LANDSLIDE DETECTION ON SLOPE AREA BY USING CLOSE-RANGE PHOTOGRAMMETRIC DATA

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Abstract. Slope area is one of the important areas that need to be monitored for safety and maintenance purposes. Monitoring of the slope area can be performed easily by using a Digital Elevation Model (DEM). Landslide and mass-movement on the slope area can be detected by calculation of DEMs derived from two difference epoch data. In this study the DEMs were derived by using close-range photogrammetric method from stereo photographs captured on two different times (13/05/2007 and 07/04/2008). This method is preferred due to its reasonably cost and its suitability for measuring inaccessible and risky areas. Restitution of stereo model is performed by involving Ground Control Points (GCP) to yield some camera parameters, positions and orientations of each photo. Having these parameters, positions of all sampling points on stereo photos can be transformed into ground coordinate system. Terrain data sampling points in this research were performed by regular sampling methods. To measure the quality of this technique in DEM generation, resulted DEMs were compared with a set of correct data measured by reflector-less Total Station (TS). The result yield DEMs with accuracy in elevation interpolation is in centimeters level, and accuracy in volume estimation is less than 0.5 %. The result shows that in period of one year there were significant terrain changes on ground surface. It was indicated by distribution of gain and loss areas on the slope, and extremely changes in longitudinal-section and cross- section profiling.

Keywords: close-range photogrammetry, landslide detection, digital elevation model, low-cost mapping technique, commercial pocket camera

1. Introduction

Monitoring of a hazard potential area is important to be performed, in order to analyze and predict for disaster occasion and its mitigation. One of the hazard potential areas is slope area. Slope area is considerable to be monitored especially if the location of the slope is nearby a residential area or infrastructure. Landslide hazard has devastating impact on human life. Disaster prevention planning was absolutely required here to avoid a terrible condition. As a component of monitoring, mapping of slope area inclined to landslide is significant for detail documentation and characterizing of its spatial behavior.

Monitoring of the slope area can be performed easily by using a Digital Elevation Model (DEM) [1]. A Digital Elevation Model (DEM) can be expressed as a digital and mathematical representation of an existing or virtual object and its environment within a selected area [2]. To date, monitoring of landslide based on DEM calculation can be done by several methods, such as by using Total station [4], [5]; Satellite positioning system GPS/Galileo [4], [6], [7], [8]; Interferometry Synthetic Aperture Radar (InSAR) [5]; Aerial photogrammetry and satellite images [1], [5], [8], [9], [10]; Laser scanner [9], [11].

Close-range photogrammetry technique was initiated since 1926 as terrestrial, architectural, and engineering photogrammetry, which later is known as non-topographic photogrammetry. The technique was implemented from stereo aerial photogrammetry and continuously developed parallel with the advancement of computer and digital technology [12]. DEM can be derived from 2D points on overlapping photographs measured by a certain stereo restitution method such as by analytical stereo model (interior, relative, and absolute orientations) or bundle block adjustment (interior and exterior orientations). Images on close range photogrammetry can be captured using three types of camera: metric camera, semi-metric camera, and non-metric camera [13]. Included in the non-metric camera is the commercial pocket camera. By using this type of camera, close-range photogrammetry becomes a low cost alternative of slope monitoring data collection tool.

As a slope monitoring data collection tool, close-range photogrammetry can be used to detect mass movement or landslide on the slope area. Mass movement can be detected by calculation of DEMs derived from two difference epoch data. In this study the DEMs were generated by using close-range photogrammetric method from stereo photographs captured on two different periods of time. The surveys were carried out on 13/05/2007 and 07/04/2008 over an unstable slope of an ex-mining pit area at Taman Bandar University, Seri Iskandar, Perak Malaysia. This paper focuses on the detection of landslide on the study area based on DEMs calculation, and mass movement distribution. The images captured by using Canon A540 digital camera, with Ground Control Points (GCP) as tie points of the 3D model measured by using a Topcon GPT3000 N/LN reflector-less Total Station (TS).

