International Snow Science Workshop Grenoble – Chamonix Mont-Blanc - 2013

Snow avalanches mapping – evaluation of a new approach

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ABSTRACT: Recent snow avalanche hazard mapping tools and procedures offer methods to improve the accuracy and reliability of risk and hazard localization. The validation of numerical mass movement models mainly depends on recorded historical avalanche data sets such as avalanche outlines and release volumes. These data sets are often unavailable or of an unknown accuracy. Avalanche characteristics such as release area, flow height and flow path, runout distance and total amount of released snow mass are essential parameters for proper calibration and evaluation of numerical simulation tools. Incorrectly calibrated models can influence decision-making which directly affects human safety. The acquisition of high quality data regarding observed avalanche events is often hindered by the high risk permanently present in avalanche terrain. This paper describes a promising method based on photogrammetry and computer vision and also introduces AVALMAPPER software that allows using a single terrestrial photograph with unknown exterior and interior orientation parameters to accurately map avalanche outlines. We evaluate this method by comparing its results with GPS measurements made in the field. We discuss the optimization of measurement efficiency, costs and human safety.

KEYWORDS: snow avalanche mapping, risk and hazard localization, avalanche outlines, historical data, AVALMAPPER.

1 INTRODUCTION

Avalanche hazard mapping tools and procedures developed by avalanche specialists from all over the world offer an increasing number of methods for providing more accurate risk and hazard localization. Numerical avalanche dynamics models like RAMMS (Christen et al. 2010), SAMOS (Sampl and Zwinger 2004) or ELBA+ (Volk and Kleemayr 1999, Sauermoser and Illmer 2002) coupled with GIS have become an essential part of snow engineering and hazard mapping studies (Christen et al. 2010).

Unfortunately, a constant fundamental problem in the science of snow mass movements is to record and document occurring events. Post-event mapping is helpful to determine release areas, volumes of the released masses, runout distances and inundation areas. This kind of data is necessary for developing and evaluating new mitigation methods and tools. Avalanche mapping is also important for risk assessment verification and accident documentation. Beside conventional avalanche data (altitude, aspect, slope, size, etc.) a general outline marked on maps should be a part of each avalanche survey (Meister and Jeller 2009).

On a global scale, the documentation of avalanches remains sparse and therefore incomplete, and its accuracy is unknown. Currently, detection and mapping of observed avalanches relies mainly on isolated observations acquired by individual experts under field conditions. Quite often, only avalanches causing accidents or resulting in heavy damages are mapped (Bühler et al. 2009).

At certain locations, such as Davos in Switzerland, long-term records of well documented events exist. However, because of the changing climate and missing records, historical data may not show the complete picture of the current threats.

A common lack in high quality data of localized snow avalanche releases and depositions is more often caused by the high risk permanently present within avalanche areas (especially in the release zone), rather than limited availability of measurement devices. This is the reason that the most popular method used by experts is manual mapping based on remote observations and topographic maps. However, according to opinions of avalanche experts, this method requires high skill levels, and very often leads to numerous discrepancies between field measurements and drawn extents (Meister and Jeller 2009). Traditional hand-held Global Navigation Satellite System (GNSS) measurements allow cheap, easy and accurate mapping of avalanches, but they are time consuming and often of restricted applicability, due to avalanche danger. The quality of these measurements strictly depends on the available satellite signal which

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may be significantly reduced in the complex terrain (Chrustek et al. 2010).

Remote and high resolution survey is enabled by integrating the two technologies: Light Detection And Ranging (LiDAR) and GNSS (e.g. Deems and Painter 2006; Jörg et al. 2006; Vallet 2008; Prokop et al. 2008). Unfortunately, the most important disadvantage of this method is high price and limited repeatability. For many years, obtaining this kind of data has been impossible for many operational and research budgets. Application of these technologies also requires large amounts of time for detailed measurement planning, and qualified staff that may operate system and process data (Deems and Painter 2006; Prokop 2009).

Single terrestrial photographs can also be used as a source of valuable geographical information. Recently, Aschenwald et al. (2001) and Corripio (2004) presented an approach to incorporate a single terrestrial photograph into geographical analysis. Their methods, however, employed photographs taken from known or measured locations, and this subsequently limits potential data sources to a new or well-documented set of photographs.

