Supporting rock-fall risk analysis of cliff faces by terrestrial laser scanning and UAV imagery

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Abstract
Cutting edge close-range remote sensing technologies, such as terrestrial laser scanning or dense3D from UAV imagery provide different kinds of point clouds that can be fused to achieve improved quality spatial models. While laser scanners are mounted on or close to the ground and therefore suffer from disadvantageous incidence angles and potential occlusions, UAV images can be captured from view positions close to perpendicular to the surface. On the other hand laser can penetrate through vegetation that can be especially problematic for dense3D algorithms in obtaining terrain models.

This paper demonstrates how the point clouds derived from different sources can support engineering geological survey and related slope stability analyses. Steep rhyolite tuff cliff faces hosting a hill top castle have been laser scanned and captured by UAV in the same time. The observed cliffs are located above a footpath and subjected to rock-fall hazards, hence can be dangerous to the visitors walking around the castle.

The investigations proved how the high resolution laser point clouds can be complemented by the data coming from the dense3D procedure in the occluded areas. Accurate CAD products have been created as inputs for engineering geological profiling and cliff stability analysis. RGB images and point cloud intensity images were used to create streetview-like application that enables geologists to dynamically observe the texture of the rocks through high resolution panoramic imagery.

Introduction
Current remote sensing technologies prove their capabilities in broad application areas. However, fusing remotely sensed data still have potential in multiple fields. If data is needed from large areas and not only in dedicated points, surface oriented data acquisition comes into the focus. This paper discusses the survey of cliffs around a historical castle. Considering the size of the area and since the cliff faces have amorphous, irregular shape, terrestrial laser scanning seems obvious data acquisition technology to provide appropriate input data to rock-fall analysis for engineering geologists. But major parts of the cliffs are hard to access, either because they are too steep or are dangerous due to loosed rocks. Therefore a combination of laser scanned data with that of provided by the UAV was applied. UAV-based mobile mapping already proved its potential (Eisenbeiss, 2008); the paper shows how the fused dataset can support engineering geologic analysis.

Spreafico et al. (2015) used terrestrial laser scanning and close-range photogrammetry for monitoring landslide hazardous areas. They used the obtained 3D surface model to define structural features, to recognize fractured areas and to perform kinematic analyses. Westoby et al. (2012) showed the potential of the SFM (Structure-from-motion) technology through the example of surveying various landforms, including rocky coastal cliffs. Danzi et al. (2013) used UAV images for rockfall instability studies.

Site
The castle is located in Northern Hungary (Central Europe) between Mátra and Bükk mountains. Sirok castle is on the top of a steep rhyolite tuff hill (Fig. 1.). The first castle was built in the 13th century on the hilltop, however, since then several reconstructions and war damages caused major changes in the castle structure. Recently the castle walls are mostly ruined, but the ongoing restoration project aims at rebuilding the walls and parts of the castle buildings (Török et al. 2016).
Visitors can go around the castle’s south side on a path, this is a nice place to enjoy the view around and that of the castle from below. In 2014 rock falls have been observed, the responsible authorities closed the path and ordered the complex stability analysis of the cliff faces. The Miocene rhyolite tuff is very porous and thus sensitive to frost weathering. It showed severe signs of frost damage, loose pumice and other rock fragments and crumbling and micro-cracking were also observed. This in combination with the displacement along the joints caused the stability problems. In order to assess the slope stability the results of the site survey needed to show the details of the faults and joints as well as the centimetre-scale geometry of cliff faces.

Surveying

The surveying took place in February 2015, the vegetation was leafless at that time, although dense bushes and small trees still occluded the line-of-sight from the ground. The weather was clear, optimal for laser scanning but a bit windy for UAV flight.

Two scanners were used, Z+F Imager 5010C and Faro Focus 3D. The Focus 3D is a small, light scanner, easy to move and deploy, therefore this device was used from the top off the cliffs and on steep slopes. Both scanners have factory supplied tie points; planar markers for the Z+F and white spheres for the Faro. Besides, numerous additional markers as ground control points (GCP) were placed all over the area on locations clearly visible from the sky, these were measured by RTK GNSS receiver. In the post-processing phase these markers were used to join the laser scanned point clouds with UAV datasets. Table 1. shows the applied laser scanning parameters for both scanners.

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Z+F Imager 5010C</th>
<th>Faro Focus 3D 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers of scan stations</td>
<td>10</td>
<td>29</td>
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<tr>
<td>Resolution</td>
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<td>3 mm/10 m</td>
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<tr>
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<td>Color information</td>
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<td>Yes</td>
</tr>
<tr>
<td>Tie points</td>
<td>Checkerboards</td>
<td>Spheres</td>
</tr>
</tbody>
</table>

Table 1. Laser scanning parameters

The UAV flight was carried out by a DJI Phantom quadrocopter with a GoPro Hero3 action cam mounted on it; 1043 images were captured altogether. Due to the windy weather the UAV surveyed the area from a safe distance (Fig. 2.). Even though live stream was available, permanent visual contact was ensured during the flight.
Coloured point clouds of 39 scan stations and 1043 images of the UAV flight was captured within 8 hours, without disturbing the visitors or the castle’s personnel.

**Results**

The primary datasets are point clouds from the scanners and image sequences from the UAV measurements. Both point clouds were pre-processed separately and were joined in the geodetic reference system using the GCPs. As a result of densifying UAV images, point clouds and surface mesh models were produced. Since only a part of the observed area was covered by vegetation and it was practically leafless in the time of the measurements, the point cloud derived from UAV images ensured decent point density and coverage (Fig. 3.)

Laser scanning on the other hand suffered from occlusions caused by the vegetation and from the fragmented surface of the cliff faces. However, the point density and low noise level of the point cloud on the favourable parts enabled high resolution, accurate modelling and analysis. Point clouds derived from laser scanning and that of UAV have been registered and compared, our investigations show that the difference are within 1-2 centimetres on most parts, only vegetation covered areas result in differences higher than 4 centimetres. (Fig. 4.)
For the particular engineering geology analysis 2D CAD products, i.e. sections are to be derived. Horizontal and cross-sections have been derived directly from the point clouds and from the surface models. Besides on-site geological measurements aiming at deriving information on rock stability, the size, shape and location of the observed cliff segments are to be considered. As a result, geologists calculate and map stability zones and risk factors for rock-fall (Fig. 5.)

Geologists also prefer taking multiple images on-site, this pictures can be used in the future on demand, e.g. by checking the extension of a crack on the cliff face. The Faro scanner takes 85 images at each scan station that can be transformed to sphere-panoramic images during the post-processing. We developed a web-based application for 360° photo visualization that enables browsing and zooming all pictures taken on-site (Fig. 5.). This product is easy to share online and used on mobile devices.
Conclusion

In many cases one selected data acquisition technology cannot fulfil all the raised demands. In the project presented in this paper terrestrial laser scanning was complemented with UAV measurement; images captured from the sky ensured the coverage in areas occluded to terrestrial instruments. The presented investigations proved how the different 3D data acquisition methods can complement each other resulting a complete, high resolution point cloud and surface model. The provided accuracy and geometrical resolution supported detailed geological analysis by deriving various products, such as point clouds, 3D surface models, 2D CAD sections, and street view image sequences. In such outdoor scenes, that are hard to access and the site cannot be totally closed for public, the speed of the data acquisition has high priority: both laser scanning and UAV ensures the rapid surveying.

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References


