TERRESTRIAL LASER SCANNING AND PHOTOGRAMMETRY USED FOR MONITORING MASS MOVEMENTS OCCURRING IN THE HIGH-MOUNTAIN AREA

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ABSTRACT: The study of slope phenomena has been a popular subject of geomorphological studies, allowing to explore the development trends of slopes located in high mountain areas. Typically, changes in terrain of mountain slopes can be observed in the long term. However, the impact of morphogenetic processes is unavoidable, and their effects are mass movements. Therefore, there is a necessity for monitoring mountain slopes, justified by the modern evolution and confirmed by research conducted by the Institute of Geography and Spatial Organization of the Polish Academy of Sciences in the Tatra Mountains. Measurement methods used to monitor the phenomena, especially considering large area of land, can be terrestrial measurement techniques such as laser scanning and photogrammetry. The technologies used in recent years, despite their diversity – from phototheodolite to 3D laser scanner - with the current development of technology, provide ample opportunities in the processing and integration of so obtained data. The paper presents the use of modern terrestrial laser scanning technology for the purpose of obtaining information about the area, and thus the study of mass movements occurring on the slope of Skrajna Turnia in polish Tatra Mountains. The possibilities of using laser scanning for such purposes are discussed on the basis of fieldworks conducted in that area. Elaborate study concerns both the data obtained from scanning and archive data, composed of a pair of photogrammetric photos, made for the same object twenty years ago with the use of phototheodolite. The data can be then compared, as a result of conducted transformation and georeferencing. The obtained final results such as contour maps, cross-sections, dense surface models enable the further development of the studies. In addition, we have formed a cooperation with the Institute to analyze terrain changes that have occurred in the studied area believably.

1. Genesis and purpose

Surveying and Mountains is the perfect combination for lovers of mountain expeditions and adventurous young surveyors, as we have seen ourselves as participants in measuring student camp, organized by the Student Geodetic Society 'Dahlta' (KNG *Dahlta*) working at the University of Science and Technology in Crakow. Science camp was held in September 2012, and one of its objectives was terrestrial laser scanning of mountain slope of Skrajna Turnia. The slope was also the object of photogrammetric work carried out by the researchers of our University in 1991. The initial goal of the project was to create a digital terrain model of slope based on scanning measurements and so processed data to be transferred to the resources of the Tatra National Park (TPN). Thereby, the opportunity for further research and their complex issues, raised in our interest and willingness to take additional challenges. As a result we undertook the elaboration of terrain model based on archival photogrammetric data (1991), and thus the attempt to analyze changes occurred on the mountain slope over the last 20 years. What is more, the slope of Skrajna Turnia is also the research object of long-term geomorphological studies carried out by the Institute of Geography and Spatial Organization of the Polish Academy of Sciences [1].

2. Logistics

Science camp in 2012, of which we took part, was a continuation of the previous ones, so that as the Student Geodetic Society we started to cooperate with the Tatra National Park. Measuring team consisted of eight members of KNG *Dahlta* and two academic teachers. Preparations for the 10-day mountain expedition required us, as participants of the camp, a number of things and good cooperation. It was necessary to divide the responsibilities and tasks, each of us had to live up to their best. Well in advance of the camp, we started looking for the financial support for our expedition. As a result, we were able to get funding from our university and several surveying companies. Furthermore, we received the additional support in exchange for cooperation with the surveying magazine and geoinformatic web portal, which took over the sponsorship of our science camp. The expected scope of work in the mountain area also required the appropriate authorization from the Directorate of TPN to trek besides the available hiking trails, and so we had to be particularly careful because of the difficult character of mountainous area. Because of that, we had to sort out appropriate insurance. The logistic issues were present at every step. During the camp, we were under the care of our academic teacher, so that in the beginning we learned how to use the scanner and what is important in scanning measurement planning. The object of our measurements was located about 40 minutes from our camp accommodation, and from there we went to destination carrying equipment such as tripods, total station and scanner on the back. During the camp we realized together a few measurement projects using terrestrial laser scanning technology. However, after the expedition each of us had assigned tasks to do that are then passed on to the resources of TPN.

