# Geologic Mapping with Scaled 3D Images

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## Abstract

An important contribution to rock mass characterization is related to the mapping of discontinuities. Contact-free measuring principles tremendously improve conventional geologic mapping due to the ability to take measurements fast and consistently without access and time restrictions, as well as to provide objective records of the rock mass.

This paper describes an approach for rock face characterization using scaled three-dimensional images. Two digital photos taken with a zoom-lensed, calibrated off-the-shelf camera serve for a three-dimensional reconstruction of the rock face geometry. The related principles originate from computer vision, allowing highly-flexible picture taking and automatic image processing.

The rock face is represented on the computer by a photorealistic spatial representation – a 3D image. From it, measurements are taken by marking visible rock mass features, e.g. spatial orientations of joint surfaces and traces, as well as areas, lengths, or positions. Orientation measurements are depicted in hemispherical plots together with statistics on their spatial distribution and rock mass parameters such as joint spacing are provided. Two commercially available systems have been used for a variety of mapping projects proving their significant support to conventional field work.

Key words: 3D image, geologic mapping, rock mass characterization, photogrammetry, computer vision, discontinuity

## 1. Introduction

The acquisition of geometric information on rock discontinuities is an integral part of ground investigation of excavation and construction works. There is potential to enhance conventional geologic mapping due to existing access restrictions, sampling difficulties, human bias, and instrument errors. However remote (contact-free) data acquisition techniques provide several benefits, including:

- efficient, detailed, and accurate outcrop and discontinuity data acquisition, including orientation, geometry, and position;
- enhanced worker safety (e.g. avoiding personnel at the rock face threatened by rock falls);
- data archiving (permanent digital records are acquired allowing later assessments without time restrictions); and
- data base for further analyses, such as slope stability assessments or numerical simulations.

The idea of using photos for geologic mapping is straightforward and not new. Restrictions due to limited time and access were already identified and addressed by several authors, such as Linkwitz (1963), Rengers (1967), Hagan (1980), or Crosta (1997). These previous approaches showed the successful application of photos for supporting geologic mapping; however efforts were too high for reasonable and economic daily use.

Emerging digital imagery and mobile computing power at reasonable cost opened new possibilities as described more recently by Roberts & Poropat (2000), Gaich et al. (2004), or Haneberg (2006).

In the following, a brief introduction on the measuring principle is given, followed by the use of 3D images for geologic mapping, and ending with a brief description of case studies.

## 2. 3D image generation

### 2.1 Background

A 3D image is a combination of a real (digital) photograph with the geometric information on the objects it shows. In the actual cases the objects are rock faces and walls. The geometry of the exposed rock mass can be reconstructed from digital images using methods of Photogrammetry (Slama, 1980; Wolf & Dewitt, 2000). Stereoscopic photogrammetry deals with the measurement of three-dimensional information from two images showing the same object or surface but taken from different angles. This principle is also referred to as Shape from Stereo (see Figure 1). The geometric relationship between two corresponding points in a stereoscopic image pair is used to determine the position of the original object point in space. This requires accurate information on:

- the image formation process of the camera (interior orientation) – see below; and
- the camera position and angular orientation when taking the pictures (exterior orientation).

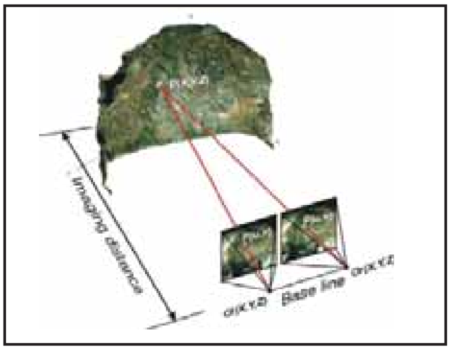

Figure 1. Shape from Stereo principle. From a pair of images taken from different angles the geometry of an object is reconstructed. Note that the determination of the baseline is not required when following the computer vision approach.

Historically, the first issue led to purpose-built cameras relying on mechanically accurate imaging (so-called metric cameras), thus being expensive. The second issue was handled either by observation of control points (points with known co-ordinates visible in the images) or by external measurements (Roberts & Poropat, 2000), which is elaborate.