2. Methodology

2.1. Calibration of Total Station

GCPs and check points were measured by using TS. As common law in measurement (no exact value in measurements, and all measurements contain errors) so the TS have to be calibrated in order to get their coordinates with minimum error. In calibrating this device, the instrument with its related target is necessary to be verified to evaluate its constant and scaling errors. The TS used in this study is a GPT3000 N/LN reflector-less TS with an angle accuracy of 5". Range measurement for its *Non-Prism (N) Mode* up to 250 meter with accuracy ± (10mm) mse, and for *Non-Prism Long (LN) Mode* up to 1200 meter with accuracy ± (10mm+10ppm*Distance) mse. The target used in this calibration is a plate of concrete. It was chosen because of the material is same with the real object at study area. Pictures of the TS, target, and the pillars were given on Figure1.

Figure 1. Instrumentations were used in total station calibration.

The calibration was accomplished by measuring series of distances on one base-line which is divided into six sub base line, as presented on Figure 2. Then they were calculated by a parametric least squares formula for zero error and also for constant and scaling errors calculations. This calibration determined the value of corrections for systematical errors of the instrument. The calibration survey was performed at JUPEM's permanent calibration benchmarks at Batu Gajah, Perak Malaysia.

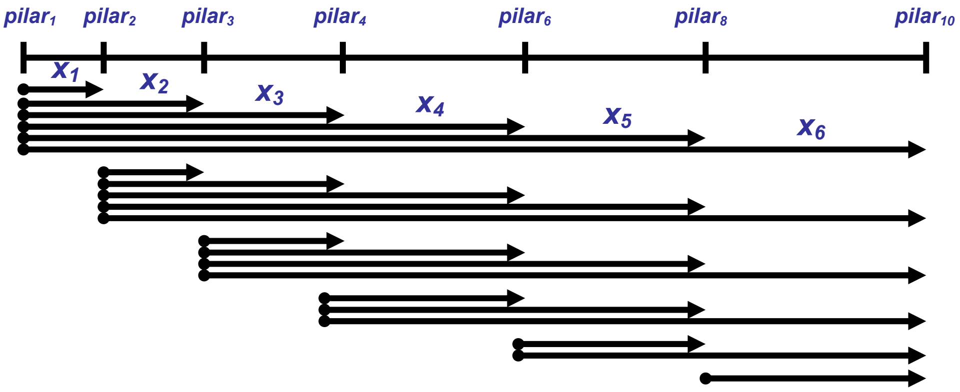

Figure 2. Series of measurement on total station calibration.

2.2. Calibration of Camera

Camera calibration is a necessary step in photogrammetry and 3D computer vision in order to extract 3D metric information from 2D images which are captured by lenses/camera [14]. By camera calibration, systematical errors which are caused by lens can be reduced and the position and orientation of the cameras when the images were taken can be calculated. Include in systematical errors because of lens distortions are radial and tangential distortions parameter. Radial distortion is radial displacement of actual image point in the image plane. Tangential distortion is the displacement of actual image point which is caused by the position of center of lens' curvature (lens' surface) not being strictly collinear [15]. The camera used in this paper was a Canon A540 6 Mega pixel camera with a Canon 5.8 – 23.2 mm lens. The photographs focal length used in this research was fixed at 11.5 mm (for epoch 1) and 9.8 mm (for epoch 2) and the focus at infinity. Resolution of all photos was set on 180 dpi with 2272x1704 pixels (pixel size of approximately 2.5 μm). Camera calibration devices were presented on Fig.3.

Figure 3. Devices used in camera calibration.

This calibration only consider about the errors caused by lens of the camera. In this paper a flexible camera calibration technique was used. It requires observing a planar pattern from a few (at least three) different orientations. It was done by moving the position and orientation of the camera, the motion of the camera did not need to be known. This paper assumes that each point in the object space is projected by a straight line through the projection center into the image plane, or known as pinhole model. By calculating the transformation matrix, both intrinsic and extrinsic parameters from the camera can be derived. These parameters can be used to obtain undistorted images.

2.3. Three Dimensional Stereo Restitution

Capturing the unstable slope from any surrounding position in this research is very difficult due to some issues such as; accessibility, safety, and cost. Pictures were taken from front side of the site of interest with a stereo base line of 8 meter, and at a distance of 50-65 meter (both for epoch 1 and epoch 2). In close-range photogrammetry, ratio of the stereo base line and the distance between camera and object should lie in 1:5 and 1:15 [13].