3. Object of research

The object of our research is a northern slope of Skrajna Turnia (2097 m) - one of the highest peaks of the Tatra Mountains situated in a polish-slovak border. The studied slope is located in a subalpine zone , at an altitude from 1700 to 1850 meters above sea level and covers an area of about 40 000 m^2. The slope has a length of 250 m, and its average slope is about 35 ^{o}. Genesis of slope is inseparable connected with the development of the rock wall, and thus the processes of denudation, transport and accumulation of rubble, resulting from the effect of mass movements. The studied landform is built by granite rocks in the form of sharp-edged rock fragments. Slope surface is exposed, only the lower part is covered with dense vegetation (dwarf mountain pine).

Figure 1. Orthophotomap showing the slope of Skrajna Turnia with a range of land accepted for studies.

Such shaped landform is constantly exposed to the activity of slope processes, which in more or less dynamic way shape the surface of the slope. Due to the character of the obtained data – deficiency of complete information about the relief of the studied area (blind spots in the point cloud) - it was necessary to limit the area admitted to further analysis. The slope area being the object of our studies is shown in Figure 1.

4. Data sources

As part of our project, in order to carry out the analysis of terrain changes we use the data from measurements made in the same area in a different period of time and with the use of different measuring technique.

The first dataset used in research (archive data), being a basis to analysis, is a pair of photogrammetric images (Figure 2) made in 1991 using terrestrial photogrammetry methods by using phototheodolite Photheo 19/1318.

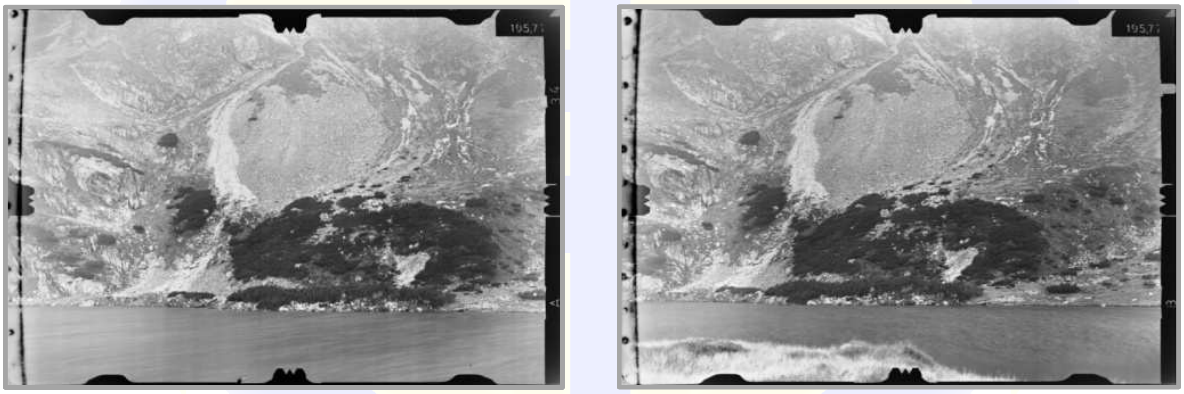

Figure 2. A pair of the photogrammetric images made by phototheodolite Photheo in 1991.

The entire documentation from the first period of measurement includes: scanned photogrammetric images and data acquired from supplemental geodetic measurements. For the analyzed images the pixel size amounts 14 microns, whereas the ground pixel size was estimated in the range of 1,0 cm to 3.2 cm, appropriate for the lower and upper parts of the area. The images were taken by using a photogrammetric camera, which has the focal length (constant camera) equals 195.77 mm. Unfortunately, terrain conditions in the mountainous area had a great influence on mutual camera positions, and thus unfavorable B/H ratio (1:25), what as a result could have affected the results of further studies. Moreover, due to no geodetic reference available, the archival data could be located only in the local coordinate system.

The next fieldworks in the same area was conducted by ourselves in 2012 with the use of terrestrial laser scanning technology. So the second data set was a point cloud (Figure3) obtained by merging scans taken from different measuring scanner stations.

