geosciences

MDPI

Article

The Use of Gigapixel Photogrammetry for the Understanding of Landslide Processes in Alpine Terrain

Saverio Romeo [1,2], Lucio Di Matteo [3,*], Daniel Scott Kieffer [4], Grazia Tosi [5], Aurelio Stoppini [5] and Fabio Radicioni [5]

1 Department of Earth Sciences, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy; saverio.romeo@uniroma1.it
2 Natural Hazards Control and Assessments S.r.l. Spin-Off, Sapienza University of Rome, Via Bachelet 12, 00185 Rome, Italy
3 Department of Physics and Geology, University of Perugia, Via Pascoli snc, 06123 Perugia, Italy
4 Institute of Applied Geosciences, Graz University of Technology, Rechbauerstraße 12/EG, A-8010 Graz, Austria; kieffer@tugraz.at
5 Department of Engineering, University of Perugia, Via Duranti, 06125 Perugia, Italy; grazia.tosi@unipg.it (G.T.); aurelio.stoppini@unipg.it (A.S.); fabio.radicioni@unipg.it (F.R.)
* Correspondence: lucio.dimatteo@unipg.it; Tel.: +39-075-584-9694

Received: 31 December 2018; Accepted: 18 February 2019; Published: 21 February 2019

check for updates

Abstract: The work in this paper illustrates an experimental application for geosciences by coupling new and low cost photogrammetric techniques: Gigapixel and Structure-from-Motion (SfM). Gigapixel photography is a digital image composed of billions of pixels (≥1000 megapixels) obtained from a conventional Digital single-lens reflex camera (DSLR), whereas the SfM technique obtains three-dimensional (3D) information from two-dimensional (2D) image sequences. The field test was carried out at the Ingelsberg slope (Bad Hofgastein, Austria), which hosts one of the most dangerous landslides in the Salzburg Land. The stereographic analysis carried out on the preliminary 3D model, integrated with Ground Based Synthetic Aperture Radar Interferometry (GBInSAR) data, allowed us to obtain the main fractures and discontinuities of the unstable rock mass.

Keywords: remote sensing; Gigapixel photogrammetry; Structure-from-Motion; landslide

1. Introduction

The use of photography always was a key part of most geological fieldwork. It is used to document landscape changes for image analysis over time, and it is also fundamental for illustrating key geological features. Moreover, nowadays numerous representations of geological information exist, most of them are in 2D images (e.g., geological maps), and only a few are in 3D images (e.g., block diagrams). One of the challenges in geological mapping consists of collecting more accurate data and integrating all the geological information to build better 3D models [1]. The use of terrestrial remote techniques with high-resolution 3D images for geological mapping and monitoring is largely tested even if not yet widely used. More specifically, the LiDAR (Light Detection And Ranging) represents a valid and fast solution for rock mass characterization [2]. The use of such new instruments has some practical limitations: it requires highly qualified personnel able to interpret data, as well as an important economic investment due to the high cost of the equipment. In recent years, technological development has allowed the use of new images called Gigapixel—digital images composed of billions of pixels or more (equal to or greater than 1000 megapixels). Modern digital single-lens reflex (DSLR) cameras generally use sensors with more than 20 million pixels (20 megapixels), thus no commercial camera is able to directly create a Gigapixel image, but using new technologies and instruments (e.g., GigaPan) similar result can be achieved. Within the geosciences community, there are very few papers dealing with testing and validating Gigapixel surveying especially in complex geological environments [3]. The terrestrial and close-range photogrammetry is used for 3D reconstruction in urban environments, and for cultural heritage in archaeological sites [4–6]. The digital stereo-photogrammetry technique—coupled with innovative technology (e.g., GBInSAR)—has been recently gaining ground for geological mapping, structural evaluation, and rockfall hazard assessment [7–10]. The use of these techniques is important in geotechnical monitoring sites, where a reliable 3D model is required. In such cases, the relative high resolution of the obtained 3D model could significantly increase the quality of monitoring, in terms of spatial resolution and correct geocoding of data, as well as improving the general understanding and interpretation of the observed scenario. This approach is particularly useful in complex landslides, as in the alpine terrain where most landslides occur in remote and inaccessible areas. Under these conditions, for safety reasons only a very limited portion of the rock mass can be surveyed by traditional geo-mechanical investigation, and remote surveys are preferred for acquiring information on the unstable slope [2]. The present work integrates photogrammetric surveys through the use of Gigapixel images with data from a GBInSAR monitoring campaign aiming to provide a robust three-dimensional model useful to investigate the main fractures and discontinuities of an unstable rock mass. For these purposes, a case study of the Ingelsberg slope (Salzburg Land, Austria) was considered, where in the period 2013–2016 both GBInSAR and Gigapixel photogrammetry campaigns were performed [11–13].

