The solid ortho-image: a new tool to identify avalanche terrains

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ABSTRACT: In mountain areas the correct identification of avalanche terrains is mandatory in order to avoid, or at least prevent, avalanche accidents in inhabited areas. Moreover, the localization of these terrains is also useful in remote areas with the purpose of increasing the overall knowledge of the investigated territory and in the prevention of avalanche accidents during tourist or generally outdoor activities.

Generally, the identification of avalanche terrain in large areas is carried out through stereovision devices with aerial images. This approach needs the use of specific software and hardware in order to accomplish the analyses in the best way.

The solid ortho-image is a new image that can improve terrain analysis allowing the operator, whether skilled or not in photogrammetry, to accomplish complex analysis. The solid image conjugates in a unique support the chromatic information of a traditional photogram and the three-dimensional one of a digital terrain model.

By moving the cursor on the image the operator is thus able to spot avalanche terrains by image interpretation but is also helped by the three-dimensional content of the support; the final output is a 3D plotting of avalanche areas. These data can be directly employed in avalanche mapping or as input in avalanche modelling.

KEYWORDS: Image analysis, land planning, avalanche hazard, GIS.

1 INTRODUCTION

Snow avalanches are natural phenomena that in some areas may interact with human activity such as roads or settlements. In order to execute an appropriate risk assessment and consequently a correct land planning, analysis tools that investigate probable avalanche location have been developed. The described instrument in Italy is a cartographic support named “Carta di Localizzazione Probabile delle Valanghe” (“Avalanche potential location map”) or C.L.P.V. The map is produced at 1:25000 scale and shows those areas potentially subjected to avalanches and those already known as avalanching. The map is produced following a procedure subdivided in three steps: (1) the photointepretation of past phenomena from stereo pairs of aerial images, (2) the field investigation by site inspection and (3) the investigation among the local population and historical records (Buser et al., 1985).

Usually, the photointerpretation phase is carried out by drawing potential avalanches directly on a paper map. The boundaries are interpreted by the observation of hard copy stereo pairs with a stereoscope. An alternative technique has also been tested by employing digital photogrammetry methods (Faletto, 2005); the results have been encouraging but the feasibility of the methodology was not assured, due to the complexity of digital photogrammetry procedures.

In this work, a new kind of image support and software are proposed in order to optimize the photointerpretation phase: the solid orthoimage.

2 MATERIALS AND METHODS

The solid orthoimage is an innovative image support joining the bi-dimensional informative content of a traditional orthoimage with the three dimensional attributes belonging to a digital elevation model (DEM). The advantage of this support is to provide an image support that is easily interpreted and contemporary allow the recording of three-dimensional coordinates of collimated objects.

As defined by Bornaz and Dequal (2003) the solid orthoimage is computed by summing an additional matrix to the orthoimage, provided with the elevation component stored into its cells. Usually, this last component is the same elevation matrix previously employed in the image rectification procedure. The two matrices must be congruent according to their dimension (rows and columns number) and to their resolution (pixel/cell size).

In an orthoimage, the coordinates of the centre of the pixel (x_0 ,y_0), located at the origin of the matrix (position 1,1), are known as the pixel size (d). According to the following formulas every image pixel (x ,y) is thus defined:

$$x = x_0 + d \cdot (c-1);$$
$$y = y_0 + d \cdot (r-1) \qquad (1)$$

where:
c = number of columns;
r = number of rows.

The DEM matrix is defined by a number of columns and rows with cells containing elevation information (e). If the digital elevation model has the same dimension and resolution of the ortho-image the elevation of the image pixel, given its location in columns and rows (c, r), is obtained from the corresponding position on the digital elevation model $e(c, r)$. The solid orthoimage is thus defined by these equations:

$$x = x_0 + d \cdot (c-1);$$
$$y = y_0 + d \cdot (r-1); \qquad z = e(c,r)$$
$$(2)$$

where:
c = number of columns;
r = number of rows;
d = pixel size;
e = elevation.

The solid orthoimage is elaborated and managed by OSP (Ortofoto Solida di Precisione – Precision Solid Orthoimage) software experimentally programmed by Prof. A. Lingua - DITAG, Politecnico di Torino, (Lingua et al., 2007).

Inputs data, as previously described, are an orthoimage and a digital elevation model; the software manages the two data sources and joins the information, showing the image on a screen window and the three-dimensional coordinates in another one.

The software (Figure 1) is capable of basic plotting options like polyline or polygon drawing and the calculation of their length and surface. Moreover, advanced tools are available, allowing the user to calculate simple volumes, to define planes intersecting the digital model and to compute volumes between different planes and surfaces.

The test site of the experiment is located in the Aosta Valley at the end of the Ayas Valley in the surroundings of Palasina (Estoul village - 45°45′ N, 7°42′ E, 1815 m a.s.l.). The site lacks of avalanche mapping or surveys, even those carried out by Alpine Troops, as the site has never been interested by any kind of drills (Warrant Officer Vagheggi, personal communication 2008).