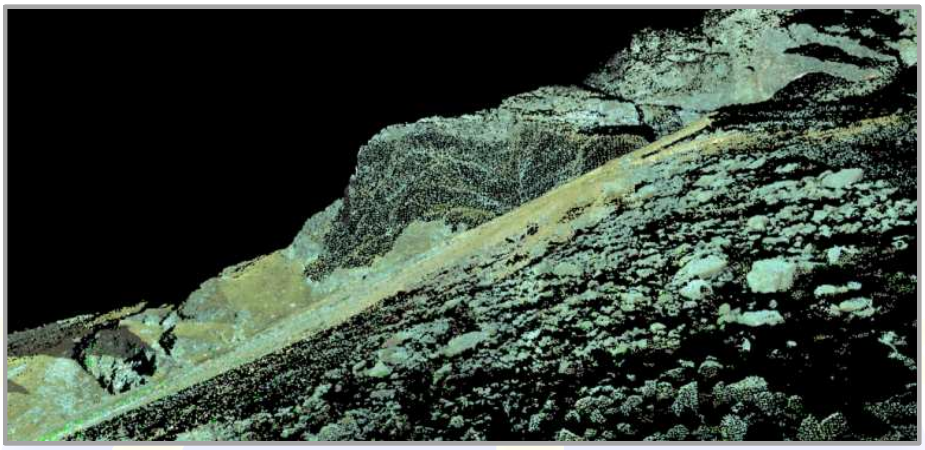

Figure 3. Fragment of point clouds procured from laser scanning method in 2012.

In order to conduct laser scanning we used 3D laser scanner and HDS **circular planar targets**. The carried out measurements made it possibile to locate the data in polish coordinate system and consequently in real space by georeferencing.

Despite the use of two different measurement techniques, thanks to specialist software, it was possible to link all the obtained data. Subsequently we could manage to conduct accuracy analysis and elaborations and then have a trial to analyze changes that have occured in the studied area.

5. Fieldwork

During the fieldwork carried out in 2012 we made laser scanning for the area of scree slope beneath Skrajna Turnia and measurements of the scanning control points position. In field work were used: laser scanner Leica ScanStation C10 and total station Leica TCR407. In accordance with the technical specifications scanner, used to surveying, is characterized by the accuracy of the point position determining equal to 6 mm at a distance 1-50 m. Precision parameters for total station attains values: 2mm + 2ppm and 7'' - respectively for distances and angles. During laser scanning measurements it turned out that the range of the scanner in the local field conditions was much shorter than intended (only about 100 meters). Probably it was due to a very low level of reflectance (albedo*)* in the mountain area.

Therefore, it was necessary to carry out measurements in the area of slope (also in its upper part), what required us to extreme caution and proper logistics (Figure 4).

Figure 4. Terrestrial laser scanning on the scree slope of Skrajna Turnia (September 2012).

To ensure the proper conduct of further studies, it was important to plan measurements appropriately. It is connected with suitable design and arrangement of laser scanner and targets positions. Terrestrial laser scanning of target terrain was carried out from nine scanner positions, located near or directly on the scree slope. Point clouds, obtained from different measuring positions, were connected by measure of the HDS targets spaced on tripods, which accounted scanning control points. Each subsequent two scans are interconnected by at least three targets. Fieldwork in every measuring position included scanning planar HDS targets, that were visible from scanner station, scanning the fragment of slope with the average resolution of 5cm/100m and making photos, taken by the camera built into device. Only in the last scanner position the images of area were not made - it was caused by low light, because of finishing our fieldworks in the evening. Due to the difficult terrain conditions, scanning measurement lasted several hours and was carried out in the course of one day, the measurement time for a single station was about 45 minutes. Beneficial effect on the field work had favorable weather conditions (windless weather, lack of rainfall, temperature around 18-23 ^{0}C). The orientation in geodetic coordinate system for scanning measurements was conducted by measuring the position of HDS target plates with reference to geodetic control network, existing on this area. This measurement refers to the two control points with known geodetic coordinates in a coordinate system "2000".

6. Data processing

Working with the received data was carried out in three stages. First-step was the processing of the data from the year 1991 (photogrammetric images), the second step included working with data from the 2012 (laser scanning). The third and final phase of the project was the unification and analysis of such prepared data. To work with photogrammetric data of 1991 were used PhotoModelerScanner software that is designed to create precise 3D models from images. The program enables obtaining point clouds, and mesh models with a great accuracy as well as high density and data resolution. Work in the program was initiated from defining the parameters of the camera (camera constant ck, coordinates of principal point x0, y0) in the pixel coordinate system, which was tantamount to the process of interior orientation for each photo. The next stage was the creation of the stereoscopic model in the relative orientation process, performed on the basis of 16 points, which were details of the terrain identified in both digital images. Created model was then situated in the local coordinates system by performing absolute orientation based on 3 control points with known ground coordinates that were measured during photogrammetric works. Exterior orientation mean error reached the value of 0169 m. On the basis of stereo pair images was generated a new point cloud with an average resolution 0.35 m (Figure 5).