2. Materials and Methods

2.1. The Case Study of Ingelsberg Landslide

The experimental application was carried out in the Ingelsberg slope where one of the most dangerous landslides of the Salzburg Bundesland is located (Figure 1). The landslide, covering an area of about 4 hectares (volume of about 120,000 m^3), is placed in the Gastein valley within the municipality of Bad Hofgastein, in Salzburg Bundesland (47°10′53.8″ N; 13°06′40.0″ E). The B167 Gastein Bundesstraße national road and the Tauernbahn railway line are located within the potential run out area for large rockfall, some dwellings are at the toe of the landslide area. The unstable zone is in the middle of Alpine region at an altitude of 1100–1500 m a.s.l., which is very prone to snowfalls, particularly during autumn/winter periods. From a geological point of view, the area around Bad Hofgastein is located in the Glockner nappe (within the Tauern window) belonging to the Penninic Unit [14]. The Ingelsberg slope is characterized by the outcropping of highly weathered anti-dip layered metamorphic rocks (green and calc-mica schists), having different geo-mechanical characteristics (Figure 1). At least three main sectors with similar characteristics can be identified along the slope (e.g., similar lithology, response to rainfall and snow, type of movement, etc.): the slope is composed of a source area in the upper part where the rock mass is prone to failures (Head Area), stable rock walls, and areas of debris accumulation. Talus produced from the Head Area accumulates along two main channels and is periodically moved because of heavy rainfalls or melting snow. The Ingelsberg slope was monitored for about 16 months (2013–2014 period) by means of the GBInSAR technique coupled with some extensometers (placed in the landslide Head Area, Figure 1), and three cameras useful to record the landslides occurrence and movement. Further details on the monitoring system are available from [15] and [13]. Apart from the detection of a landslide event that occurred on 29 April 2013, the monitoring campaign allowed us to develop some hypotheses about triggering factors and kinematics of the landslide. As reported by [13], the rockfall was probably triggered by factors such as rapid snow melting (added to first spring rainfall events) combined with rock thermal expansion. Toppling has been proposed as the main movement governing rock mass failure. Despite the interruption of monitoring in July 2014, the information obtained have been useful for constraining the results from the GigaPan campaign carried out in May 2016, the findings of which will be presented in Section 3.

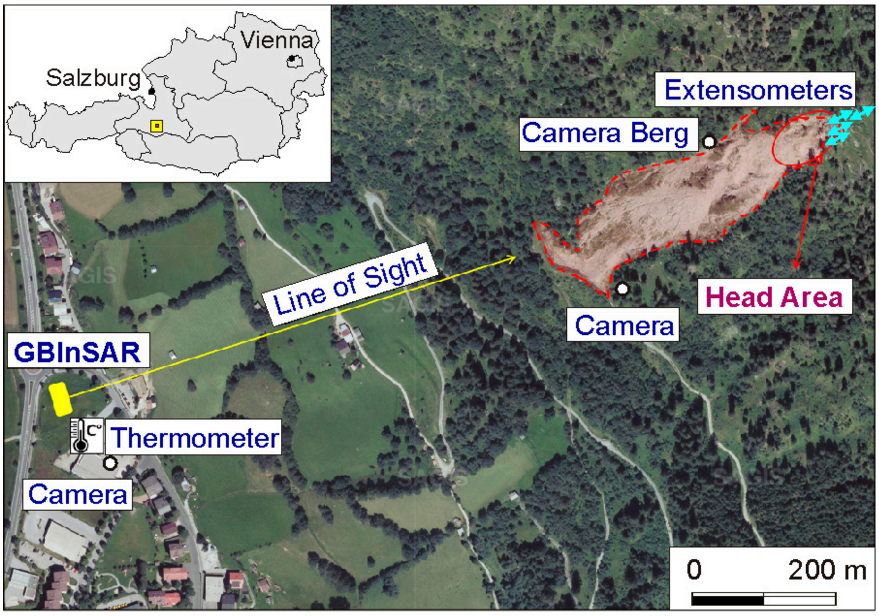

Figure 1. Study area with the location of the Ingelsberg landslide and monitoring systems (base map from SAGIS—Salzburger Geographisches Informations system).

