

# CONTACT-FREE MEASUREMENT OF ROCK MASS STRUCTURES USING THE JOINTMETRIX3D SYSTEM

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**Abstract:** JointMetriX3D is a novel system for measuring rock mass structures without physical contact. Using a special digital camera, two images of a rock face are taken and then processed by specific software components which results in a 3D image that represents a highly detailed, metrically correct model of the rock surface. Special software enables an assessment of the 3D image by quantifying discontinuity orientations, spacing, trace lengths, or areas with no longer need for manual access. This principle increases the safety for the data collection process, improves the quality of the acquired data, and reduces cost. Besides, the 3D image is a comprehensive documentation or conservation of evidence enabling also later assessments. The system was applied at tunnel sites, a subsurface mine, as well as several quarries in Austria and might have the potential to become a standard procedure for structural data collection, especially when having difficult rock mass situations.

**Keywords:** Discontinuity orientation, rock mass characterisation, stability analysis.

## 1. INTRODUCTION

Rock mass characterisation comprises to establish a geometric model of the rock mass including its discontinuity network. The measurement of the discontinuities commonly requires physical contact in order to apply a compass-clinometre device and a tape-measure. As there are regions with difficult or even hazardous access, measurements often cannot be taken as requested. It might take considerable time to get access to all relevant measurement locations which is sometimes problematic or in any case costly.

This led to several attempts in the past to measure structural rock mass parameters without physical contact, e.g. from images. Among those, Linkwitz (1963) and Rengers (1967) used a photo theodolite and a stereoscope to measure points from a rock surface deriving discontinuity orientations. Both showed that measurements in inaccessible regions become possible and claimed a more reliable analysis over large areas. Hagan (1980) used a stereoscopic camera frame for orientation measurement and applied that successfully in underground mines.

A more recent approach applying the same principle but using digital images and automatic procedures to assess the images is described by Roberts & Poropat (2000). It showed that orientation measurements for mapping a high rock wall can be derived from standard digital images.

Feng (2001) and Kemeny et al. (2003) proposed to use a laser scanning system to get 3D measurements of fracture orientations by computing 3D surface patches from a number of single point measurements. This active measuring principle showed that orientations can be quantified by a bunch of 3D surface points. Up to now laser scanning lacks from providing a good image of the rock face that allows the identification of structural details.

Conversely it is possible to start from at least two images and get 3D surface points from it. Draping the image on the surface leads to a 3D image. Several descriptions for structural evaluations of images were given, such as interactive ones (Crosta, 1997) or automatic (Reid & Harrison, 2000) detections. However, it is emphasized that high quality visual data is the key

for a useful structural analyses. The goal therefore is an image that gives a similar impression to the operator as being directly in front of the rock face with no access limitations and the possibility to measure on the image.

## 2. THE JOINTMETRIX3D APPROACH

JointMetriX3D is a system consisting of a hardware for data acquisition and a software component that allows the image analyses. The system produces high resolution 3D images that are assessed on the computer (see fig. 1).

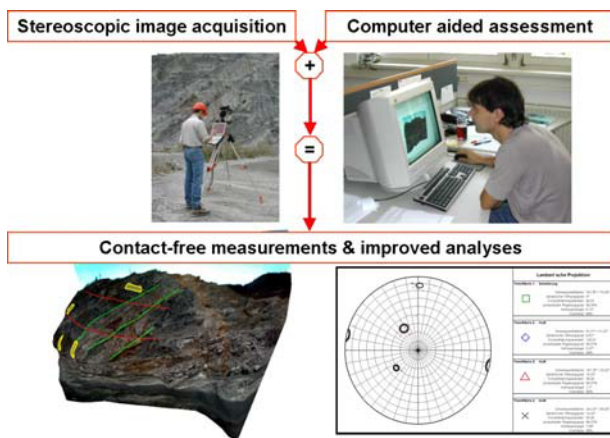


Figure 1. JointMetriX3D principle: high resolution 3D imaging and geotechnical assessment software.

### 2.1. System description

The hardware component of JointMetriX3D is an imaging system, basically a digital panoramic camera on a tripod connected to a controlling notebook computer. The panoramic camera solves a contraction present for commonly used cameras that follows perspective projection geometry: It allows to generate images with small angle of view (i.e. showing fine details) in one image direction and a large field of view in the other one as the camera is rotated during imaging, thus scanning the surrounding column by column. With this principle even 360° full panoramic views can be established with single images having about 100 Megapixel, a value clearly beyond present high end digital cameras.

Following example points out the resolution capabilities of the panoramic camera: consider a rock face with 250 m height and 400 m width. One single panoramic image of the whole face will show a geometric resolution of 5 cm/pixel.