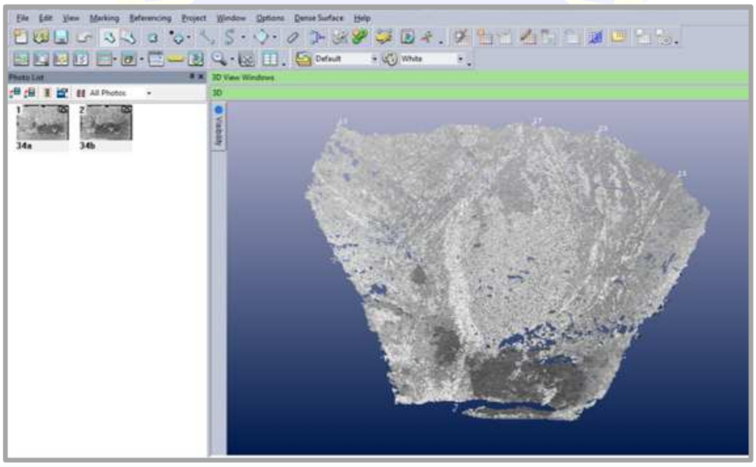

Figure 5. Point cloud generated in PhotoModelerScanner from the photogrammetric images made in 1991.

Data processing of scanning measurement from year 2012 was made in Leica Cyclone software which ensures fast processing of large amounts of data as point clouds, obtained from laser scanning. Working with point cloud started from the registration process – this function provides broad set of tools for aligning point clouds captured from different scanning stations, quickly and accurately. On the basis of total station measurements the combined point cloud was situated in the geodetic coordinate system "2000". The registration process empowered assigning georeference to combined scans, *Mean Absolute Error* of final aligning amounted a 0.026 m. In the next step unified point cloud was colored with images taken during the terrestrial measurement scanning. Further necessary procedure was data filtering, intended to remove redundant information (plants, equipment, the person performing the measurement) from colored point cloud. This process was made manually based on the terrain details interpretation according to their color. To minimize data volume obtained cloud was processed with special functions to form of irregular triangle mesh (called TIN - Triangulated Irregular Network). After verification the TIN model in program was generated new point cloud with an average density of 0.08 m. As a result of the described research two relief models of analyzed scree cone were obtained, prepared on the basis of measurements taken after an interval of about 20 years. In order to make reciprocal comparison, this two models had to be situated in common coordinate system.

7. Unified coordinate system

The initial set of data was in the local coordinate system while the second data set was worked out in polish State Coordinate System "2000" (based on Gauss-Kruger projection) therefore it was decided to perform the analysis in State Coordinate System "2000". Integration of coordinate systems required transforming of the point cloud based on data from 1991 to selected coordinates system. Data integration was one of the most difficult and labor-intensive steps in our elaboration and possibile to do using photointerpretation uniquely. The photointerpretation was made with the use of two computer workstations. The work at that stage consisted in finding the corresponding terrain details possible to identify both on the photogrammetric images, as well as on the point cloud obtained from laser scanning (Figure 6).

