3D Reconstruction of a Landslide by Application of UAV & Structure from Motion

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Abstract

Landslides exhibit complex geomorphologies and are very difficult to measure. Photogrammetric methods are promising tools to overcome such problems by reconstructing 3D from overlapping images of the surface. Airborne and terrestrial image acquisition platforms are possible data sources for comprehensive digital landslide modelling. This study presents a computer vision application of the structure from motion (SfM) technique in three-dimensional high-resolution landslide monitoring. In this study, we used an Unmanned Aerial Vehicle (UAV) – DJI Phantom 3 Advanced to collect high-resolution images of landslide. A total of 72 photographs were taken on 14 July 2016 covering the whole landslide. For more key points/feature matching, more than 70% overlapping was kept between two consecutive images. Based on feature detection technique such as scale invariant feature transform (SIFT), image features can be automatically detected, described, and matched between photographs. A bundle block adjustment is then performed on the matched features to identify the 3D position and orientation of the cameras, and the XYZ location of each feature in the photographs resulting in a sparse 3D point cloud. Densification of sparse points cloud was done using Clustering View for Multi-View Stereo (CMVS) algorithm. Finally, surface reconstruction was performed using Poisson Surface Reconstruction method. For visualization and analysis of final 3D model, open source software CloudCompare/MeshLab was used. It was concluded from the study that UAV-based imagery in combination with 3D scene reconstruction algorithms provide flexible and effective tools to map and monitor landslide.

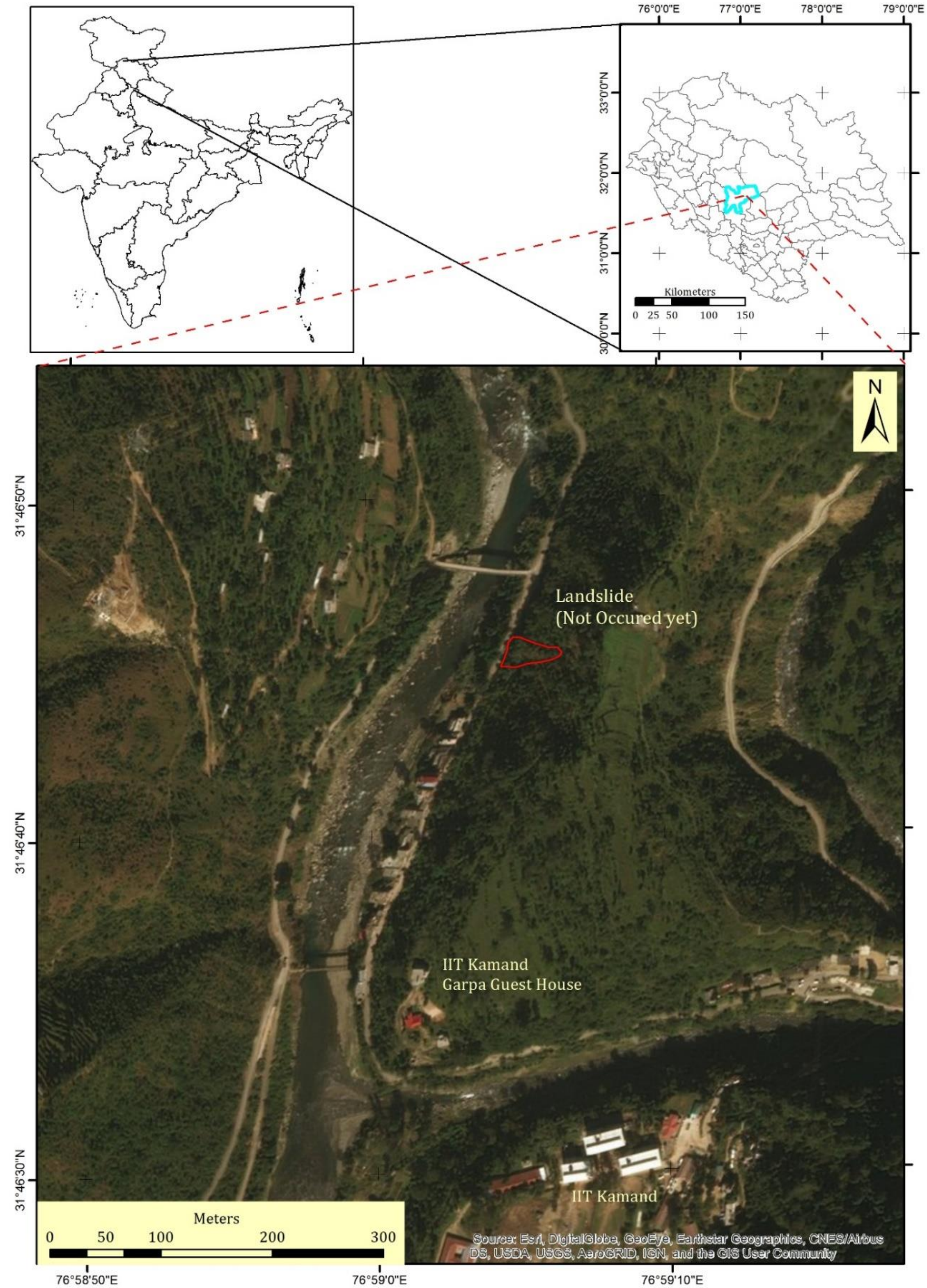
Keywords: 3D reconstruction; SfM; UAVs; Poisson Surface Reconstruction; point cloud