Stereo photographs used in this research were taken with overlapping more than 80%. Points that appear on the overlapping area construct a 3D stereo-model, calculated by some steps of computation. Transformation of points from 2D left-right photo coordinate systems into 3D ground coordinate system determined by an analytical stereo-model. Generally this transformation consists of three main steps: interior, relative, and absolute orientation.

Interior orientation is the mathematically reconstruction of geometric camera when a particular photograph was taken. It requires camera calibration information resulted from the camera calibration stage. The information was used to refine the stereo images, so the images were free lens distortion. The process begins with measurement of fiducial positions and image point coordinates by a comparator. A 2D coordinate transformation is used to relate the comparator coordinate to the fiducial coordinate systems. *Relative orientation* is the process of determining the relative angular orientation and positional displacement between the images at the time of exposure. It involves defining certain elements of position and orientation of the cameras at the time of execution. *Absolute orientation* can be performed using a 3D conformal coordinate transformation. This stage transforms the coordinates from comparator coordinate system into world coordinate system.

Photogrammetry workstation used in this research is PhotoModeler Pro 5. In this software, interior orientation automatically calculated after camera calibration information was given. Whereas relative orientation requires marking some of tie points on all overlapping photos, at least there are six marked points. Process to mark the tie points were performed by manually pointing on all overlapping photographs. Certain terrain data sampling method must be applied here to construct a 3D stereo model. This paper used a regular sampling method to select the tie points. For absolute orientation, there are three techniques that can be used here (defining three transformation points; defining rotation axis, translation vector, and scaling distance; defining at least three Ground Control Points)

Figure 4. Distribution all GCPs on photographs captured on epoch 1.

Some GCPs were measured by using the calibrated reflector-less TS. GCPs were well distributed around the slope surface, and its position should be recognized clearly on all photographs. Those GCPs coordinates were required in stereo restitution of this reseach, especially for exterior orientation process. By these coordinates, parameters of transformation from 2D image coordinate system (rows and columns) into 3D world coordinate system (Easting, Northing, and Elevation) can be calculated based on least square bundle block adjustment formula. Distribution all of GCPs on all photographs captured on epoch 1 and epoch 2 were given on Figure 4. and Figure 5.

Figure 5. Distribution all GCPs on photographs captured on epoch 2.

2.4. Derivation of Digital Elevation Models

Resulted 3D coordinates of the photogrammetric data, was derived to be a DEM of the slope surface by using Triangular Irregular Network (TIN). TIN generation was formed by connecting triangle edges between nearest tie-points based on Delaunay criterion. TIN was used in this research because it is possible to represent the digital 3D model at a both small and large scale of resolution, and also it is easier to calculate the volume of the DEM. There are several methods that can be used to measure quality of the resulted DEM. In civil engineering only two parameters that traditionally used define the quality, they are elevation interpolation error calculation, and volumetric different calculation. This parameter is preferred because the implication of the DEM quality can entail important economic deviation during project execution as well as its technical influence.

40 check points measured by using calibrated reflector-less TS, were used to calculate the Root Mean Square (RMS) of the elevation interpolation error. Value of the RMS shows the accuracy of the resulted DEM. The smaller value of RMS means the resulted DEM has higher accuracy, and vice versa. Volume of the resulted DEM was compare to the reference DEM measured by using TS, to get the difference in volume. Similar with elevation interpolation error, result from this calculation also shows about the accuracy of resulted DEM. Volume of the DEM can be calculated based on a simple mathematical formula of triangular prism. The volume is determined by the multiplication of the area with its medial high. The volume equation for volumetric calculation is given [17]:

$$h_{m_i} = \frac{h_{i1} + h_{i2} + h_{i3}}{3}$$

$$V_i = F_i * h_{m_i}$$

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} F_i * h_{m_i}$$

i	: name of one triangle
n	: number of all triangles
h_{i1}, h_{i2}, h_{i3}	: height of each vertex of one triangle
h_{mi}	: medial height of one triangle
V	: volume of the object
V_i	: volume of one triangle
F_i	: area of one triangle

2.5. Landslide Detection Based on Two Epoch DEM

Velocity and direction of the landslide can not be accurately identified because no permanent points on the slope. The most possible way to detect the landslide is by calculating the DEMs from two different epochs. By this calculation the distribution and the volume of mass movement can be able to be modeled. There are two kind of representations used in this work: by using 3D DEM, and cross-long sections.