For the geotechnical data collection procedure two images of the rock face taken from different angles are required. As a rule of thumb the distance between the two camera standpoints in relation to the rock face distance should be around 1:5. This ensures a proper perspective change of the rock surface within the image pair which is the basic requirement for the computation of the 3D image.

### 2.2. 3D image computation

The basic geometric arrangement for the very well known shape from stereo principle is shown in figure 2.

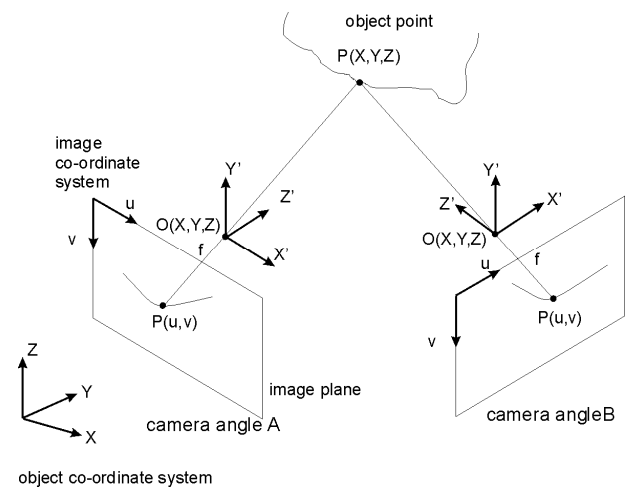


Figure 2. The shape from stereoscopic images principle is used for the reconstruction of the rock face. A corresponding pair of image points  $P(u,v)$  and the known camera orientations lead to a reconstructed object point  $P(X,Y,Z)$ .

Following prerequisites are required to finally allow a reconstruction of the object by a 3D image:

- **Mathematic camera model:** It describes how an object point is projected into the camera forming an image. As this is a mapping from 3D to 2D, there is an implicit loss of information within this procedure, which is also the reason for the requirement of a second image. Based on the camera model, the calibration of the camera takes place, i.e. the determination of the deviations that the real camera from its (ideal) mathematical model has.
- **Interior camera orientation:** this includes the focal length, the axis of rotation, the principal point, and the correction of lens distortions.

- *Exterior camera orientation*: this is the pose of the camera when the image is taken with respect to a given external co-ordinate system. The exterior orientation can be described by six parameters, three for the location of the centre of projection and three for the rotation of the camera frame within the object co-ordinate system (Slama, 1980). The exterior orientation is usually determined by the observation of points with known co-ordinates in the object system (so-called control points). Having at least six control points within a single image the exterior camera orientation can be rigidly determined.
- More recent camera description approaches within the computer vision community also combine the interior and exterior camera orientation within a single projective camera model without explicit knowledge of the single parameters but sufficient information for reconstructing a surface (Hartley & Zisserman, 2001)
- *Point correspondences*: this computationally expensive step, also known as image matching, is the task to search for a high amount of image points that correspond to each other within the image pair. Several strategies were proposed in the past differing in the density of the found positions, their accuracy, or computation performance, (Faugeras, 1993, Sonka, 1999).
- *Triangulation*: Once the camera orientations and corresponding points are known, the 3D reconstruction by intersecting viewing rays are possible. One single viewing ray is defined by connecting the centre of projection with the image point and going out into the object space. By intersecting this ray with its corresponding counterpart a point in 3D is found. For every point correspondence, a 3D point is reconstructed which leads to a bunch of points densely distributed over the object surface.
- *Mesh generation*: The next step is to connect the points with each other resulting in a surface description. The generation of triangular irregular networks is widely used for that procedure.
- *Texture mapping*: The last step is the geometrically correct overlay of one image from the stereoscopic pair the model bases on with the reconstructed surface which finally leads to the 3D image.

## 2.3 Geometric features

The previous stage delivers a high resolution 3D image. Little user interaction is required for that. The next task is the assessment of the rock surface model formed by the 3D image and the determination of rock mass parameters. This should be done by the same person that does the field work and can be seen as an extension to that. The assessment software component provides several tools for the structural analysis process. Briefly following items can be annotated on the 3D image:

- *Discontinuity traces* following the surface represented by polygonal lines
- Freely definable *area patches* represented as transparent overlays on the surface model
- *Discontinuity orientations* displayed as surface normals and defined by dip and dip direction.
- *Virtual tape measurements*
- Definition of *joint bridges* used for statistical descriptions
- *Reference planes* on which a discontinuity set can be projected if needed.