1. Introduction

Landslide is the most common natural hazard in the mountain regions and can result in enormous casualties and huge economic losses every year. Many landslides in mountainous terrain are induced by heavy rainfall on slopes. Slope failure usually occurs as soil resistance deteriorates in the presence of the acting stress developed due to a number of reasons such as presence of tectonically active thrusts, high slopes, increased soil moisture content, change in land use etc. Therefore, monitoring of such landslides is of high importance to enable appropriate protection and mitigation measures. Different monitoring techniques can be applied to detect changes on surfaces, topography and sub-surfaces, ranging from simple and qualitative methods, such as photo documentation and field observation, to more complex methods, such as Global Navigation Satellite System (GNSS) measurements, Remote Sensing techniques [1].

The last decade has witnessed a technological innovation in geomatics, which has transformed digital elevation modelling and geomorphological terrain analysis. With the developments of modern surveying instruments such as differential GPS and reflector-less robotic total stations etc., the acquisition of topographic data has been transformed by a new generation of remote sensing technologies [2]. Traditional methods of landslide analysis require the acquisition of physical measurements in potentially dangerous and remote environments. The ability to safely collect high-resolution topographic data at little to no cost is making it possible to more accurately monitor the world around us [3]. Photogrammetry is the process of reconstructing 3D scenes from image data. Landslide research has been benefited largely from the advent of 3D modeling. Various people have used UAV's for study of geographical features. Bundler SfM tool was used to study geological features such as volcanic bread-crust bomb sample from Soufriere Hills volcano, Montserrat and Coastal cliff site, Lancashire [4]. Bundler software was used for 3D reconstruction of stalagmite, volcanic bomb and breccias outcrop using low cost consumer grade camera [5]. UAV photography and SfM was used for measurement of landslide displacement [6]. Recently, a large landslide in Pechgraben, Upper Austria was monitored and documented using ortho-photos generated from UAV images [1]; however, such type of work has never been attempted in the Himalayan region.

Figure 1: Map showing the study area of the landslide (that did not occur as on the date of acquisition of image) within the vicinity of IIT Mandi, Kamand campus. This landslide was mapped and reconstructed using DJI drone.