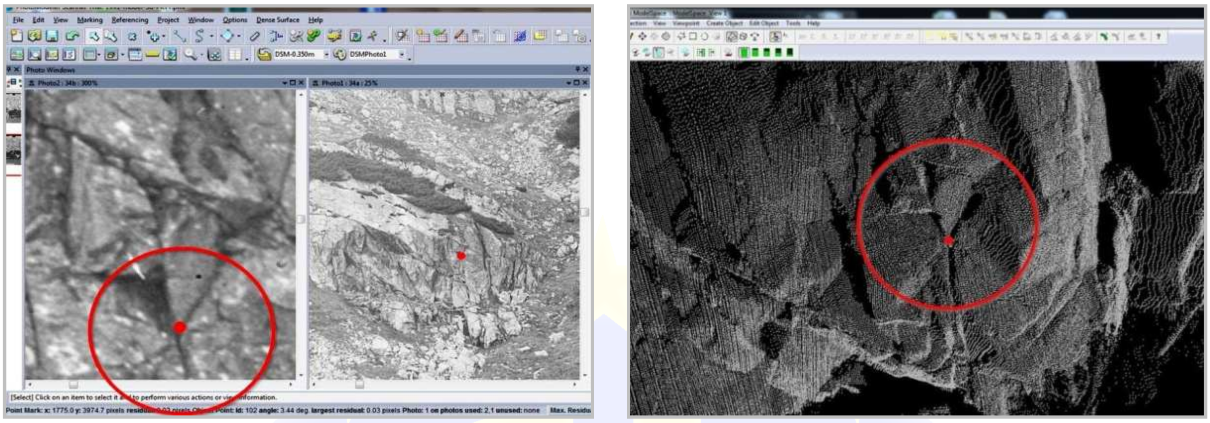

Figure 6. Identifying terrain details using PhotoModeler Scanner (left) and Leica Cyclone (right).

Selected points were located in the rocky massifs outside the scree slopes. Chosen details of terrain were used as known points, that enabled the determination of the transformation parameters. Entire calculation process of coordinates transformation was made in GeoNet software with the use of 12-parameter affine transformation based on 5 points. Transformation error was 0.06 m. Based on photogrammetric analysis and carried out transformation the accuracy of processed transformation model (1991) was estimated to ± 0.18 m. Bringing data into a common coordinate system allowed to conduct further comparative analysis and to attempt illustrating the changes that have occured on the slope.

8. Final analysis

Final analysis was performed in specialist software designed for XYZ data complex visualization, named Surfer. The program provides, among other things, contour mapping and their spatial illustration by using a regular grid of squares (GRID). Point clouds imported to the program, were generated using the kriging algorithm with a given GRID density equal to 2 meters. Analysis was performed in a limited fragment of slope surface defined in the program with cutting function (by defining the coordinates of the boundary points). The first data imaging were contour maps that subsequently enabled to create cross-sections and longitudinal profiles in specific parts of the slope. Cross sections in the most readable way illustrate changes in the geometry of scree slope on selected sections - bottom, middle, top for cross sections and located along the slope in the left, middle and right side for the longitudinal profiles. The overall visualization of compared terrain models was presented on the map of height differences. Conducted analysis is an attempt of interpretation of the changes in geometry of studied slope that are caused i.a. by occuring mass movements in the mountain area.

8. Results presentation

Point clouds derived from laser scanning or processing data acquired by other methods are basic products which make it possible to perform multiple activities and operations in order to obtain detailed information about the object. In the present project, we based on the data acquired by two different techniques such as terrestrial laser scanning technology, and terrestrial photogrammetry. The accuracy and completeness of the received data is illustrated in Figure 7 that shows the significantly higher density of the points in the case of cloud generated by scanning measurements.

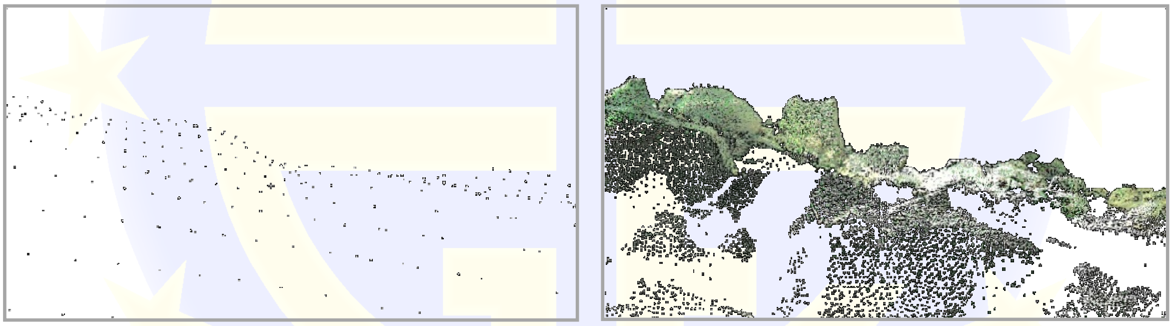

Figure 7. The comparison of point clouds acquired from photogrammetric images (left) and terrestrial laser scanning (right).

