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Developing a robust workflow for acquisition of high-resolution full-3D cave topography, surface topography integration, and digital structural mapping

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Caves in karst are formed by corrosion and erosion of bedrock, therefore the 3D geometry of cave voids is a key information for understanding cave-forming processes. Cave surveying was revolutionized with the advent of 3D laser scanning, which, however, is hindered by the expense and limited portability of instrumentation, and the time-consuming registration of acquired point clouds. Consequently, only a limited amount of cave studies using full-3D laser surveying is published in the literature, and those are almost exclusively limited to easily accessible small caves, or short sections of larger caves.

We propose a new workflow for full-3D laser surveying of caves to overcome these problems and to increase accessibility of laser scanning technology to cave science. We use a highly portable, reasonably-priced Leica Geosystems BLK360 scanner, using a simple setup procedure at scanning stations, which makes this scanner extremely easy and fast to use in all kinds of cave environments. Leica Cyclone REGISTER 360 processing software with cloud-to-cloud matching algorithm is used to register overlapping point clouds; therefore, the complicated and time-consuming tie points registration is not needed. We evaluated the accuracy of our scanning method at several test sites and find it slightly lower than with using conventional TLS scanners, but still fully satisfactory for most cave science surveying purposes.

We demonstrate the usability of our workflow in the Kamnik cave, a 2 km long technically challenging Alpine-type cave in the Alps of northern Slovenia, requiring access with single-rope techniques and free climbing. We successfully acquired full-3D point cloud data in vertical shafts with up to 40 m drop and in narrow meandering canyons, features that to our knowledge were never scanned before in 3D for scientific purposes. The resulting point cloud of the entire cave with the average resolution of 5-10 mm comprises 3.3 trillion points captured from 219 scanning stations. Emerson Paradigm SKUA modeling software was used to interpret and model 3D structural surfaces, such as fault planes, fractures, and bedding planes, from the cave point cloud data. Supporting orientation measurements of structural features were made digitally in the cave using a tablet computer and MVE FieldMove geological mapping application. We additionally used a consumer-grade UAV to survey the rugged and well-exposed mountain terrain above the cave to produce a 3D surface model using Agisoft Photoscan SfM photogrammetric software. Ground control points around the cave entrance were used to tie the surface model to the 3D cave point cloud. The surface model was used to digitally map the outcropping fault planes and fracture zones, inaccessible to classical field mapping. Surface structural data were correlated with subsurface structures observed in the cave to better understand the 3D structural geometry of the area.

The resulting synthesis of all datasets – the full-3D cave topography point cloud, the subterranean structural surfaces measured in the cave and interpreted from the point cloud, and the surface topography model and its structural interpretation – facilitates unprecedented visualization and understanding of the structural control on cave geometry and its evolution.