An interesting approach in the avalanche outline mapping context was presented by Meister and Jeller (2009). They used a digital "Atlas of Switzerland 2" (2004) and digital terrestrial pictures containing Global Positioning System (GPS) coordination and azimuth parameters and based on the digital elevation model (DEM) panorama and tools for adjusting digital pictures, avalanche outlines were drawn on screen.

Our aims were to develop an innovative method and create the AVALMAPPER software which allows to map an avalanche extent using a single terrestrial photograph with unknown exterior and interior orientation parameters. Our idea is based on creating an orthoimage from the terrestrial photograph by means of photogrammetric and computer vision rules, and subsequent visual interpretation.

2 METHODS

2.1 Theoretical background

The proposed methodology contains three principal steps. First, the photograph needs to be oriented in a global coordinate system to obtain camera position and to perform function mapping of 3D points into a 2-dimensional (2D) image. Next, the viewshed analysis is performed to determine parts of terrain that are not visible from the particular camera position. In the third step the visible DEM points are projected into the photograph by means of the mapping function, to obtain color information out of the photo. All mentioned steps were coded using Python programming language and linked with the Graphical User Interface (GUI) developed for this task (Fig. 1).

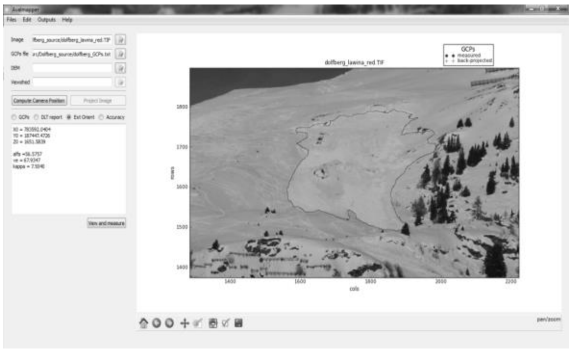

Figure 1. Graphical User Interface of AVALMAPPER software.

To orientate a terrestrial photograph, the Direct Linear Transformation (DLT) method is applied (Abdel-Aziz and Karara 1971; Luhmann et al. 2006; Kraus 2007). The DLT establishes the relationship between the 2D image coordinates and the 3D object coordinates, using projective transformation rules and ground control points (GCPs). The control points must have image and global coordinates measured to compute the camera orientation parameters. A minimum of 6 points are necessary to solve the DLT; however, to cope with images from non-calibrated camera or scanned old photographs, more GCPs are necessary to obtain accurate results.

Global points' coordinates can be surveyed in the field, most likely with GNSS device, or determined by examining existing aerial orthophotomaps and elevation models.

Output from this procedure is the orthophotograph, saved as a TIFF file and georeferencing parameters stored in a TFW world file.

The output orthophotograph is visually investigated. It involves both checking the general appearance of the image and comparing it with existing data, e.g. traditional (aerial) orthophotomap. Usually it can be seen if such an image contributes some new, additional information, or if it rather contains smudges or other artifacts. Finally, computed orthoimages become a base layer for manual or automatic vectorization process. Correct interpretation of the processed image strictly depends on the operator experience, the selected map scale and assumed automatic classification method.

2.2 Experimental work

The study areas were located in the Polish Tatra Mountains and the eastern part of the

Swiss Alps around Davos. To test the approach two different locations were chosen (Fig. 2):

Dorfberg Mountain (DB) – a 2592 x 3872 pixels digital photograph, taken with non-calibrated digital SLR Sony A100 camera equipped with 10.8 millions pixels CCD-matrix and a zoom lens 17-50 mm. RGB colors show south-eastern exposed slopes of the Dorfberg Mountain and surroundings (picture from 9th of February 2010). The photograph recorded a few small and medium size snow avalanches, the biggest one in the central part of the picture (aproximately 220 m long) was also measured by GPS Trimble GeoXH device (with decimeter accuracy). Metadata are not available from the EXIF file.

Goryczkowa Czuba (GC) – a 1013 x 661 pixel copy of the scanned analog photograph, RGB colors show Czuba Goryczkowa Mountain and avalanche rescue action that took place on 11th January 1985. Part of medium size avalanche (approximately 600 m long) visible in the picture was released by a tourist. It killed one person and caused injuries to another.

Figure 2. The test images with marked GCPs: DB (left), GC (right).

DEM for the GC test sites was available as the TIN (Triangulated Irregular Network) model based on contour lines with 5 m intervals digitized from topographic maps 1:10 000), mass points and hardlines. It was converted to the raster format with spatial resolution of 1 m. DEM for the DB site, with 2 m resolution, was produced from aerial images.