2.2. Techniques and Tools Used

The research was carried out by coupling two different photogrammetric techniques and a semi-automatic method for rock mass characterization: Gigapixel photogrammetry (e.g., [7]), Structure-from-Motion [16], and Discontinuity Set Extractor (DSE) [17], according the diagram proposed in Figure 2. Moreover, data from photogrammetric techniques were compared and integrated with those from a GBInSAR monitoring campaign developed during 2013–2014. GBInSAR was placed at the base of the slope, about 1.2 km away from the Head Area (Figure 1): it is an active microwave acquisition sensor that provides its own illumination and measures the reflected signal (temporal resolution of 5 min). GBInSAR provides a remotely sensed measurement of ground displacements, with sub-millimeter accuracy, and is able to supply a deformation map of the slope, without the need for positioning targets on the ground and without any physical contact with the slope [13,18,19].

Gigapan was created in 2008 by a research collaboration between NASA and Carnegie Mellon University, to develop a very high-resolution imaging technique for use in the Mars Exploration Rover mission. Essentially, the GigaPan system acquires in sequence—by using a robotic head—hundreds of images partially overlapping, avoiding parallax errors. Thanks to a proper stitching of images, the reconstruction of an exceptionally detailed 2D Gigapixel image is possible.

GigaPan products can be applied in geological mapping as an extremely useful tool for documentation, detection, and evaluation of geological features such as landslides (e.g., [6–10]). Although this method has many advantages (short installation time, low cost instrument, and fast acquisition), compared with other images sources—such us Unmanned Aerial Vehicle (UAV)—it shows some disadvantages as the presence of shaded areas in the acquired images, due to its ground-based nature.

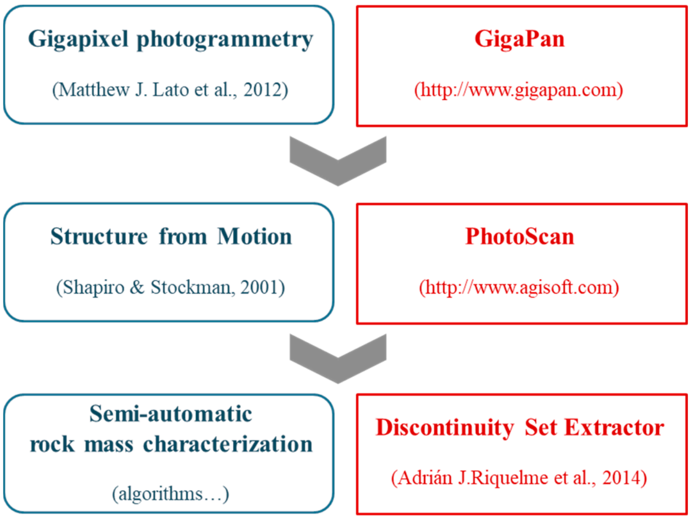

Figure 2. Block diagram showing techniques and steps used for rock mass characterization.

With the aim of creating a 3D representation, high-resolution digital photos were collected from different positions. The 3D model was georeferenced using GPS coordinates associated with camera locations and Ground Control Points (GCPs) along the slope. In the case of Ingelsberg, the GigaPan survey was carried out on May 2016 using four observation points located at about 1000 m distance from the landslide slope. A Nikon D800 with a 400 mm lens camera were used. The images were acquired in raw format at the maximum available resolution of 36.3 Megapixel: every single image was composed of 7360 × 4912 pixels on a FF (Full Frame) sensor of 35.9 × 24 mm size. Therefore, the pixel size on the sensor was 0.00488 mm. The camera's sensitivity was set up at 400 ISO (International Organization of Standard); with the available light (a sunny day at the end of May 2016, at about noon) the shutter speed was set at 1/800 s and the aperture at f/5.6. The images were then converted and saved in TIFF format with no compression, to preserve the original resolution and quality. The image-overlapping ratio in horizontal and vertical direction varied from 60% to 80% of the image side.

Equation (1) illustrates the computation of the mean value of the GSD (Ground Sampling Distance, corresponding to the pixel size on the objects) on the landslide Head Area, considering the mean object distance (H = 1000 m) and the lens focal length (f = 0.400 m).

$$\mathrm{GSD} = \mathrm{f}/\mathrm{H} = (4.88 \times 10^{-6} \times 1000)/0.400 = 0.012\ \mathrm{m} \quad (1)$$

Processing of the digital images and the 3D reconstruction were performed with the Agisoft PhotoScan software, based on the Structure from Motion (SfM) technique [20–23]. SfM is a photogrammetric method used for creating three-dimensional models of an object or terrain portion from a high number of overlapping two-dimensional photographs taken from many locations and orientations to reconstruct the three-dimensional object geometry. SfM algorithms arise from analytical photogrammetry and have greatly evolved thanks to the implementation of computer vision methods. The analytical principles of photogrammetry (based on the geometric principles of collinearity, coplanarity of projective rays, and camera inner calibration) are flanked by the typical algorithms of the robotic vision, which permit the analysis and correlation of digital images in fast and automatic ways. The name "Structure-from-Motion" means that by moving and acquiring images of an object from different positions, it is possible to reconstruct its three-dimensions structure.