In cross (or longitudinal) section modeling, elevation from certain points lay on a straight line in a cross (or longitudinal) direction from both DEMs were modeled in a chart. So from the different elevations thickness of gain-loss soil can be examined, as presented on Figure 10. Distribution of gain-loss soil can be represented by using DEM calculation.

3. Result and Discussion

3.1. Total Station Calibration Result

Each distance was measured for nine times by the TS, then average of them used to the next calculation. By using parametric least square adjustment method zero error, constant, and scaling errors caused by target and TS (as systematical errors) can be computed. Result for this stage is given on Table 1.

Based on the calculation, the TS has significant systematical errors. The errors were not only for reflective and scaling error as written on the manual book, but also a zero error. Even the errors were big enough, but it is tolerable and still not exceed from the value claimed by producer. Based on the calculation result, it can be concluded that the TS is still accurate to measure distances until three hundred meters length.

Table 1. Result of total station calibration calculation

Parameters		Calculation Result	Real Distance	Unit
Zero Error	*z0*	3	-	mm
Observed Baseline	*X1*	5.006	5.004	m
	X2	10.005	10.002	m
	X3	49.006	49.002	m
	X4	125.002	125.000	m
	X5	201.005	201.002	m
	X6	300.011	300.008	m
Reflective Error	*a*	1	10	mm
Scaling Factor	*b*	6	10	ppm

3.2. Camera Calibration Result

Auto self calibration calculation was used in this study to define the intrinsic camera parameters. Include in intrinsic parameters are focal length, principal point, and lens distortion parameters as follow on table 2. These parameters must be needed in photogrammetric process, because they were required in image refinement when interior orientation was performed (both for aerial and close range photogrammetry). By this calibration characteristic of the camera can be calculated, and systematical error in the camera can be eliminated.

Table 2. Result of camera calibration calculation

Camera Parameters		Epoch 1		Epoch 2	
Focal length	*f*	11.4895	mm	9.7683	mm
Format size	Width	5.7241	mm	5.7236	mm
	Height	4.2926	mm	4.2926	mm
Format pixel	# of row	1704	pixel	1704	pixel
	# of column	2272	pixel	2272	pixel
Principal point	*Xo*	2.9992	mm	2.9840	mm
	Yo	2.1899	mm	2.2023	mm
Radial distortion	*K1*	0.001142		0.00161	
	K2	0.000009116		0.00000679	
Tangential Distortion	*P1*	-0.0001116		-0.00012	
	P2	-0.00001888		-0.00001524	

3.3. Stereo Restitution and DEM Generation

There are three kind of point used in this work: tie point, control point, and check point. Tie point and control point were absolutely needed in stereo photogrammetry; while check point was needed in quality measure of the resulted DEM. Tie points were marked on each overlapping photos (as shown on Figure 6. and Figure 7.), then measured its position in image coordinate system. The next step was transforming the coordinates from image coordinate system into world coordinate system. Calculation method applied in this research was by using bundle block adjustment. It means relative and absolute orientations were calculated in one process, as known as exterior orientation.

Figure 6. Distribution all tie points on photographs captured on epoch 1.

Figure 7. Distribution all tie points on photographs captured on epoch 2.

When transformations were accomplished, the resulted 3D coordinates were used to generate a DEM by TIN principle as presented on figure 8. To evaluate quality and accuracy of resulted DEM derived from close-range photogrammetric data, interpolation error and volume difference calculations were carried out. Result of these quality measurements presented on Table 3 and Table 4.