One of the final products of point cloud processing is digital terrain model (DTM), often presented as a 3D visualization that makes it easy to percept and interpret. To effectively reflect the character of terrain in the area, point clouds were manually filtered. On the basis of prepared data, terrain models of Skrajna Turnia's slope were created, using the method of a regular grid of squares GRID (Figure 8).

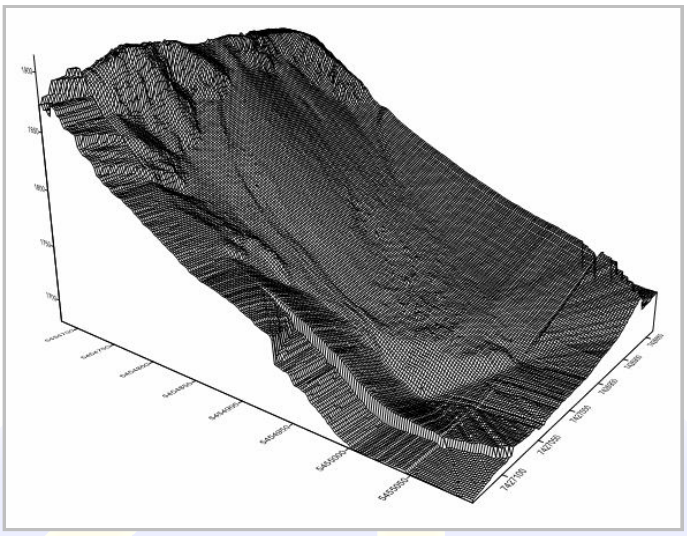

Figure 8. The 3D terrain model (2012) of the slope of Skrajna Turnia covered with a grid created in Surfer.

Then, based on generated contour maps we created longitudinal profiles and cross-sections located in characteristic parts of slope. Cross section analysis shows both the increase and decrease of rock material in particular areas what may indicate on transport and accumulation of rock material in the studied period of time.

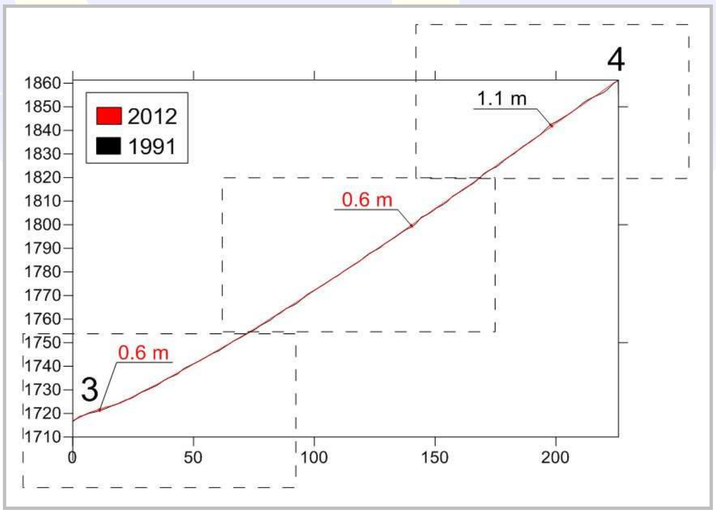

Figure 9. The longitudinal profile of the middle part of the slope showing the evolution of slope geometry.

An examination of the chart (Figure 9) pointed out that the greatest land surface changes occured in the upper part of the slope, their value reaches up to 1.1 meters In this part of the slope is a noticeable loss of rock material compared to previous measurements of year 1991. In the middle and lower parts of the researched area the opposite can be observed, which indicates the transport and accumulation of rock in the analyzed period of time. The growth of the debris quantity in these parts of the slope reached to about 0.6 meters.

Height differences map was created as a result of using the mutual subtraction function on the resulting maps of 1991 and 2012. An interpretation of that kind of data visualization demonstrates the changes in the surface area in the range from -1.5 meters to 1.5 meters. Height differences map indicates loss of rock material (yellow) in the upper part of the slope with a maximum value of 1.5 meters. For most of the study area, these changes do not exceed value of 0.5 meters. Uttermost impact of mass movement activity is noticeable on the east side of the slope, where a rock gully was shaped. Confirmation of this fact is evident in the Figure 7, where on the left side we can observe the accumulation of rock material (red) with a maximum value of 1.5 m.