The first product of SfM processing is a dense 3D Point Cloud, that is a very high number (millions) of object points, whose 3D coordinates have been determined in an external reference frame. A large variety of products can be generated from a point cloud: three-dimensional models formed by polygonal facets, DEMs (digital elevation models), orthophotos, vectors, or raster maps.

SfM software implement modules for some of the analysis described, or alternatively it is possible to use external cloud point management software (CAD, GIS), paying attention to the exchange formats. The integration of SfM technique with a very high-resolution Gigapixel images as input represents a new step in photogrammetry studies applied for geologic purposes, and further tests should be encouraged. In the case of the Ingelsberg slope, the 3D dense point cloud generated by SfM analysis was imported in the DSE open-source software [17], which is programmed in MATLAB environment, for extracting geo-mechanical parameters of the rock mass. In summary, this method aims to identify surfaces outcropping in a rock slope by using—as input data—a 3D point cloud. Thanks to the algebraic equations from different planes of the slope surface, and by applying an analysis based on a neighboring points coplanarity test, it was possible to find the principal orientations by Kernel Density Estimation.

3. Results

During May 2016, a GigaPan survey (Figure 3a) was carried out with the aim of observing the Ingelsberg slope from four observation points located at the base of the slope, close to the national road B167 Gastein Bundesstraße. Figure 3b illustrates the location of surveying points numbered in order of the acquisition time (from 1 to 4).

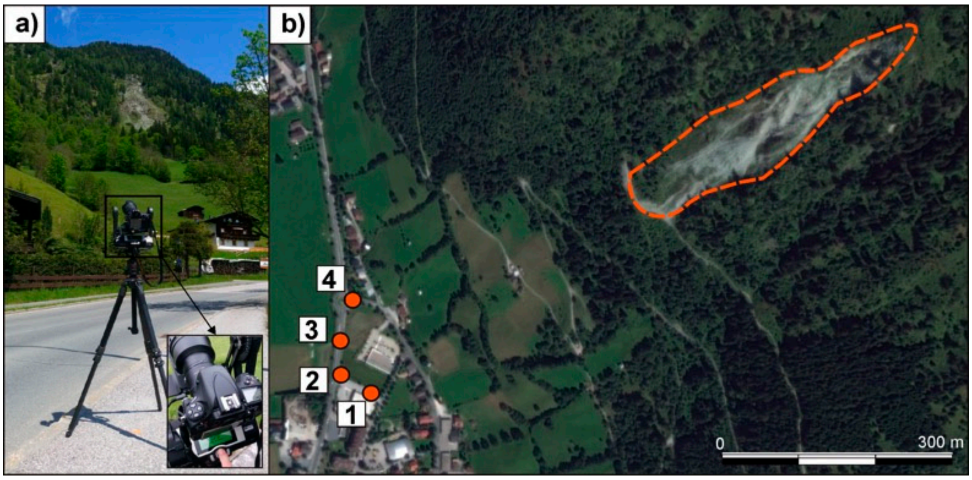

Figure 3. (**a**) GigaPan equipment used; and (**b**) location of the GigaPan surveying points (base map: Google Earth, Image 2016 Digital Globe).

Using the high-resolution Gigapixel imagery from GigaPan and the SfM technique (see Section 2.2), a dense point cloud of the Ingelsberg slope was obtained. The analysis and processing of the images was quite difficult, mainly due to the presence of diffuse vegetation bordering a consistent part of the unstable slope (see Figure 3b). Due to leaves and branches mobility caused even by light wind, the geometry of the vegetated part of the slope changed from one image to another. On the contrary, the processing software on the rock surfaces individuated numerous tie points. Tie points are points recognized as the same point in two or more images. Figure 4 shows the dense point clouds generated by SfM processing, with a focus on the tie points (in blue) detected in the landslide Head Area, with a centimeter-level density. Using the dense point cloud, a 3D model of the slope was generated (Figure 5), which was useful for performing rock mass characterization, limited to the Head Area.