Table 3. Calculation result for elevation interpolation error

	Epoch 1			**Epoch 2**		
	Max.	Min.	Average	Max.	Min.	Average
# of check point	-	-	40	-	-	40
$Z - Z_{photo}$	0.1785	-0.1304	-0.0099	0.1033	-0.1940	-0.0098
$(Z - Z_{photo})^2$	0.0318	0.0001	0.0038	0.0376	0.0000	0.0025
RMS Error	-	-	0.0619	-	-	0.0504

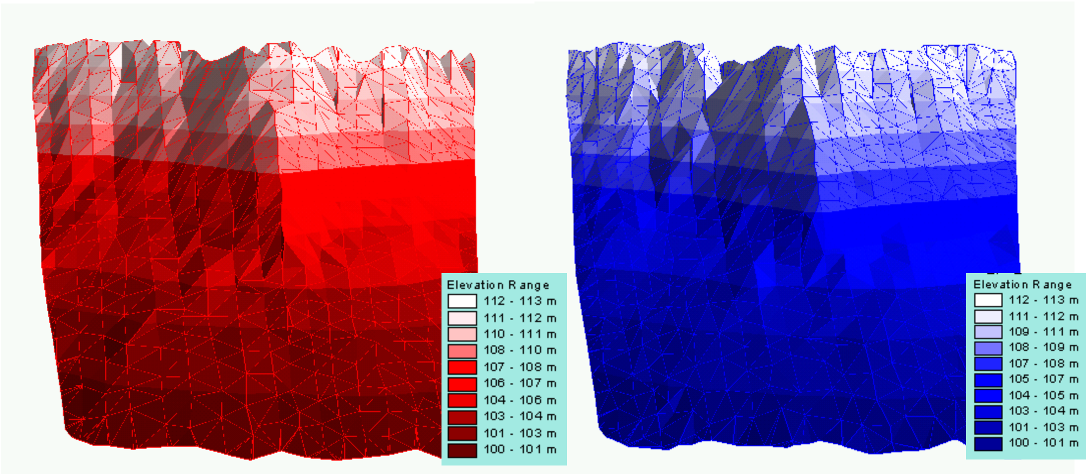

Figure 8. Resulted DEM generated from photogrammetric data on epoch 1 (left) and epoch 2 (right)

Table 4. Calculation result for volume difference calculation between 100m to 112m contour lines

	# of tie points	Volume Calculation		Volumetric Error	
		Total Station	Photo Stereo	Absolute	Percentage
Epoch 1	390	1532.823	1535.067	385.057	0.146396
Epoch 2	450	1541.309	1542.133	385.198	0.053461

Based on the calculation result as presented on table 3 and table 4, DEM of epoch 1 which was derived from 390 tie points yield the a DEM with accuracy in elevation is 6.2 cm. and 0.15 % in volumetric error; While DEM of epoch 2 which was generated from 450 tie points yield a DEM with accuracy in elevation is 5.0 cm and volumetric error is 0.05 %. It can be concluded that with the same terrain data sampling method, increasing in number of tie points has significant impact in rising of accuracy.

3.4. Landslide Detection on two epoch DEMs

Changing on slope surface elevation indicated that there was a landslide on the slope area. Mass movement and its distribution can be recognized easily by calculation of both DEMs, as presented on figure 9. Thickness of the elevation changes can be measure by cross-long sections, as given on figure 10.

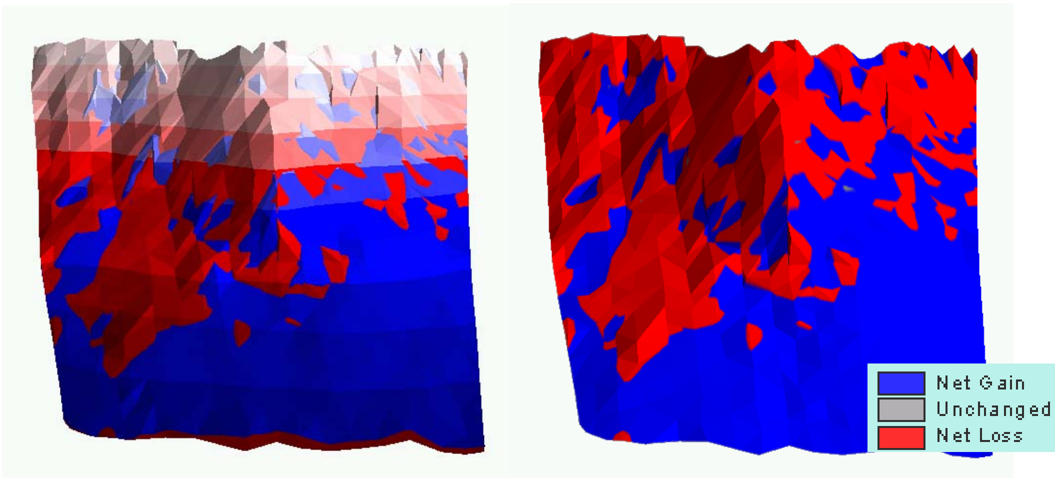

Figure 9. Left picture is presenting about overlapping between DEMs of epoch 1 (red graduation) and epoch 2 (blue graduation); Right picture is presenting about the distribution of loss and gain of soil on the slope.