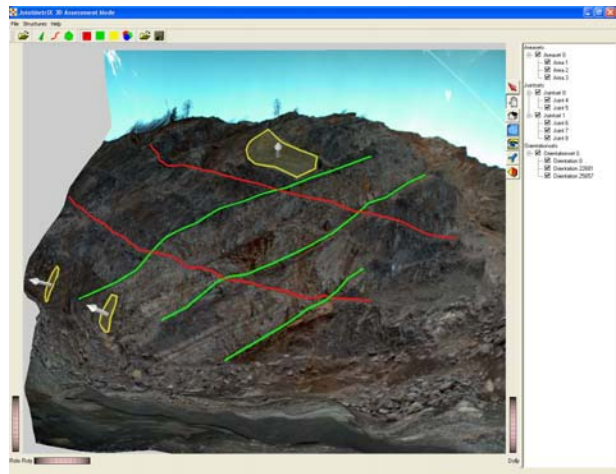


Figure 3. Snapshot of quarry assessment.

Figure 3 gives an example for a simple assessment of a quarry. It shows some discontinuity traces, some area patches, as well as orientation measurements. An easy-to-use mechanism allows a grouping of the single structural measurements to sets that are statistically evaluated. For example distributions of trace lengths, bridges, or spacing is possible.

## 2.4 Discontinuity orientations

Special attention is paid to the quantification of discontinuity orientations as this is seen as a very advantageous measurement feature of the system. The principle behind is a cursor, that visualises the normal vector of the surface, moved by the user along the 3D image. This “surface cursor” is placed on a location where an orientation should be determined by moving a computer mouse and the values for dip and dip direction are available simultaneously. The perspective view of the 3D image itself and the measured orientations can also be freely chosen, as well as the observation scale by zooming. Figure 4 shows a part of a 3D image with two orientation measurements.

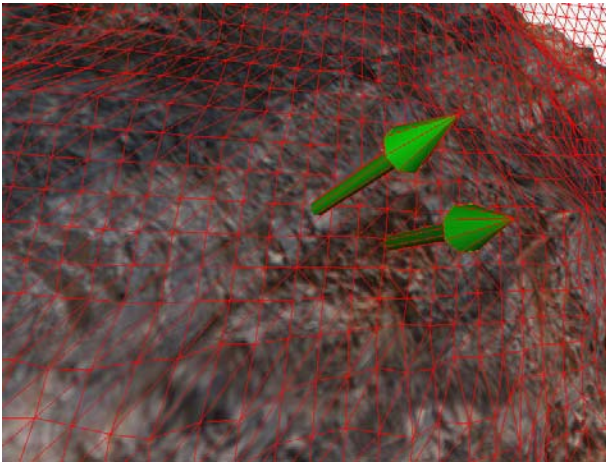


Figure 4. The orientation measurement uses a cursor (arrow) that is moved along the surface. Note that in the given example the surface mesh was made coarser in order to visualise the principle.

The orientation measurement relies on a dense point cloud forming the 3D image. The closer the surface points are to each other, the smaller is the area patch needed to apply the surface cursor properly.

At every measurement location six values are delivered, three for the orientation of the surface normal and three for the location on the surface. The surface normal can be transformed into a dip, dip-direction pair on the fly, if a relationship to the geographic north is existing. Otherwise relative orientation measurements are resulting.

### *Orientations from joint traces*

If the rock face itself deviates considerably from a plane and a discontinuity is planar (and not folded), it becomes possible to determine orientations only from the observation of joint

traces. The reason is that the observed structure follows the 3D surface which allows to determine a best fit plane which coincides with the discontinuity plane.

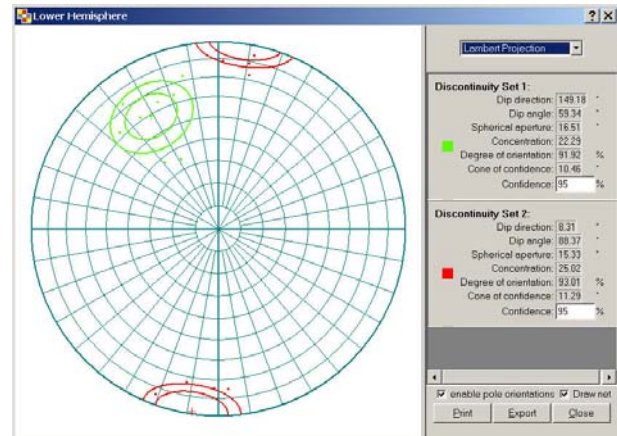


Figure 5. Stereoplot of two discontinuity orientation sets. An arbitrary number of sets can be defined.

## 3. APPLICATIONS

JointMetriX3D is useful in any rock engineering project where a good rock mass model is required, when there is a difficult access or little time to take the measurements. Applications implemented so far are given in the following paragraphs.

### 4.1. Quarrying and underground mining

When applying a compass-clinometre device the operator usually determines those locations with the steepest inclination by visual examination. For slightly dipping discontinuities the visual judgement on the steepest inclination becomes even harder which leads to misinterpretations. The same applies when the rock face gets larger and overview might get lost.