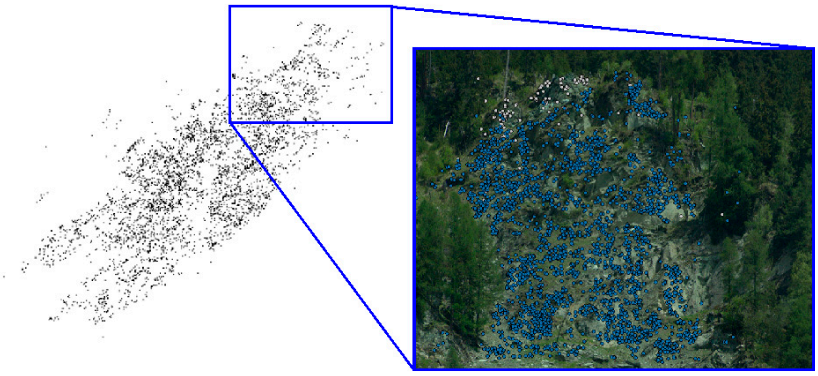

Figure 4. Dense point cloud generated by SfM processing with a focus on the of Ingelsberg's landslide Head Area.

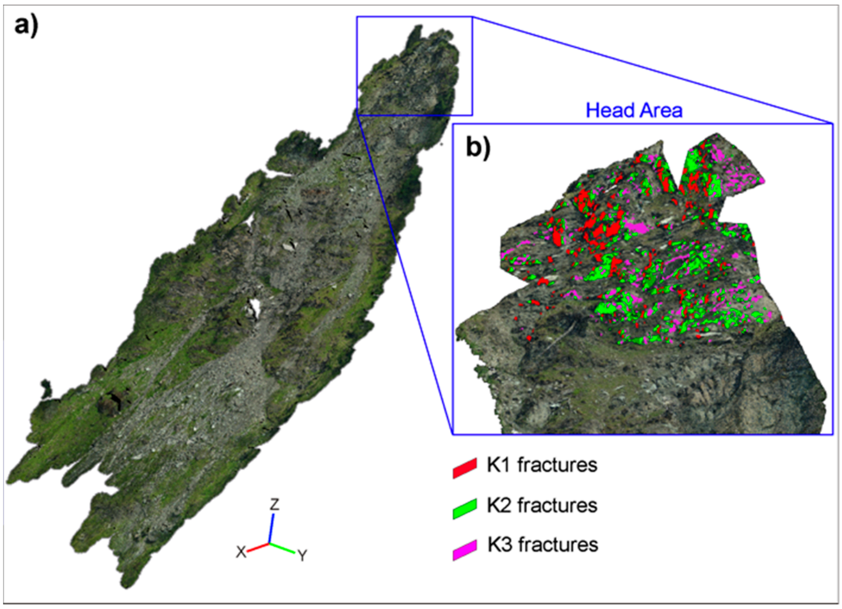

Figure 5. (**a**) 3D model of the Ingelsberg slope as a result of the processing of dense point clouds using SfM; and (**b**) 3D model of the Head Area of the Ingelsberg slope with planes extracted by the DSE software.

As illustrated in Section 2.1—using the DSE open-source software—the geo-mechanical parameters of the rock mass were extracted from the 3D dense point cloud identifying the number of discontinuity sets and their orientations. The 3D point cloud was also graded, and each exposed plane was detected. Moreover, stereographic analysis of the rock mass in the landslide Head Area was refined and constrained by also considering visual observations on the georeferenced 3D model, and results from field investigations on the safe portion of the rock mass previously carried out by [13]. As shown in Figures 5 and 6, in addition to schistosity K0 (010/25) recorded by field measurements on safety portions of the rock mass, three main persistent joints families were detected: K1, K2, and K3. In other words, sub-vertical joints intersect the schistosity forming a blocky rock mass structure. According to the flexural toppling analysis described by [24], the K1 pole falls within the critical zone for flexural toppling, while the K3 pole plots within the critical zone for sliding (Figure 6a). In other words, the opening of K1 joints produces a flexural toppling movement of the rock mass, which in turn produces sliding of near-surface blocks along K3 discontinuities. Figure 6b shows that K2 joints families can produce some failure in the case of weathering and erosion processes affecting the base of the Head Area, or as a consequence of sliding of some portion of the rock mass delimited by K3 joints families induced in turn by flexural toppling movements governed by K1 joints (Figure 6c).

K1 fractures played a key role in a rockfall that occurred on 29 April 2013 (at 17:00), which detached a volume of ~20–40 m^3 of rocks from the Head Area. The event was recorded by the Camera Berg (see Figure 1 for location): in detail, the opening of the main K1 fracture (Figure 6c), located 10 m behind the Head Area, led to the toppling of the rock mass from the Head Area with a gradual shift of its center of mass, inducing the sliding and falling of blocks facing the slope (along K3 fractures). As shown in Figure 7, the displacement data from GBInSAR and extensometer placed behind the Head Area confirmed the interpretation on movements rising from the interpretation of Gigapixel images. During the pre- and post- rockfall events that occurred on 29 April 2013, the behavior of rock mass in the Head Area was strictly affected by the opening of K1 fractures (see the extensometer trend): the rock mass moved along the radar line of sight (Figure 1) toward the radar, while the extensometer recorded the opening of K1 fractures. Further details on interpretation of GBInSAR and extensometers data are given by [13,15].