In the decade or so since its emergence, automated aerial and close-range digital photogrammetry has become a powerful and widely used tool for three-dimensional topographic modelling. Advances in computer vision and image analysis have led to the development of a novel photogrammetric approach called Structure from-Motion (SfM) that when coupled with Multi-View Stereo (MVS) offers a fully automated method capable of producing high resolution DEMs [7]. This paper aims to provide a detailed explanation of the methods employed for three-dimensional reconstruction of landslide, starting from the initial acquisition of the images from the UAV, to the final output generation. To achieve this, we describe a workflow, which uses the freely available software VisualSfM [8] to process the images and produces the sparse as well as dense point cloud. The reconstruction system integrates several open-source applications including, in order of execution, SiftGPU [9] for key-points identification, multicore bundle adjustment [10] for camera parameter estimation and sparse point cloud generation, CMVS/PMVS2 [11] for point cloud densification. CloudCompare/MeshLab software has been used for generation of surface from dense point cloud.

2. Study Area

The investigated area is located in the Kamand valley of river Uhl, near Indian Institute of Technology Mandi, Kamand Campus. There is one petrol pump in Kamand village, which suffered severe damage due to this landslide. It lies at an elevation of 1020 m from mean sea level and is surrounded by high mountain ranges. This landslide took place on 06th August 2015, that's why this landslide is not visible in the high resolution map in figure 1. Field work for acquisition of images, was performed on 14th July 2016 and for validation of results, was performed on 16th November 2016. In second field work, some measurements of landslide were performed such as scar width near to the toe of landslide.

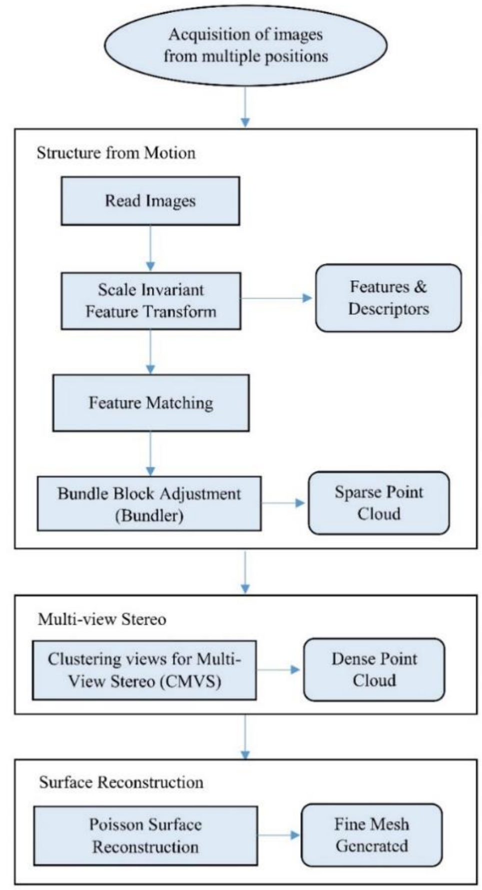
3. Materials & Methods

Methodology for the complete process from image acquisition to the surface reconstruction is described in upcoming subsections and shown as flowchart in Figure 2.

3.1 *UAV*

Multi-rotor UAVs are becoming more commonplace and are frequently used for commercial and recreational aerial photography. For this study we used a DJI make Quadcopter four rotor micro-UAV with 3 axis stabilization Gimbal. The Quadcopter has a flight duration of 20-23 min, and a stabilized camera mount to maintain nadir photos during the flight. To collect visible imagery, we used a Sony EXMOR 1/2.3" lens with 12.4 Megapixel, 4000 x 3000 pixels, FOV 94°, focal length 20 (equivalent to 35 mm full format lens due to crop factor), aperture F/2.8 and shutter speed of 8s-1/8000s. The navigation system onboard the DJI drone, receives signals from GPS/GLONASS constellation.The standard sequence for three dimensional geometry reconstruction from images involves three major algorithmic steps [12]:

Figure 2: Flowchart of the methodology used in 3D surface reconstruction of landslide.



i. Structure-from-Motion (SfM) reconstructs the extrinsic parameters of camera such as position and orientation and the camera calibration data such as focal length and radial distortion by finding correspondences between images. A sparse point-based 3D representation of the subject is generated as a byproduct of camera reconstruction.