GCPs were measured in ArcGIS software, on a basis of orthophotomaps and DEM. Created orthoimages became base layers for vectorization. Avalanches outlines were manually vectorized on screen using GIS software.

3 RESULTS

Despite the low contrast of the snow surface, both release and deposit zones are visible in the processed orthoimage from the DB test site (Fig. 3 d). A few tests showed that more detailed shape of the avalanche outline may be obtained when the outline is marked on the input photograph. The vectorization process on the orthoimage then becomes much easier. Figure 3 c shows the comparison between vectorized and field measured data. This example strongly demonstrates that high accuracy avalanche outline mapping based on traditional terrestrial photograph is possible. The measured vertical differences between the outlines do not exceed 15 meters. It is worth mentioning that vertical distance between camera and the avalanche was over 1500 m. Based on this fact, we can say that the most important advantage of this method is that it works very well without accessing dangerous areas. It also saves time, cost and effort.

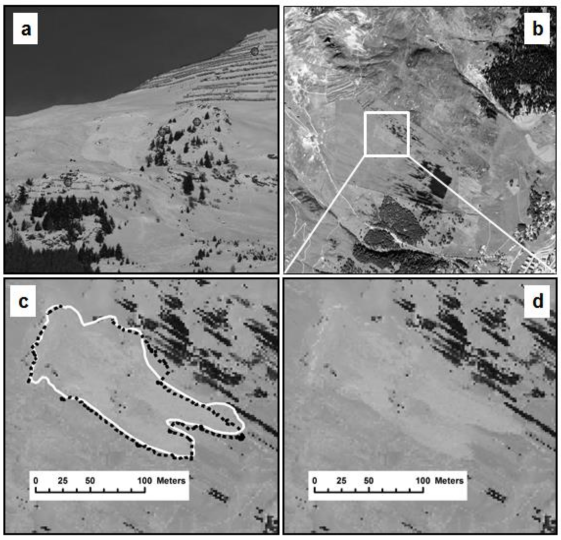

Figure 3. DB site orthoimage on the traditional orthophotomap background (b) and vectorized avalanche outline (c) compared with field GPS measurements (dashed black polylines).

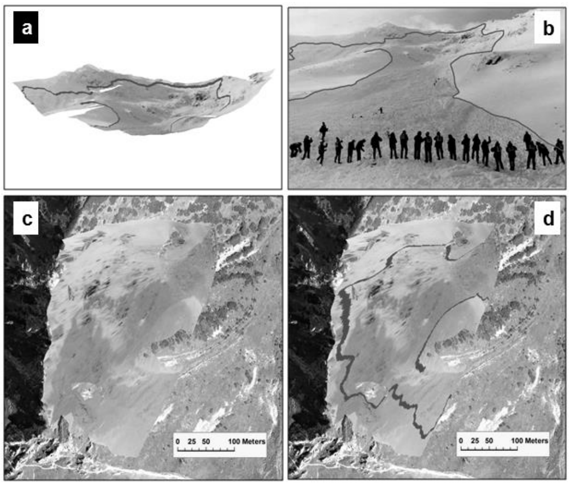

Figure 4. CG site orthoimages on the traditional orthophotomap background (c) and 3D visualization of the draped ortoimage on the DEM (a). D: orthoimages with visible avalanche outline (continous line) drawn earlier on the source image

Very promising results were obtained when analyzing orthoimage processed from the old scanned photograph in the CG test site (Fig. 4).

This example showed that processing of an old photograph with limited identification of reliable locations of the GCPs is possible (most of characteristic terrain features were completely covered by the snow).

Because of the lower resolution of the source photograph, the vectorization of the visible avalanche outline was also much easier when the outline was marked on the source image (Fig 4 b). The avalanche boundaries visible on the orthoimage processed from the raw picture are not so clear (Fig. 4 c), and the whole outline of the avalanche was not visible. As the documentation prepared after the rescue action contains a detailed description, it can help identify precise location of the runout limits and draw them on the map in the next step.

4 DISCUSSION AND CONCLUSIONS

Our paper presents the method that minimizes necessary input information and replaces approximate data with mathematical calculations, based on the DLT method that has several advantages as compared to earlier works by Aschenwald et al. (2001) and Corripio (2004). First, mathematical computations seem to be more reliable than error-prone visual estimation; another DLT advantage is that it works with terrestrial, oblique and aerial photographs, making this method multi-purpose. Mathematical formulae also gives a chance to compute errors in the camera orientation and assess its influence on further processing of the photograph.