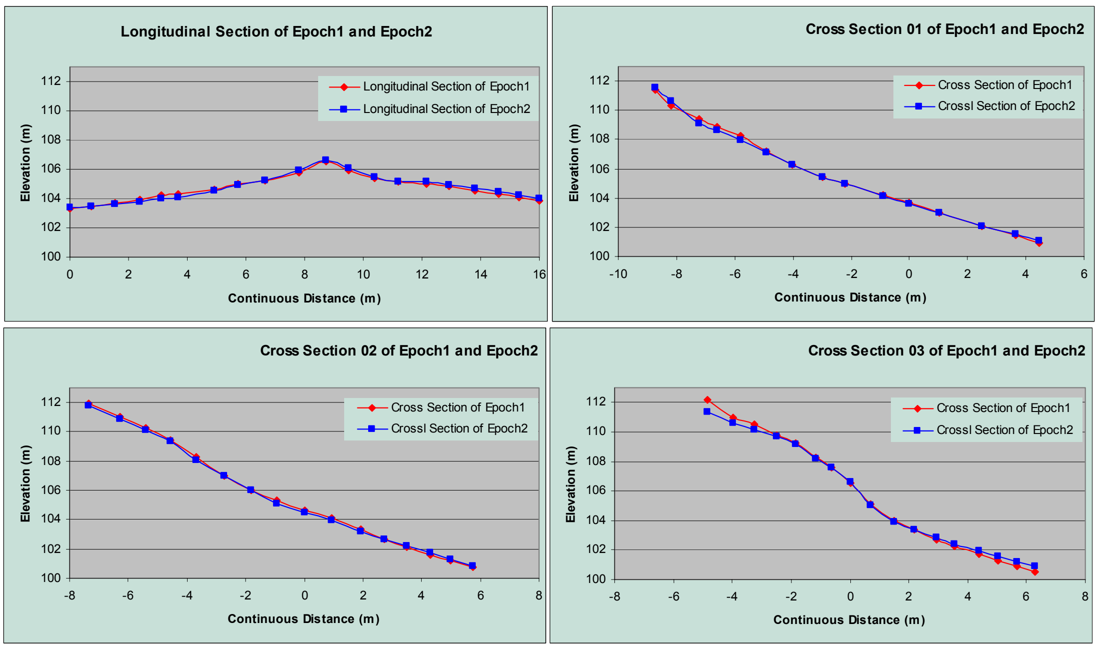

Figure 10. Longitudinal and cross sections of the slope surface

From the pictures we can see that during period of 13/05/2007 and 07/04/2008 (330 days) there is mass movement from top side of the slope moved downward. The blue color (gain) means that there was increasing value of elevation and volume of the soil. The red color (loss) indicated by decreasing of the elevation and reducing volume of soil.

4. Conclusion

The TS used in this research has some systematical errors (reflective error, scaling error, and zero error), but it were tolerable and still not exceed from the value claimed by producer. Based on the calculation result, the TS is still accurate to measure any distances until 300 meters length. The systematical error on the camera caused by the lens distortion can be modeled and calculated by using auto self calibration. Therefore the value of radial and tangential distortion can be used to refine all captured images in interior orientation process.

3D DEM can be derived from selected tie points on overlapping images. Transformation from image coordinate system into world coordinate system can be calculated by analytical stereo model. DEM of epoch 1 has 6.2 cm accuracy in elevation interpolation, and 0.15% in volume difference error. DEM of epoch 2 has better accuracy (5 cm and 0.05%), but derived from 450 points (60 points more). It can be concluded that with the same terrain data sampling method, increasing in number of tie points has significant impact in raising the accuracy.