Beyond undertaking classical photogrammetry, computer vision in the 1990's brought new algorithms and mathematics to the same topic (Faugeras, 1993). The computer vision approach had significant impacts on field handling and image data processing as it caused several improvements such as:

- Zoom lenses can be applied. This significantly eases the usability and increases the flexibility in the field;
- Pictures can be taken freehand. The relative orientation between two images is determined fully automatically without any control points;
- Generic 3D images can be computed fully automatically. There is no need for explicitly knowing or determining the interior and exterior camera orientation, i.e. generic 3D images can be generated from pictures of virtually any digital camera;
- Metric 3D images can be generated without information on the external orientation of the cameras. By observing an object with known size, a generic 3D image can be scaled to a metric 3D image and
- Simplified procedure for calibrating a camera, i.e. determination of the interior. The interior orientation comprises the focal length, the intersection of the optical axis with the image plane, and a description of the lens distortions.

### 2.2 Data acquisition

Utilizing the computer vision approach data acquisition on site comprises the following steps:

- Installation of reference elements:
  - o Either a range pole (a vertical pole with two targets mounted at a known distance) for local co-ordinate measurements or
  - o Installation ground control points (surveyed in a given co-ordinate system) for global co-ordinate measurements
- Taking two images (freehand) of the rock face from different positions ensuring the reference figure(s) being visible in both images. Measuring the length of the base line (see Figure 1) is not required. However, practical experience showed that this length should be approximately one fifth to one eight of the mean imaging distance and almost parallel to the strike of the face; and
- Calibration of the imaging system. Camera calibration is crucial for obtaining accurate results. Usually pre-calibrated cameras are used, thus this step can be skipped on site.

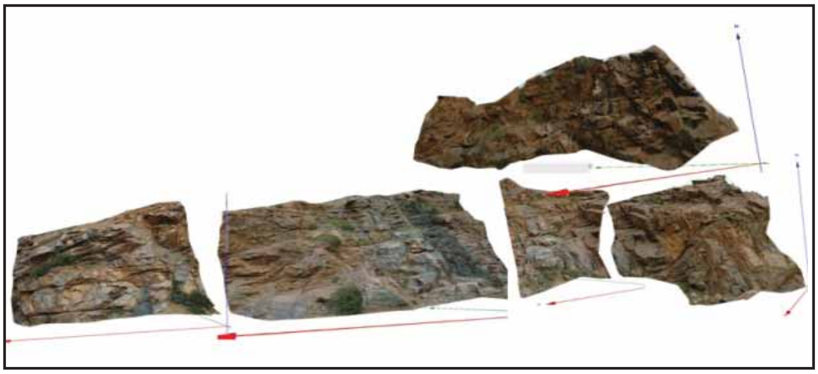

Figure 2. Several overlapping 3D images of a highway roadcut, Morrison, Colorado. All pictures were taken freehand without surveying any camera station.

### 2.3 Combination (merging) of 3D images

Practical tasks often involve dealing with large areas, complex shapes or high resolution, each of what go beyond the capabilities of a single stereoscopic image pair. In these cases, the rock wall is to be acquired by several overlapping 3D images. They are connected to a larger 3D model that allows for taking measurements (see Figures 2 and 3). During processing, common image information in the overlapping regions is used to determine a transformation from one 3D image to the next.

## 3. Assessment of 3D images for rock mass characterization

Once a 3D image is ready, measurements can be taken directly from it. A purpose-built 3D software component is used that allows rotating, panning, as well as zooming a 3D image in and out, thus allowing a thorough inspection. The photorealistic representation of the rock surface together with the three-dimensional shape provides a natural impression and allows for decisions on the geologic relevance of certain structures and their geometric properties.

In the following possible uses for geologic assessments are briefly addressed. They are subdivided into basic mapping features and higher level features, i.e. rock mass related properties and evaluations.

### 3.1 Basic mapping features

Geometric measurements are taken by placing graphical markers onto the 3D image. These markers denote points or regions of interest, e.g. visible discontinuity traces or discontinuity surfaces. All measurements taken from a 3D image are inherently three-dimensional in the given co-ordinate system. Point-based, line-based, and area-based items are available as basic mapping features.

### Co-ordinates and distances

Basic magnitudes are related to surface point measurements (x,y,z coordinates) and the determination of the Euclidean distance between arbitrarily chosen surface points which correlates to a virtual tape measure. By clicking on the designated position(s) the metric information is instantly provided.

Figure 3. Merged 3D image of Morrison site. Note that all subsequent analyses and measurements can be performed directly in the merged 3D image.

### Individual orientations

Any location on the 3D image can be touched with a spatial cursor that follows the actual 3D shape of the reconstructed surface. It changes its pointing direction according to the actual orientation of the surface (see Figure 4). In this way orientation measurements are taken which is comparable to the application of a compass-clinometer device on a particular location.

Figure 4. Orientations can be measured at arbitrary locations on the 3D image. Dip angle and dip direction are instantly provided.