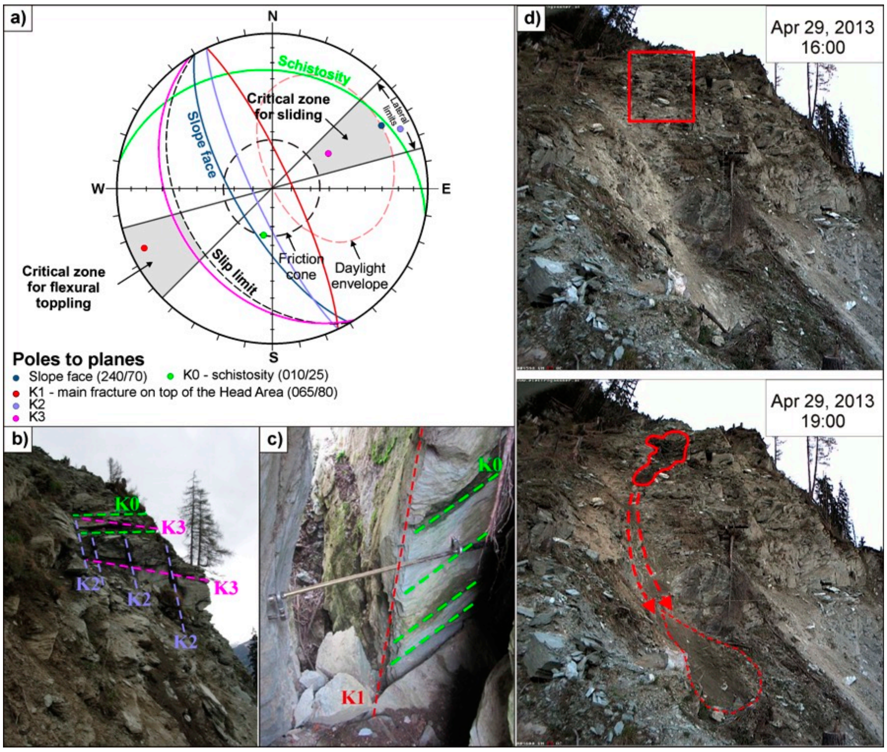

Figure 6. (**a**) Stereographic projection of planes and poles of the rock mass extracted from the 3D dense point cloud (Equal Area Stereonet, lower hemisphere—Schmidt); (**b**) picture from Camera Berg with K0, K2, and K3 fractures families; (**c**) detail of the main crack K1 located 10 m behind the Head Area with K0 schistosity); and (**d**) example of a portion of the rock mass mobilized during the event that occurred on 29 April 2013—17:00 (red square is 4 m $\times$ 4 m wide).

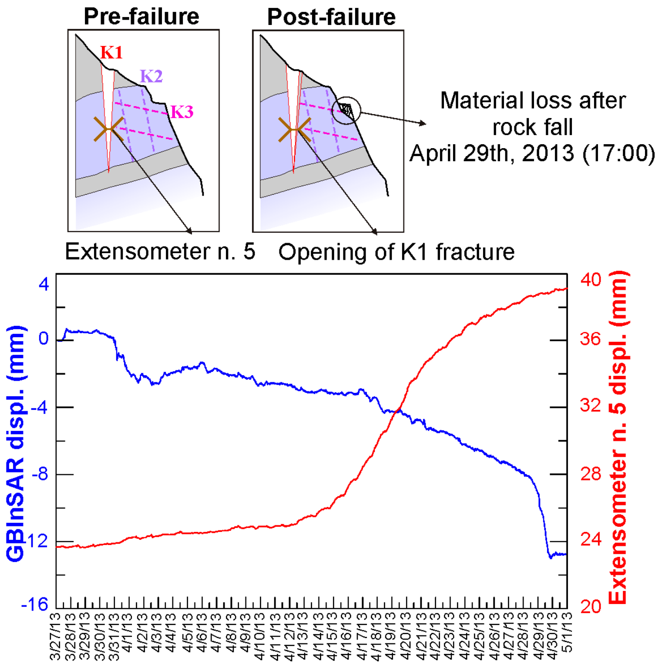

Figure 7. Displacement recorded by the extensometer n. 5 in K1 fracture (in red) and GBInSAR (in blue) for the main event that occurred on 29 April 2013 within the Head Area. On the top of the figure, a schematic representation of the rockfall process (not to scale) is shown from pre- to post- failure (based on [13]).

