Measurement and assessment of rock and terrain surfaces by metric 3D images
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1 ShapeMetriX3D - Overview

ShapeMetriX3D is an innovative System to measure and assess surfaces using three-dimensional images on basis of digital photos taken freehand. In particular rock surfaces and their geological/geotechnical evaluation are addressed. ShapeMetriX3D is not designed to be software for photogrammetry users but rather a system supporting to solve questions from engineering geology, geotechnics, and geometry in general.

For data acquisition a standard digital camera is used which is calibrated by software from 3GSM. With the calibrated camera the designated area is imaged from two different angles. Only a range pole must be placed in the imaging area in beforehand (see Figure 1) – the time need for the complete data acquisition process (establishment of range pole, taking two pictures) is about some minutes.

Common applications are within tunnelling, mining, geotechnical engineering, and for different kind of documentation. An important characteristic of ShapeMetriX3D is that a 3D assessment software component is included.

ShapeMetriX3D is complete system comprising a calibrated imaging system and 3D processing software.

![Figure 1: Stereoscopic image pair of a tunnel face. A marking element providing scale is highlighted.](image)

After data acquisition the images are transferred to a standard PC and processed into a three-dimensional image using the SMX Reconstructor software. The used principle is stereo-photogrammetry with certain extensions from computer vision, such as having no need for explicit reference markers to determine the relative orientation of the images among each other.

Fundamentally the used principle is scalable which means that surfaces of various sizes can be imaged and processed to 3D images. However, a fundamental requirement is that the surface must show certain irregular structure (texture).

The result is a 3D image that represents the shape of the recorded surface (refer to the name of the system). From the 3D image, measurements can be taken and assessments performed using the provided 3D software.
Figure 2: 3D image of a tunnel face.

Main **distinctions to conventional documentation:**

1. Rock mass conditions are represented objectively and reproducible
2. There are no access problems and no pressure of time for the assessment
3. Metric measurements (lengths, distances, areas) are possible
4. Measurement of orientations are enabled (dip and dip direction)
5. Derived properties, such as spacing can be determined directly

Main **distinctions to conventional surveying:**

1. A 3D image is not an (abstract) bunch of 3D surface measurements but a real image with hundreds of thousands assigned measurements behind.
2. No special skills for data acquisition required (use of a digital camera)

Main **distinctions to similar systems:**

1. Free hand photo taking (no tripod)
2. Support of zoom lens
3. No photogrammetry knowledge required
Figure 3: Principle of the three-dimensional surface measurement. From the determined orientation between the two images and a pair of corresponding image points $P(u,v)$ imaging rays (red) are reconstructed whose intersection lead to a 3D surface point $P(X,Y,Z)$. This procedure is repeated for a dense grid of 3D measuring points which are connected then to 3D surface model. Overlaying one image with the 3D surface model leads to a 3D image. Note that the baseline and the camera locations do not need to be surveyed.

This kind of 3D imaging results in a local co-ordinate system of no other information is provided. However, a registration using existing objects (such as e.g. arcs in the case of a tunnel) is possible.

A coarse alignment to geographic north becomes possible based on a single compass reading.

If geo-referencing is required then at least three (control) points with known co-ordinates within the imaging area are used (surveyed e.g. by total station or accurate GPS). The final result is then transformed into the co-ordinate system of the control points.
Figure 4: 3D image of a bench face in a quarry (a). The result consists of a dense set of 3D point measurements (b) plus the photo. Using the integrated 3D assessment tools geological mapping can be done simple and contact-free (d). Hemispherical plots (e) as well as the determination of spacing (f) allow for an instant assessment of the rock face.
Figure 5: Data acquisition on site consists simply on establishing a range pole and taking images with the calibrated camera.
2 Fusion of several 3D images

Sometimes it is not possible to acquire the whole measurement area at sufficient resolution with a single stereoscopic image pair. In that case several partial views are merged together to an overall 3D model.

There is no need for special markers to merge several views – the only requirement is that images show overlapping areas.

![Figure 6: ModelMerger principle – from overlapping 3D images a merged 3D image is generated.](image)

2.1 Long rock walls and complex shapes

Long or high rock walls are acquired several overlapping image pairs where photos are taken at high flexibility. Long walls include lengths of more than 1.000 metres.
Figure 7: Long wall in an open pit mine captured by 12 photographs.

Figure 8: Corner situation captured by 6 photographs.
2.2 Tunnel face patches

For merging tunnel face patches each of the single views should show the whole tunnel face. It is important also to covers a portion (some metres) of the tunnel walls which is used to detect a relationship between the single views. This way several patches can be merged to single 3D image of a tunnel face allowing an assessment and measurements of the whole structure which is not possible in the field.