This characteristic has led the decision to perform the test on this area in order to provide a basic avalanche mapping with this new technique.

The plotting of potential avalanche boundaries has been carried out using the “area tool” of the OSP software (Figure 1b). The boundary is defined by pointing its vertexes on the image and the measured three dimensional-coordinates are stored in a text file; contemporarily, the coordinates of the vertex are shown on the dialog window.

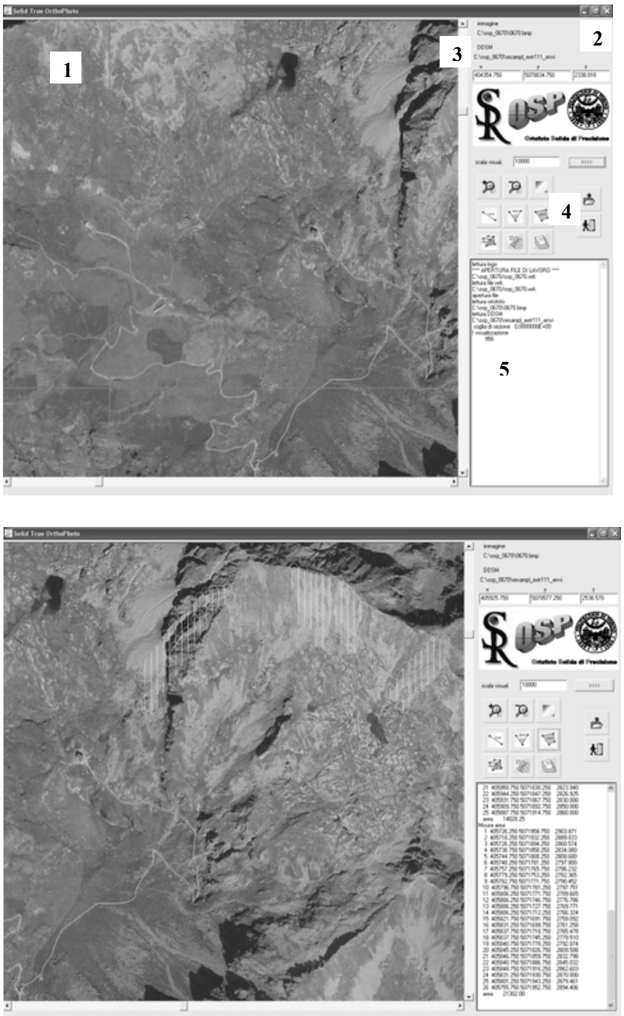

Figure 1. OSP software interface (left): 1 – Orthoimage window; 2 – Three-dimensional coordinates; 3 – Input files path; 4 – Tools (scale, drawing…); 5 – Dialog window. and Potential avalanche plotting

While moving the cursor over the image, the operator is assisted in boundary drawing by the orthoimage interpretation and by the display of cursor coordinates.

The coordinates of each avalanche have been converted in a polygon shape file with the employment of the “Create Feature from Text File” tool in ArcMap™, which allows the creation of geometries from a text file properly formatted, containing vertex coordinates. In this way the OSP output is nearly directly linked with GIS environment.

In order to exploit the three-dimensional characteristic of the data, the three-dimensional surface of every plotted avalanche has been calculated through a free ArcView™ extension.

3 RESULTS

The image plotting has provided a list of polygon 3D coordinates of potential avalanches identified by the procedure. The coordinates have thus been converted in shape file format obtaining the final layer (Figures 3). The text output was also provided by the surface of every plotted polygon.

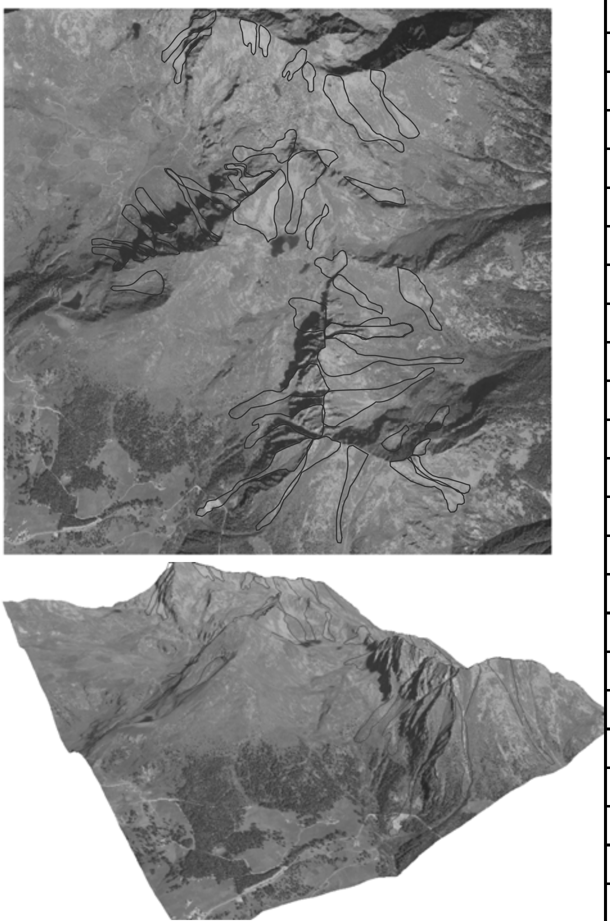

Figure 2 – 2D Solid orthoimage plotting of potential avalanches and 3D visualization – Clip of the Aosta Valley Region orthoimage in background