According to the classification in [25], the Ingelsberg landslide is a complex landside where different movements coexist (rock topple, slide and fall).

4. Discussion and Conclusions

The work in this paper, based on the integration of data from different techniques and methods, contributes to the understanding of some open problems on landslide characterization and processes occurring in complex alpine terrain. The work has been carried out on an unstable mass that developed in weathered schistoid rocks, the surveying of which was not possible with traditional geo-mechanical techniques. In this framework, the Gigapixel survey—coupled with other photogrammetric techniques—resulted in useful support tools for cost-effective mapping, 3D modeling, and remote surveying of the Head Area in Ingelsberg landslide. Stereographic interpretation from the DSE open-source software, based on the 3D dense point cloud generated by SfM analysis, was validated and constrained by data arising from the GBInSAR monitoring. The present research demonstrates—once again—that thanks to the technological evolution that has occurred in recent years, new instruments are now available to lead monitoring campaigns more efficiently and with different purposes (e.g., aimed at knowledge monitoring). The proposed approach enables a detailed comparison between independent data recorded on the rock mass in the landslide Head Area, even if the acquisitions deferred in time. The structural constraints found in this study, provide significant insight regarding the overall slope behavior and failure tendencies. These results are extremely useful in the design of landslide mitigation actions—especially in mountain regions where several critical elements can coexist—and also to enhance monitoring plans and evaluate possible structural and non-structural solutions aimed at ensuring appropriate safety standards. In order produce more reliable interpretations of the Gigapixel technique on unstable schistoid rocks, further tests and research should be performed especially when other independent monitoring data are present.

Author Contributions: Conceptualization, S.R. and L.Di M.; Data curation, S.R. and L.Di M.; Formal analysis, S.R., L.Di M. and A.S.; Investigation, S.R., L.Di M. and D.S.K.; Methodology, S.R., L.Di M., D.S.K. and A.S.;

Software, S.R. and G.T.; Supervision, L.Di M. and F.R.; Validation, F.R.; Writing—original draft, S.R., L.Di M. and A.S. All authors contributed equally to the research.

Funding: This research was partially supported by RICVADIMA and CONLABGEOAP funds.