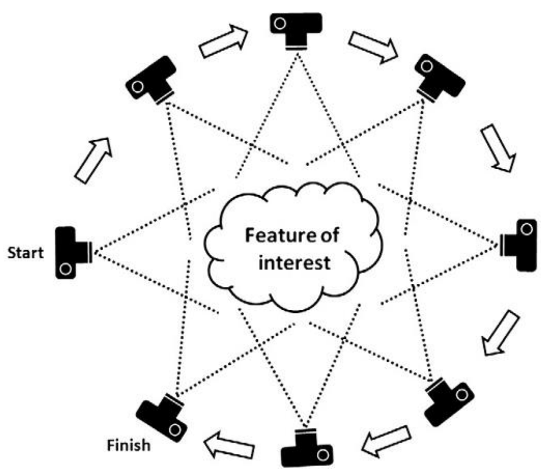
ii. Multi-View Stereo (MVS), which reconstructs dense 3D geometry by finding visual correspondences in the images using the estimated camera parameters. These correspondences are triangulated yielding 3D information.

iii. Surface Reconstruction, which takes as input a dense point cloud, and produces a globally consistent surface mesh.

3.2 *Structure from Motion & Multi-View Stereo*

Structure-from-Motion has the basic principle, same as stereoscopic photogrammetry, that 3-D structure can be determined from a series of overlapping, images. In conventional photogrammetry, the geometry of the scene, camera positions and orientation is solved automatically without specifying, a network of targets, which have known 3-D positions, whereas in SfM, these are, solved simultaneously using a highly redundant, iterative bundle adjustment procedure, based on a database of features automatically extracted from a set of multiple overlapping images [2]. The SfM process starts by acquiring images of the object of interest with sufficient overlap (e.g. 80–90%) from multiple positions and/or angles [6] as shown in Figure 3. Usually, three important steps are performed, such as identification of homologous image points and their subsequent matching, reconstruction of camera orientation and position as well as internal camera parameters by an iterative bundle block adjustment and finally densification of sparse point cloud [13].

Figure 3: Structure-from-Motion (SfM). Instead of using a single stereo pair, the SfM technique requires multiple, overlapping photographs as input to feature extraction and 3-D reconstruction algorithms [2].



To start the SfM reconstruction process, all acquired images were processed by an automatic feature detection algorithm SIFT [4] [14]. Differences in the images require invariance of the features with respect to certain transformations, such as image scale, rotation, noise and illumination changes [12]. The most prominent features are then matched in different images within the image set. After the features has been matched, it is then possible to use an iterative bundle adjustment to estimate the positions of the matched features, positions, orientations, and lens distortion parameters of the cameras.

The name, bundle block adjustments, refers to the 'bundles' of light rays leaving the 3D feature and converging on each camera center, which are adjusted optimally with respect to both feature and camera positions [15]. The goal of bundle adjustment is to find 3D point positions and camera parameters that minimize the re-projection error. For 3D geometry reconstruction, Bundler uses the resulting network of matched features and, starting with one image pair and incrementally adding images, determines the focal length and two radial distortion parameters per image and the camera orientations (position and direction) [4]. The bundle adjustment produces sparse point-clouds. This sparse point-cloud represents the 3D coordinates of the most prominent features within the image set. For generating enhanced density point-cloud or dense cloud, Clustering View for Multi-View Stereo (CMVS)/Patch based multi-view stereo (PMVS2) can be used [11]. The CMVS process uses the camera orientations, positions and surface points output by bundle adjustment process to automatically select and group overlapping images in to clusters of manageable size, based on scene visibility. PMVS2 is used to independently reconstruct 3-D data from these individual clusters. The result of this additional processing is a significant increase in point density.

