS® environment whether deployed on the desktop, in the cloud, or online. Execution uses a customized ArcGIS® script tool.
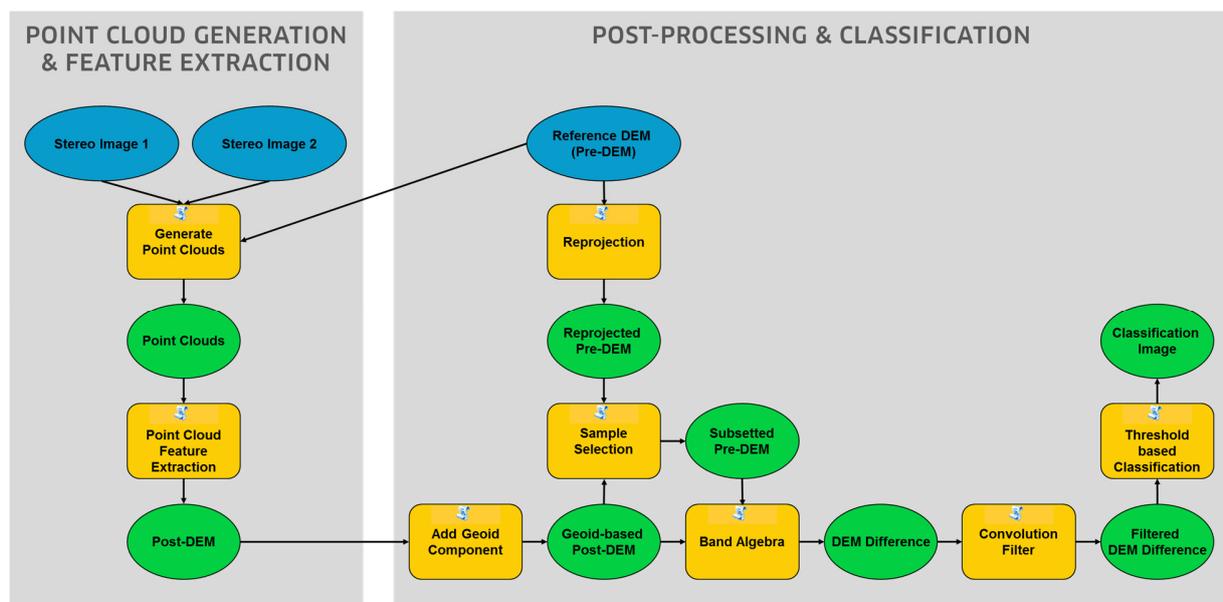
Fig. 7: Workflow for a point cloud based change detection implemented in the ArcGIS® ModelBuilder.

A Python script file retrieves the parameters from the user interface and runs the precompiled IDL code. That IDL code is used to interface between the Python script and the relevant ENVITasks. Figure 7 shows the workflow for a point cloud based change detection approach implemented in the ArcGIS® ModelBuilder.

- Publishing the point cloud processing tasks as services via the ENVI Services Engine (ESE). ESE is a cloud-based image analysis solution to publish and deploy advanced ENVI image and data analytics to existing enterprise infrastructures. For this purpose the entire IDL code can be capsuled into a single ENVITask.

- Integration in an existing geospatial workflow using the IDL bi-directional Python bridge. This mechanism allows calling IDL code within Python on a user-defined platform.

5   Conclusion

In the present, preliminary case study latest point cloud generation and analysis capabilities are used as part of an automated workflow to examine a landslide in India that affected an area of approx. 44.000 m^2. The topographic change detection is based on Pléiades high resolution satellite imagery and the Airbus DS WorldDEM^{TM}.

The results allow a 3D estimation of the topographic changes within the tectonically active and anthropogenically invaded area after the landslide event. Accordingly, the point cloud analysis was correlated successfully with modelled displacement contours of the slope. Based on optical satellite imagery, such point clouds of high precision and density distribution can be obtained in a few minutes to support the operational monitoring of landslide processes.

The future evolution of the automated workflow introduced here will focus 1) on the validation of the DSM products derived from photogrammetric point clouds by comparing them against existing reference products (e. g. DSMs, GPS points, etc.) and 2) on further geomorphologic analysis such as volume calculation of landslides.

6   References

ERING, P., KULKARNI, R., KOLEKAR, Y., DASAKA, S.M. & BABU, G.L.S., 2015: Forensic analysis of Malin landslide in India. International Symposium on Geohazards and Geomechanics (ISGG) 2015, IOP Conf. Series: Earth and Environmental Science **26**, 012040, 1-12.

RAMASAMY, S.M., MUTHUKUMAR, M. & SUBAGUNASEKAR, M., 2015: Malin–Maharashtra landslides: a disaster triggered by tectonics and anthropogenic phenomenon. Current Sience **108** (8), 1428-1430.

RIEGLER, G., HENNIG, S. D. & WEBER, M., 2015: WorldDEM − a novel global foundation layer. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-3/W2, 183-187.