Similarly to Aschenwald et al. (2001) and Corripio (2004), in the proposed method GCPs need to be collected. This is the most time-consuming and problematic part of the georectification process. What affects accuracy of the GCPs measurement are photograph and orthophotomap resolution and DEMs accuracy or – in case of field survey – GNSS device / measurements accuracy.

It is difficult to find reliable GCPs in old photographs, whether in the orthophotomap or in the field, due to changes in landscape features and snow coverage, when analyzing winter images. The problem applies also to very steep slopes that look different from the terrestrial and aerial perspectives or can be hardly accessible for surveys. Nevertheless, as the DLT method needs only a minimum of six GCPs, so it is highly probable that they can be found, as proven in the GC test site.

In comparison to Aschenwald et al. (2001) and Corripio (2004), an additional improvement of the method is the implementation of the viewshed analysis into the final procedure that has not been proposed until now. The algorithm of Wang et al. (2000) was successfully programmed and tested to assess its quality, with the results almost identical to viewshed procedures widely used in proprietary GIS software. The positional accuracy and quality of the final result largely depends on the input DEM quality (Fig. 5). As elevation models of high-mountainous areas produced from aerial photographs have major inaccuracies in a very steep or shaded terrain, these errors will be propagated into the derived data (Foote and Huebner 1995; Krupnik 2003).

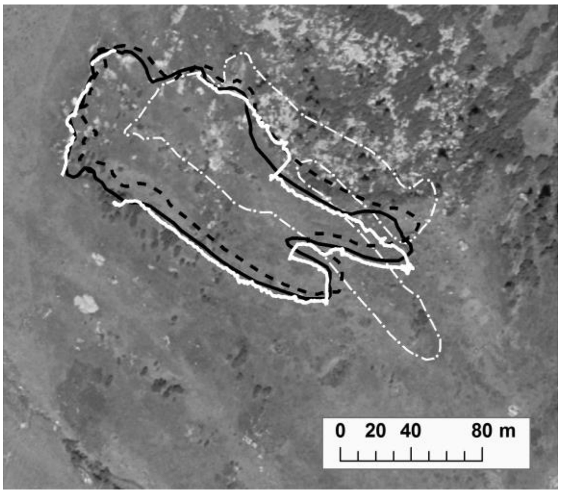

Figure 5. Results of the avalanche mapping in DB test site using AVALMAPPER software and different input DEMs: continuous black line – 2 m resolution DEM produced from aerial high resolution digital images, dashed black line – 25 m Swisstopo DEM, dashed dot white line – 27 m ASTER GDEM, white continuous polylines show GPS measurements.

Analyzed examples show that the processing of terrestrial images from different sources and different times, including old analog photographs, is possible. With a good performance of the algorithm, high-resolution orthophotographs can be easily obtained, allowing great capabilities for the visual interpretation in standard GIS software. Also for shaded slopes, results may provide as good radiometrical information as RGB aerial photographs. The unquestionable advantage of such data is their low price. They can also be obtained almost anytime, independently of the season or equipment. Bad weather conditions can be an obstacle, but it is a common drawback of many data-collecting techniques, e.g. laser scanning. Imaging at night is impossible as well. A drawback of terrestrial orthophotos is that some parts of the terrain may not be visible; however, it could be easily compensated with multiple terrestrial photographs.

The potential field of applications is wider than avalanche mapping and may be used to gather information on other natural hazards in difficult terrain such as debris flows, landslides and rock falls.

Acknowledgements We would like to express our gratitude to the Foundation for Polish Science for financial support of Paweł Chrustek. Performing the analyses was possible thanks to the VENTURES program organized by the Foundation of Polish Science and co-funded by the European Regional Development Fund under the Operational Program Innovative Economy 2007-2013. Natalia Kolecka is a grant holder of "Doctus" Programme. We also would like to express gratitude to our colleagues Marek Świerk from the Anna Pasek Foundation in Poland, for assistance in collecting field data, Wojciech Bartkowski and Jakub Radliński from the Volunteer Mountain Rescue Service (Górskie Ochotnicze Pogotowie Ratunkowe, GOPR), for assistance in collecting data and materials concerning historical avalanches in the Tatra Mountains.

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