Acknowledgments: Some of the analyses were performed in the Laboratory of Applied Geology of the University of Perugia. The authors are grateful for the technical support on GigaPan and DSE software provided by Hana Lee from the Institute of Applied Geosciences, Graz University of Technology, and Marco Baleani from NHAZCA s.r.l.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Guerin, A.; Nguyen, L.; Abellán, A.; Carrea, D.; Derron, M.H.; Jaboyedoff, M. Common problems encountered in 3D mapping of geological contacts using high-resolution terrain and image data. *Eur. J. Remote Sens.* **2015**, *48*, 661–672. [CrossRef]
2. Gigli, G.; Casagli, N. Extraction of rock mass structural data from high resolution laser scanning products. In *Landslide Science and Practice*; Margottini, C., Canuti, P., Sassa, K., Eds.; Springer: Berlin, Germany, 2013; pp. 89–94.
3. Lato, M.J.; Bevan, G.; Fergusson, M. Gigapixel imaging and photogrammetry: Development of a new long range remote imaging technique. *Remote Sens.* **2012**, *4*, 3006–3021. [CrossRef]
4. Remondino, F. Heritage recording and 3D modeling with photogrammetry and 3D scanning. *Remote Sens.* **2011**, *3*, 1104–1138. [CrossRef]
5. Ercoli, M.; Brigante, R.; Radicioni, F.; Pauselli, C.; Mazzocca, M.; Centi, G.; Stoppini, A. Inside the polygonal walls of Amelia (Central Italy): A multidisciplinary data integration, encompassing geodetic monitoring and geophysical prospections. *J. Appl. Geophys.* **2016**, *127*, 31–44. [CrossRef]
6. Radicioni, F.; Matracchi, P.; Brigante, R.; Brozzi, A.; Cecconi, M.; Stoppini, A.; Tosi, G. The Tempio della Consolazione in Todi: Integrated geomatic techniques for a monument description including structural damage evolution in time. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *42*, 433–440. [CrossRef]
7. Stock, G.M.; Bawden, G.W.; Green, J.K.; Hanson, E.; Downing, G.; Collins, B.D.; Bond, S.; Leslar, M. High-resolution three-dimensional imaging and analysis of rock falls in Yosemite Valley, California. *Geosphere* **2011**, *7*, 573–581. [CrossRef]
8. Oppikofer, T.; Yugsi, M.; Freddy, X.; Böhme, M. Back-analysis of the 1810 Pollfjellet rockslide (northern Norway) using terrestrial laser scanning and GigaPan imagery. In Proceedings of the 1st Vertical Geology Conference, Lausanne, Switzerland, 5–7 February 2014; pp. 149–154.
9. Matasci, B.; Ravanel, L.; Guerin, A.; Jaboyedoff, M.; Deline, P. Rockfalls detection and characterization in the west face of the Drus (Mont Blanc), based on Gigapixel images and Terrestrial Laser Scanning. In Proceedings of the 1st Vertical Geology Conference, University of Lausanne, Lausanne, Switzerland, 5–7 February 2014; pp. 1–7.
10. Kromer, R.; Lato, M.; Hutchinson, D.J.; Gauthier, D.; Edwards, T. Managing rockfall risk through baseline monitoring of precursors using a terrestrial laser scanner. *Can. Geotech. J.* **2017**, *54*, 953–967. [CrossRef]
11. Romeo, S.; Kieffer, D.S.; Di Matteo, L. The Ingelsberg landslide (Bad Hofgastein, Austria): Description and first results of monitoring system (GBInSAR technique). *Rendiconti Online della Società Geologica Italiana* **2014**, *32*, 24–27. [CrossRef]
12. Romeo, S.; Kieffer, D.S.; Di Matteo, L. Reliability of GBInSAR Monitoring in Ingelsberg Landslide Area (Bad Hofgastein, Austria). In *Geotechnical Safety and Risk V*; Schweckendiek, T., van Tol, A.F., Pereboom, D., Eds.; IOS Press: Amsterdam, The Netherlands, 2015; pp. 803–807.
13. Di Matteo, L.; Romeo, S.; Kieffer, D.S. Rock fall analysis in Alpine area by using a reliable integrated monitoring system: results from the Ingelsberg slope (Salzburg Land, Austria). *Bull. Eng. Geol. Environ.* **2017**, *76*, 413–420. [CrossRef]
14. Schmid, M.S.; Fügenschuh, B.; Eduard, K.; Schuster, R. Tectonic map and overall architecture of the Alpine orogen. *Eclogae Geologicae Helvetiae* **2004**, *97*, 93–117. [CrossRef]
15. Kieffer, D.S.; Valentin, G.; Unterberger, K. Continuous real-time slope monitoring of the Ingelsberg in Bad Hofgastein, Austria. *Geomech. Tunn.* **2016**, *9*, 37–44. [CrossRef]
16. Shapiro, L.; Stockman, G. *Computer Vision*; Prentice Hall: Upper Saddle River, NJ, USA, 2001; p. 608.
17. Riquelme, A.J.; Abellán, A.; Tomás, R.; Jaboyedoff, M. A new approach for semi-automatic rock mass joints recognition from 3D point clouds. *Comput. Geosci.* **2014**, *68*, 38–52. [CrossRef]

18. Bozzano, F.; Mazzanti, P.; Prestininzi, A.; Mugnozza, G.S. Research and development of advanced technologies for landslide hazard analysis in Italy. *Landslides* **2010**, *7*, 381–385. [CrossRef]
19. Mazzanti, P. Displacement monitoring by terrestrial SAR interferometry for geotechnical purposes. *Geotech. Instrum. News* **2011**, *29*, 25–28.
20. Nistér, D. Reconstruction from uncalibrated sequences with a hierarchy of trifocal tensors. In *Lecture Notes in Computer Science*; Springer: Berlin/Heidelberg, Germany, 2000; pp. 649–663.
21. Nistér, D. An efficient solution to the five-point relative pose problem. *IEEE Trans. Pattern Anal. Mach. Intell.* **2003**, *26*, 756–770. [CrossRef] [PubMed]
22. Goesele, M.; Curless, B.; Seitz, S.M. Multi-view stereo revisited. *IEEE Conf. Comput. Vis. Pattern Recognit.* **2006**, *2*, 2402–2409.
23. Micheletti, N.; Chandler, J.H.; Lane, S.N. Structure from motion (SFM) photogrammetry. In *Geomorphological Techniques*; Clarke, L.E., Nield, J.M., Eds.; British Society for Geomorphology: London, UK, 2015; pp. 1–12.
24. Goodman, R.E. *Introduction to Rock Mechanics*; John Wiley & Sons: Toronto, ON, Canada, 1989; pp. 254–287. ISBN 9780471812005.
25. Varnes, D.J. Slope movement types and processes. In *Landslides, Analysis and Control*; Schuster, R.L., Krizek, R.J., Eds.; Transportation Research Board, National Academy of Sciences: Washington, DC, USA, 1978; pp. 11–33.

© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).