*Figure 9: 3D images of a tunnel face. The 3D images are referenced to each other thus can be used for measurements in a common co-ordinate system (top). Resulting 3D image of the merged tunnel face images (bottom)*
2.3 Increase of resolution

When taking additional photos of smaller areas, resolution is increased significantly without needing additional hardware. This is used for example for roughness analyses or detailed geological mapping.

Figure 10: In this case the merge of the detailed 3D image increases the resolution by 5 times without the need for additional field equipment.

2.4 Mining stopes

The significant advantage of merged 3D images from underground is that they unite data on the excavated geometry/volume with a good capture of the rock surface hence allowing for comprehensive geological mapping on the computer.

Figure 11: 3D image taken in a drift tunnel in an underground mine. In addition to the tunnel face also sidewalls and crown (and if required also springlines) are photographed.
2.5 Combining consecutive 3D images (tunnelling)

3D images of several tunnel faces as arising during excavation can be referenced to each other without any externally measured reference points just by elements that are visible in the single 3D views. For higher accuracy geodetically measured markers are used bringing each 3D image of a tunnel face into the tunnel co-ordinate system.

Figure 12: Consecutive 3D images of tunnel faces arranged along the tunnel axis.

2.6 Determination of volumes

The difference between two 3D images corresponds directly to the volume difference originating e.g. from excavation, exploitation, or movements. Volume calculations may performed by exporting geometry data from ShapeMetriX3D (e.g. via DXF) and using third party software or more recently using 3GSM’s own volume calculation possibilities.
Figure 13: Snapshot of 3GSM’s BlastVolumeCalculator software outlining the volumetric difference of two subsequently imaged surfaces.

3 Results

Generally, geometrical parameters can be determined from 3D images. Using the included 3D software JMX Analyst an interactive inspection of a 3D image and appropriate assessments become possible.

Geometrical and geotechnical measurements:

- Length (distances, intervals) in m
- Area in m²
- Spatial orientation of discontinuity surfaces or whole rock wall areas (dip and dip direction)
- Spatial orientation of discontinuity traces or geological strata (dip and dip direction)

Derived parameters:

- Spacing (mean, normal, set, total)
- Spacing along definable scanline.
- Discontinuity frequency in traces/m
- Spatial variation of a discontinuity set
- Volume in m³
Data export:
- 3D image directly into VRML and OBJ
- Geometry directly into CAD (DXF)
- Measurements directly into MS Excel (CSV) and CAD (DXF)
- Snapshots of 3D image (JPG)

Figure 14: 3D image of a rock wall taken in an open pit with automatically grown joint surfaces.
Figure 15: Integrated assessments such as hemispherical plots and statistical parameters on orientation distributions (top left), determination of spacing (top right), contour plots (bottom left), or definable sections (bottom right).
4 Application examples

Tunnelling:
- Digital tunnel face documentation
- Geotechnical data acquisition
- Claim management, conservation of evidence

Underground mining
- Deformation monitoring
- Geotechnical data acquisition
- Assessment of pillars

Surface mining
- Update of mine maps
- Determination of excavated volumes
- Stability assessment (e.g. rock slopes)

Geotechnics
- Determination of roughness coefficients
- Laboratory and in situ
5 Main benefits at a glance

- Mobile contact-free rock wall measurement without requiring surveying skills or instrumentation
- Simple and flexible application (taking pictures freehand with zoom lens camera)
- Fast and safe data acquisition (large coverage)
- Reproducible description of rock mass conditions
- System is not only a measuring device but provides also a software tool for doing assessments
- Combines nicely with a bench face surveying and blast planning software (BlastMetriX3D)

6 Specifications

| Imaging system | Several SLR cameras available (Nikon D90, D300s, Canon EOS 5D Mark III); other models on request  
|                | Several lens options  
|                | Range pole, Calibration target  
|                | Imaging system is offered in a watertight dust-proof case |
| Extras         | Several lens and software options  
|                | Tripod (for underground use)  
|                | Ground control point targets (for georeferencing) |
| Calibration    | Camera is calibrated on delivery – calibration status can be checked anytime by taking images of the included calibration target and software |
| Geo-referencing| Requires at least 3 control points (points with surveyed co-ordinates) in the imaging area or 1 control point in the imaging area and 2 surveyed camera positions |
| 3D reconstruction | Using SMX Reconstructor software or by 3GSM as a service |
| Results        | Vertically referenced, metric 3D images in local or referenced co-ordinates |
| 3D inspection  | Using the included JMX Analyst software |
| 3D measurements | Using the included JMX Analyst software |
| Data link      | Export of the surface geometry as DXF (AutoCAD), VRML, OBJ, XYZ  
|                | Export of the measurements as CSV (MS Excel), DXF, TXT |
| Accuracy       | cm range for typical applications; smaller for close range applications |

Subject to change without notice