### Linear features

The measurement of linear rock mass features such as joints, lithological borders, or strata is performed by marking discontinuity traces on the 3D image. A marked trace consists of sample points on the surface connected to a spatial line (a 3D poly-line). If the 3D poly-line shows a sufficient variation in depth, a plane is fitted automatically to the sample points. The orientation of the fitted plane corresponds to the spatial orientation of the discontinuity trace that has been marked, thus it determines the three-dimensional orientation of the linear feature (see Figure 5).

Figure 5. A discontinuity trace marked by a 3D poly-line. A plane is fitted through the sampling points. Its orientation corresponds with the orientation of the marked trace.

### Areas

Regions of similar geologic attributes (e.g. lithology or same degree of fracturing) or joint surfaces are marked with areas. An area is defined by marking a closed poly-line on the 3D surface. The enclosed parts of the 3D surface are used to compute the mean orientation which is instantly provided by dip angle and dip direction. Figure 6 depicts an example of a marked area and the resulting surface normal indicating the spatial orientation of that area.

Figure 6: Measurement of orientations at joint surfaces. By marking points and calculating the mean orientation of the surface normal the orientation vector is determined. Additionally, it delivers the size of the area.

## 3.2 Higher level features

From the basic measurements several higher level features are derived with the aim of obtaining descriptive rock mass parameters. Basically, all rock mass parameters based on geometric information of rock structures can be determined.

### Structure maps

Basic features, such as joints and areas, orientations, as well as co-ordinates, or distances are assigned to structure sets that represent geologic units, e.g. a discontinuity set. Figure 7 shows an example of a 3D image with several structure sets marked.

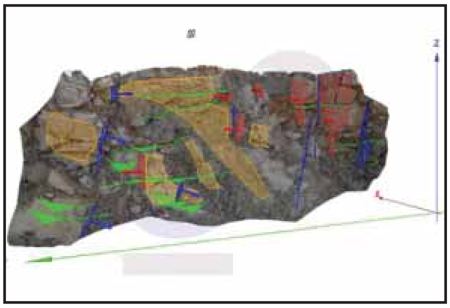

Figure 7: Snapshot of the software JMX Analyst used for interactive assessment of 3D images and the determination of descriptive rock mass parameters.

All structure sets together form a structure map.

### 3.2.1 Hemispherical plots

The measurements taken from the 3D image are grouped to sets by the operator. Each set is instantly visualized within a hemispherical plot (stereonet) in order to get an instant impression of the spatial distribution of the orientation measurements assigned to a set (see Figure 11). Since measured structures can be touched either within the 3D view or from the hemispherical plot, the proper assignment to sets is supported.

Calculated statistical parameters on the spatial distribution of a structure set include the spherical aperture, concentration (Fisher's constant), and the cone of confidence. The output is instantly updated when new orientation measurements are applied.

### Spacing

Structure maps inherently contain the lengths and spacing of traces. Spacing is referred to as set spacing, normal set spacing, and total spacing according to definitions given in the textbook by Priest (1993).

The software features two possible methods for calculating spacing. The first one is similar to conventional scan line mapping: the user places a virtual scan line on the 3D image and the software calculates spacing values of the intersected joints. The second method is a kind of multiple scan line spacing: traces of an entire structure set are projected onto a reference plane. The distances between adjacent discontinuities are determined along scan lines perpendicular to the mean orientation. Figure 10 shows an example of multiple scan line spacing. In includes an automatically generated sketch that is also used for visually reviewing the spacing calculation.

### Surface Roughness

3D images at a sufficiently high resolution can be used for obtaining discontinuity roughness values. The required resolution for measuring discontinuity roughness is not a fixed value, but depends on the scale of analysis (looking at waviness requires less resolution than analyzing roughness). Figure 8, for instance, shows a roughness profile along a discontinuity plane. The point density of the corresponding 3D image is approximately1.2 pts/cm2. The obtained roughness profiles can then be compared with standardized profiles (ISRM, 1978).

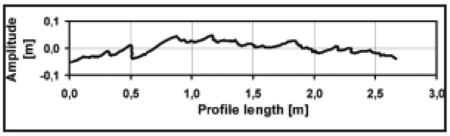

Figure 8: Roughness profile evaluated from a 3D image. The point density is approximately 1.2 pts/cm2

## 4. Applications

In the following, case studies using the commercial systems ShapeMetriX3D and JointMetriX3D are briefly touched upon in order to highlight the capabilities of the 3D imaging technology.

### 4.1 Rock slope

The stability of a rock slope with a height of about 150 m was assessed. Several parts were inaccessible, so contact-free measurements proved to be a proper way to gather reasonable quantitative geometric information on the discontinuity network and the free surface.