Detection of landslide by using close-range photogrammetric method is effective to apply for high risk and inaccessible slope area. Existing permanent point is not essential here, but GCP measurement is required. The result of this study yields that in period of 330 days there were significant terrain changes on ground surface. It was indicated by distribution of gain and loss areas on the slope, and elevation changing in longitudinal and cross sections profiling.

References

1. Honda, K., Nagai, M., 2002, *Real-time Volcano Activity Mapping using Ground-based Digital Imagery*, ISPRS Journal of Photogrammetry and Remote Sensing, vol. 57, p.p. 159-168.

2. Kasser, M., Egels, Y., 2002, *Digital Photogrammetry*, Taylor & Francis Group, New York.
3. Kraus, K., Briese, C., Attwenger, M., Pfiefer, N., 2004, *Quality Measures for Digital Terrain Models*.
4. Stiros, S.C., Vichas, C., Skourtis, C., 2004, *Landslide Monitoring Based On Geodetically Derived Distance Changes*, Journal of Surveying Engineering ASCE, Vol. 130, No. 4, p. 156-162,
5. Tarchi, D., Casagli, N., Fanti, R., Leva, D. D., Luzi, G., Pasuto, A., Poeraccini, M., Silvano, S., 2003, *Landslide Monitoring by Using Ground Based SAR Interferometry: An Example of Application to The Tessina Landslide in Italy*, Science Direct Engineering Geology, Vol. 68, p. 15-30.
6. Gili, J.A., Corominas, J., Rius J., 2000, *Using Global Positioning System Techniques in Landslide Monitoring*, Science Direct Engineering Geology, Vol. 55, p. 167-192.
7. Aguado, L.E., O'Driscoll, C., Xia, P., 2006, *A Low Cost, Low Power Galileo/GPS Positioning System for Monitoring Landslides*,
8. Mora, P., Baldi, P., Casula, G., Fabris, M., Ghirotti, M., Mazzini, E., Pesci, 2003, A., *Global Positioning System and Digital Photogramnmetry for The Monitoring of Mass Movements: Application to The Ca' di Malta Landslide (northern Apennines, Italy)*, Science Direct Engineering Geology, Vol. 68, p. 103-121.
9. Barbarella, M., Lenzi, V., Zanni, M., 2004, *Integration of Airborne Laser Data and High Resolution Satellite Images over Landslides Risk Areas*.
10. Tsutsui, K., Rokugawa, S., Nakagawa, H., Miyazaki, S., Cheng, C.T., Shiraishi, T., Yang, S.D., 2007, *Detection and Volume Estimation of Large-Scale Landslides Based on Elevation-Change Analysis using DEMs Extracted from High-Resolution Satellite Stereo Imagery*, IEEE Transaction on Geoscience and Remote Sensing, vol. 45, no. 6, p.p. 1681-1696.
11. Bitelli, G., M. Dubbini, A. Zanutta, 2004, *Terrestrial Laser Scanning and Digital Photogrammetry Techniques to Monitor Landslide Bodies*.
12. Atkinson, K.B., 2001, *Close Range Photogrammetry and Machine Vision,* Whittles Publishing, Scotland.
13. Hanke, K., Grussenmeyer, C.P., 2002, *Architectural Photogrammetry: Basic Theory, procedures, Tools*, ISPRS Commission 5 Tutorial
14. Ji, Q., Zhang, Y., 2001, *Camera Calibration with Genetic Algorithms*, IEEE Transaction on Systems, Man, and Cybernetics-Part A: system and Human, vol. 31, no. 2, p.p. 120-130.
15. Heikkila, J. and Silven, O., 1997, *A Four Step Camera Calibration Procedure within Implicit Image Correction*, http://www.vision.caltech.edu/bouguetj/calibdoc/papers/heikkila97.pdf
16. Meneses, A.S., Chasco, F.R., Garcia, B., Caberas, J., Audicana, M.G., 2005, *Quality Control in Digital Terrain Models*, Journal of Surveying Engineering ASCE, vol. 131, No. 4, p. 118-124.
17. Pflipsen, B., 2006, *Volume Computation - A Comparison of Total Station Versus Laser Scanner and Different Software*, Master Thesis