Features plotted from the solid orthoimage are in three-dimensional coordinates, therefore additional data might be extracted in order to get geometrical information as, for example, flat and 3D areas or elevation ranges (Table 1).

The 3D plotting allows also obtaining the elevation profile of every avalanche with the aim of getting inputs for numerical simulations.

ID	3D AREA (m²)	FLAT AREA (m²)	ELEVATION RANGE (m)
0	49477.18	34319.75	394.47
1	40597.02	25095.38	373.38
2	20650.92	18571.38	114.55
3	15439.09	13866.25	109.72
4	24515.57	21298.38	148.96
5	56310.81	46503.88	236.39
6	47672.73	38415.38	207.34
7	15263.38	14011.00	76.30
8	55220.78	44013.13	457.74
9	98145.39	79690.25	467.55
10	14855.06	11961.75	92.36
11	46272.00	33628.75	288.54
12	17134.56	14715.75	168.18
13	36043.11	29994.88	248.99
14	76580.37	54399.75	234.87
15	32379.77	28068.63	110.36
16	119071.71	88820.50	294.68
17	126816.58	102935.75	226.23
18	44631.99	34162.50	380.40
19	39769.60	28510.00	446.29
20	34031.82	28282.50	216.75
21	51097.53	35336.25	309.35
22	54614.82	38597.75	470.44
23	18648.02	11653.88	362.13
24	26347.26	18309.63	388.64
25	36071.76	23617.88	266.60
26	44923.50	36483.38	222.17
27	130594.95	91725.13	534.21
28	122958.03	85388.88	508.81
29	131730.22	103509.38	677.98
30	67955.78	50428.63	431.58
31	75183.45	58463.38	346.03
32	85272.04	65035.35	422.62
33	140669.78	109861.13	514.63
34	25375.62	16824.75	212.01
35	23949.77	17397.50	188.27
36	11876.27	9084.88	133.48
37	67733.78	51593.25	469.25
38	30384.69	23195.38	399.45
39	55862.39	45022.50	486.84
40	69185.20	55891.13	576.54
41	89245.66	71109.75	680.53

Table 1 - Avalanches geometrical 3D parameters obtained from the plotted features.

5 DISCUSSIONS

Avalanche danger involves the processes of land planning, as this natural phenomenon should be taken in account when defining hazard maps or risk subject zones. Usually, concerning snow avalanches, the instrument employed in Italy for the definition of endangered areas is the avalanche potential location map (Carta della localizzazione probabile delle valanghe or C.L.P.V.) or the avalanche hazard maps (Piani delle Zone Esposte a Valanghe or P.Z.E.V.). While the last one implies also numerical simulation, the C.L.P.V. is a map compiled according to three criteria: the investigation about historical events by interviewing local people eventually witnesses of past events, the search of historical records and the stereo plotting of aerial images highlighting areas affected by avalanche events.

In this work, only the third part of the methodology has been carried out, but a new different approach was tested instead of using the traditional stereo plotting.

Thank to the additional three-dimensional attributes, included in every image pixel, the solid image is capable of assuring the mean to plot avalanche terrain on a bi-dimensional image, but obtaining a three-dimensional drawing.

The extraction of avalanche boundaries has been carried out without particular troubles, as the image plotting is performed on a 2D image without the employment of additional devices, typical of softcopy-based photogrammetric softwares (Mikhail et al., 2001).

The image allows the recognition of terrain and vegetation features representative of avalanche areas and the displaying of 3D cursor coordinates helps the operator in following the correct land form.

The employed software is still at an experimental stage, therefore the final output has been a simple list of 3D coordinates of each plotted polygon; the data have then been converted into shape file format in order to be processed and overlayed with the orthoimage. The next step would be to generate a polygon file directly in the OSP software.

Conversely to the traditional bi-dimensional plotting, the solid orthoimage supplies every point, line or polygon outlined with z coordinates, without additional processing.

6 CONCLUSIONS

This new techniques is highly useful and helpful in land monitoring as it allows to combine the extremely clear informative content of an orthoimage with the three-dimensional data of a digital elevation model in a unique raster layer (Bornaz and Dequal, 2004). In addition, the solid image is an easy-to-use support and can be employed also by non-technical operators with encouraging results.

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