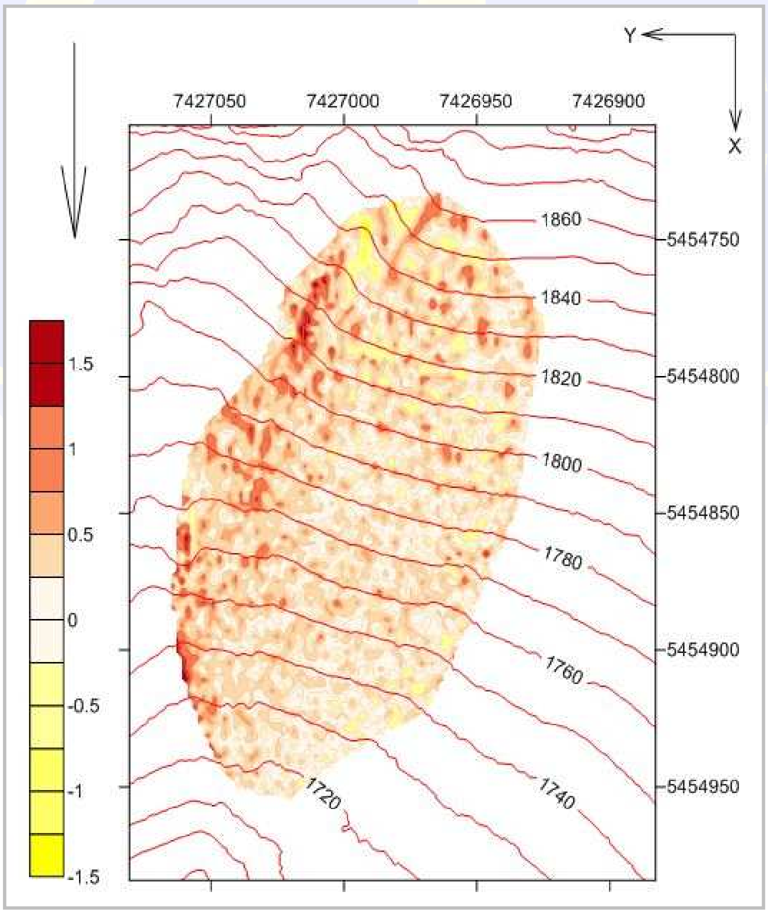

Figure 10. The height differences map of the studied area for the data obtained in 2012 in regard to data from 1991 (yellow colour - loss of rock material, red colour - rise of rock material).

10. Conclusions

The complex theme of described project enables to formulate a number of conclusions concerning the diversity of measurement techniques and data processing methods and their integration. Due to modern methods of converting data, the past photogrammetric measurement techniques (with the use of phototheodolite) can be processed, and enabled to create accurate spatial models, what can greatly facilitate interpretation of so obtained data. Moreover, the available modern software enables the integration of data derived from different measuring techniques used both in the past and at present. Therefore despite the wide variety of data and elaboration methods, it was possible to attempt to analyze terrain changes, formed under the influence of slope phenomena that have occured in this area over the last 20 years. In the analyzed period of time can be stated relatively small changes in the studied area. The rock material moves down along a north-east direction in accordance with a decrease in the area slope, which confirms the mechanism of gravity movements. The analysis revealed the presence of mass movements in particular on the east side of slope such as transport and accumulation of debris. Therefore in order to obtain reliable results, it is necessary to fulfill two conditions, the first is detailed study of data at each stage of the work (i.e. data filtering, the choice of methods for creating NMT, the most effective calculation of model parameters) and the second one a specialized interpretation of the results based on previously conducted geomorphological research. In order to fulfill the latter requirement recently we have managed to establish cooperation with the Institute of Geography and Spatial Organisation, Polish Academy of Science. The project is a great example of the close partnership between two scientific fields such as geomorphology and geodesy, that is essential in conducting research to a better understanding of our planet Besides, as shown by the disciplines names – they were always linked by solid ground under their feet - lat. 'geo' - the earth.

Both laser scanning measurements and conducted elaborations gave us a great possibility to gain new and practical experience in land surveying and also the ability of cooperation and organization while doing our interdisciplinary project.

Literature

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