3.3 *Surface Reconstruction*

Due to significant data gaps in the point cloud generated from UAV images, the calculation of cloud-to-cloud distances would lead to erroneous results [13]. For this reason, the Surface Reconstruction is used to derive a meshed 3D model of the UAV point cloud. Surface reconstruction method constructs a surface S from given set of points P, such that the points of set P lie on S. In other words, the surface S approximates the set of points P. Given a set of points P, surface S can be defined as [16]

$$S = \{P_i = (x_i, y_i, z_i) \mid (x_i, y_i, z_i) \in M \subset R^3, i = 1 \ldots k, M\ surface\ in\ R^3\}$$

Where M is the set of surfaces passing from (x_i, y_i, z_i) and R^3 is the three dimensional Euclidean space. There are various methods popular for surface reconstruction such as Poisson Surface Reconstruction [17], Delaunay Triangulation [16] etc. In this research investigation, we have used Poisson surface reconstruction.

4. Results & Discussions

4.1 *Structure from Motion Process*

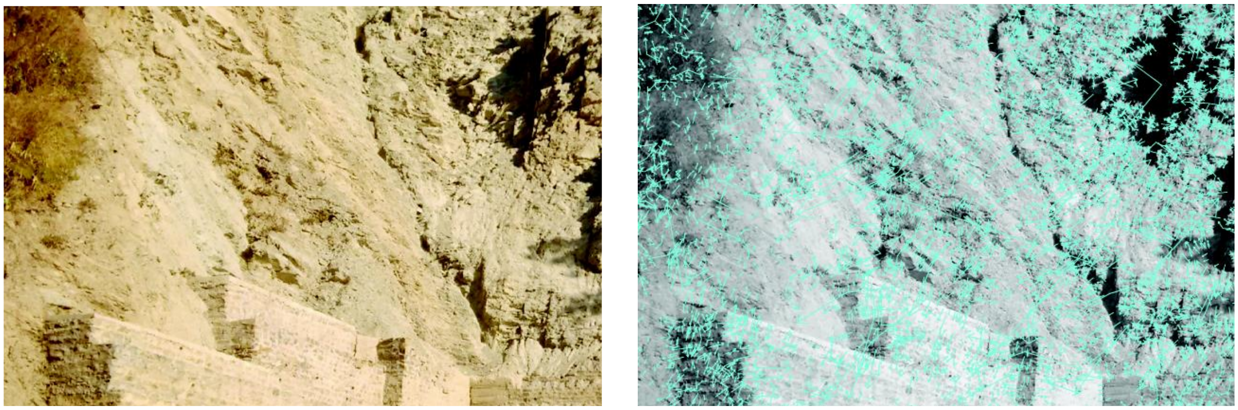
4.1.1 Image Acquisition, Feature Extraction and Feature Matching

During the field visit on 14th July 2016, the landslide was recorded by 72 UAV images. Flight altitude was varying between 15 m to 30 m. The initial processing step is the identification of features/key-points in the images, which are required for finding the matching/correspondence in the images. SiftGPU [9] is integrated in VisualSfM and it is based on SIFT [14]. The features identified by SIFT are invariant to image scaling and rotation, and partially invariant to change in illumination and 3D camera viewpoint as shown in Figure 4. SIFT algorithm not only provides key-point locations but also a local descriptor for each key-point [18]. Number of key-points detected by the algorithm depends on the texture and resolution of the image. Features, detected from the previous steps are then matched between pairs of images. Matching time depends on the size of the images, as every image is matched to all other images.

4.1.2 Bundle Block Adjustment

After matching the key-points, iterative bundle adjustment was performed to estimate the positions of the matched features, positions, orientations, and lens distortion parameters of the cameras. VisualSfM uses multicore bundle adjustment [10]. Triangulation is used to estimate the 3D point positions and incrementally reconstruct scene geometry, fixed into a relative coordinate system. In this process, those points, which are seen by less than three cameras/unstable/with large errors, are removed. A typical output, i.e. sparse point cloud, of this process is shown below in Figure 5.