This is avoided by evaluating the 3D image on the computer: The point of view can be quickly changed and the relevant features can be identified easily. The larger and/or less accessible the quarry is, the more advantageous is the system.

The data acquired by the system in a quarry can be used in various ways concerning the excavation planning:

- The general layout of a mine or quarry walls, especially their orientation and inclination in relation to main discontinuities can be controlled systematically.

- The acquired data can be directly used for identifying potential failure modes, and stability assessments of the face, berms, or the whole structure (see also paragraph 4)
- Taking images periodically it is possible to compute a difference between reconstructed surfaces which equals to the excavated volume.
- The comprehensive and periodical documentation of quarries enables the optimisation of blasting patterns as well as the selective exploitation concerning for example the mining of controlled rock block sizes, or different material types and qualities.

#### 4.2. Tunnelling

The panoramic camera used within the system shows an additional benefit when applied at (conventional) tunnel sites. As images of 360° field of view can be taken, it becomes possible to image the tunnel face and existing displacement monitoring targets in the already excavated area within one single panorama. Using the targets as control points, the exterior camera orientation is determined by spatial resection, a very well known principle from photogrammetry (Slama, 1980).

A typical 3D image of a tunnel face has a geometric resolution of 2-3 mm/Pixel, thus also fine structures are captured in the image. Doing this each excavation round, one gets a *comprehensive documentation* of the present rock mass structures, instantly available on site which facilitates the optimisation of excavation and support measures, as well as conserves the evidence helpful in claim management.

Another aspect is that critical situations can be discussed together with an expert even if he/she is not on site, as the 3D visualisation of the actual conditions enables a proper impression. This way a remote geotechnical support is possible, although it is clearly stressed, that a local survey on site cannot be replaced by the system, but strongly supported.

#### 4.3. Other

The measurement system can be used to provide the basis for *stability analyses* of slopes and scarps. Having a usually simple data acquisition phase, relevant orientation measurements can be performed which leads to a geometric model that is then processed with already existing stability assessment tools.

For *conservation of evidence* the system also was applied. In one case there was the need to record the actual condition of safety and outlet

tunnels of a hydropower station. Due to the detailed images small cracks in the concrete shell were documented safely and objectively.

#### 4. FURTHER ACTIVITIES

The recorded 3D model and discontinuity data can be used for further rock mass analyses. Tools are presently developed. The following gives a kind of procedure for the analysis of rock slopes:

- The first step includes the determination of blocks within the discontinuity network. Directed traces allow the identification of finite and removable blocks or block assemblies under arbitrary slope surfaces.
- The next step is to distinguish between the potential failure modes of the removable blocks (mode analysis). Translational failure modes can be identified by the analysis of the joint and block pyramid of the corresponding block (Goodman & Shi, 1985). Subsequently the block is investigated with respect to its ability for rotational movements.
- Once the potential failure modes have been determined, the forces acting on the block for the stability assessment need to be defined. They result from the weight of the block, dynamic impacts, joint water pressures, rock mass stresses, construction measures, and joint resistance. In rock slope analyses blocks typically are considered to be non-restricted concerning its displacements. The stability assessment results in a relation between resistant and driving forces which are determined according to the incremental displacement vector from the mode analysis. This relation definitely indicates whether the block is stable or fails.
- To account for the scatter of the geotechnical data this procedure can be performed probabilistically. Typical parameters describable by a probability distribution are, among others, the orientation of joints, the joints' roughness, or boundary conditions, all implicitly determinable with JointMetriX3D.
- This altogether leads to the probability of failure for an investigated block which serves as a decision aid for construction measures or risk analyses for rock fall hazards.

## 5. CONCLUSION

JointMetriX3D is a documentation and measurement system that allows contact-free measurements of structural rock mass parameters. Discontinuity orientations, as well as distances and areas are quantified with it. Utilising a digital camera, a high resolution 3D image of a rock face is generated and used for interactive analyses of the visible rock mass structures. Photogrammetric principles are used to reference the 3D image to a given object co-ordinate system.

The system delivers a detailed documentation of the actual rock mass conditions and preserves that for later analyses and measurements. The indirect measuring principle itself is especially beneficial at rock faces with difficult or dangerous access, or if there is little time for the survey on site. Increased data quality optimises excavation planning. Besides, the objective data basis enables later review or, through its three-dimensionality, even supports a rock mass assessment from a remote place.

The system can be used for different applications where geometric rock mass data are required, such as tunnelling or mining, as well as in quarries or for dams. The resulting data are also useful for additional analysis steps, for example investigating the stability of rock slopes. The objective data basis provided by the 3D images of JointMetriX3D and the assessment software tailored for geotechnical needs may support a new quality standard for rock mass descriptions.

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