A highly detailed 3D image (70 megapixels) was generated in order to allow a geologic assessment also of smaller structures. Figure 9, Figure 10 and Figure 11 show the achieved results of the 3D imaging and assessment activities using the ShapeMetriX3D software. Within the software measured orientations are instantly displayed together with statistics on their spatial distribution. Furthermore spacing and joint length statistics are provided.

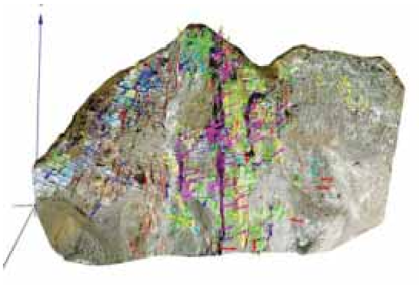

Figure 9. Application of 3D imaging technology for the analysis of a 150 m rock slope.

### 4.2 Tunnel face mapping

In conventional tunnelling, face mapping has to be performed quickly. Two photos of the tunnel face can be taken within a minute without significant disruption of excavation works (cf. Gaich et al. 2004). This provides the geologists with more time on site for the analysis of other parameters as the actual geometry is already captured.

Assessments (see Figure 12) are performed on the computer without further time and access restrictions. Subsequent 3D images of tunnel faces (see Figure 13) represent an objective, reproducible record of the rock mass conditions encountered during excavation delivering a good data base for any later review of a project.

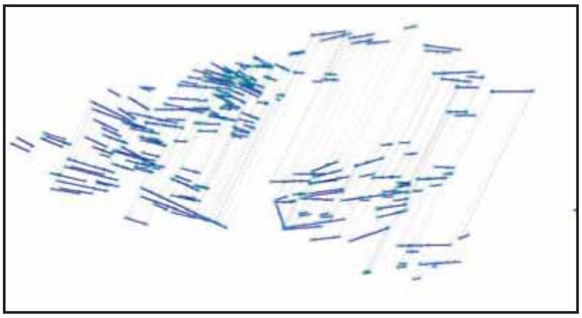

Figure 10: Computer generated sketch of joint traces for one set together with statistics for determining normal spacing and joint frequency

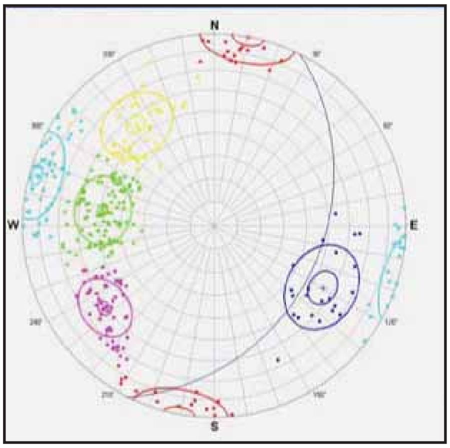

Figure 11: Lower hemisphere equal-area projection polar plot of identified discontinuity sets.

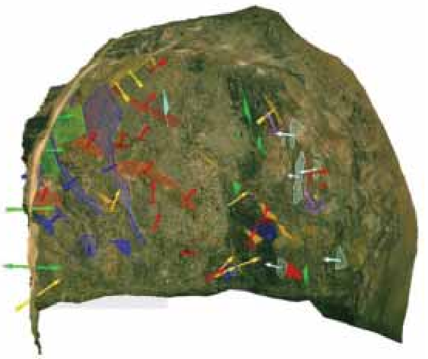

Figure 12: 3D image of a tunnel face (cross section about 25 m2) with main features mapped.

## 5. Conclusion

3D imaging is a powerful technology for the documentation and characterization of exposed rock faces. Using only two images of a calibrated imaging system together with a reference figure allows generating a scaled 3D image of the observed rock face for both visualizing the actual conditions and obtaining accurate measurements on rock structures. 3D imaging based on computer vision is easy to use, can be handled by one person, involves only light-weight equipment, and avoids operator hazards due to its remote application.

It can be used from close range (below 1 m) to large distances (beyond 1,500 m) on the surface and underground. Applications include documentation of the encountered rock mass conditions, support of geologic mapping and rock mass characterization, or discontinuity and keyblock analysis. Practitioners and engineers may explore additional applications of this technology.

3D imaging with according assessment software will have a significant impact on the current analysis and design practice in rock engineering. However, these tools are intended as a support and not a substitute to conventional field work.

Figure 13: Subsequent 3D images of a drift tunnel excavation in an underground marble mine.

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