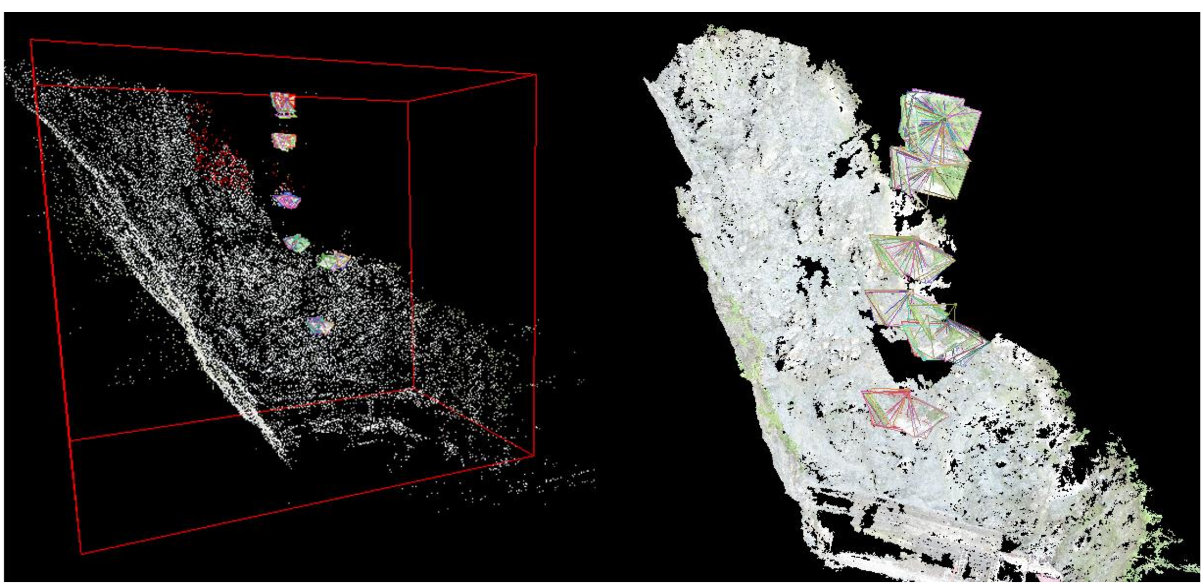
Figure 4: SIFT finds key-points and descriptors (right) in the given image (left). Individual features are represented by lines which are scaled proportionally according to the radius of the image pixel containing the key-point (SIFT code developed by Lowe, 2004 [14] available: http://www.cs.ubc.ca/~lowe/keypoints/).



4.2 *Multi-View Stereo Process*

Once the camera parameters are calculated in previous step, sparse point cloud is densified using multi-view stereo method. VisualSfM uses CMVS and PMVS2 for generating dense point cloud. The CMVS process uses the camera parameters and sparse cloud to automatically select and group images, based on scene visibility. PMVS2 generates large numbers of points by working over a grid of pixels in an image, effectively searching for the best matches for each grid cell. PMVS2 takes much of system's resources because all images to be matched are processed simultaneously. Hence CMVS is applied prior to PMVS2 algorithm so as to permit matching with large image collection. Perspective views of the sparse and dense point cloud data are shown in Figure 5. A significant increase in the point density is immediately apparent for the dense reconstruction. After manual editing, the sparse dataset comprised 29694 points, while the dense reconstruction produced 1206254 points, approximately 40-fold increase.

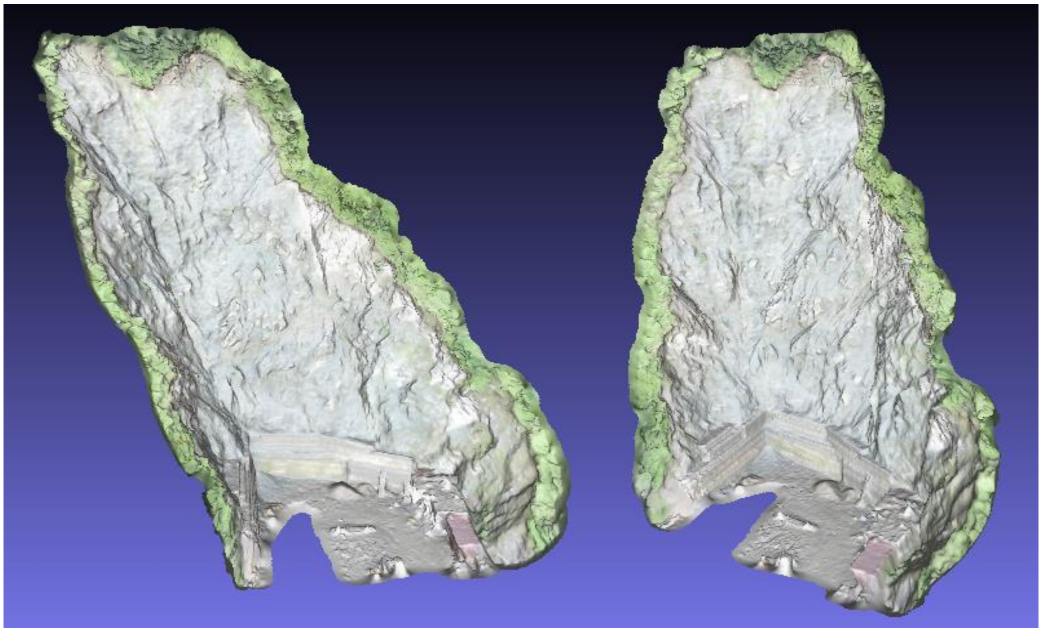
Figure 5: Structure-from-motion reconstruction showing the sparse point cloud (left) and the camera frusta after execution of MCBA in VisualSfM. Dense cloud (right) was generated after execution of CMVS/PMVS2.



4.3 *Surface Reconstruction Process*

In this process, mesh is generated from dense point cloud. The open-source software CloudCompare/MeshLab has been used to generate surface using the points cloud generated by PMVS2 in a network of triangles, which interpolates the surface of imaged scene. Surface generated from is the process is shown in Figure 6. Some analysis related to measurement of 3D landslide model were performed in MeshLab as shown in Figure 7 (a)(b). Some distances were measures on the reconstructed model in MeshLab, which were found to be approximately equal to that measured in the field.

Figure 6: Surface reconstructed after applying Poisson Surface Reconstruction and texture generation. Different perspective views of the same model are shown in figure.



Conclusion

The 3-D reconstructed from the sets of photographs is very accurate giving the measurements upto cm level. In addition, the application of freely available resources will indeed popularize the applicability in geoscience and other groups. There are various other open source software available, which can be used for 3-D reconstruction, but the basic background and understanding remains the same, which has been explained in this paper. The landslide near IIT Mandi, Kamand region has been taken for study. All the steps were carried out in open source software and finally the point cloud and reconstructed map is prepared. The field verification about the accuracy shows that the length measured in field and on 3-D matches up to cm level. Even small objects could be identified. In addition, the point cloud can generate contour of 1 m and so Digital Elevation Model of the order of 1 m could be easily generated. Such high resolution DEM can be used as inputs for various studies.

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Conflict of Interest

The author declares no conflict of interest.

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Figure 7: Field validation of the distances and objects. **(a)**The distance of wall obtained from 3-d model (14.3479 m) (left) and in field (14.3m) (right). **(b)** Steps of the ladder and a small chair in 3-D model (Left) is similar to field photo of ladder (right).