INDIRECT MEASUREMENT OF STRUCTURAL ROCK MASS PARAMETERS BASED ON A COMPUTER VISION SYSTEM

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ABSTRACT
A computer vision system based on digital panoramic images is used to overcome current problems in geotechnical data acquisition. High resolution images enable spatial measurement of geometric entities of a rock mass, like discontinuity lengths, the size of a region, discontinuity orientations, and roughness parameters. Besides, the images represent an objective documentation of the visual rock mass conditions. A system based a digital panoramic camera was tested on tunnel construction sites and quarries in Austria.

1. INTRODUCTION

The collection and evaluation of geotechnical data is vital for any rock mechanical analysis. Present field work often relies on measurements using compass-clinometer devices and measuring tapes combined with manual sketches and eventually conventional photographs. This requires tactile access to the exposed rock mass which can be hazardous and time-consuming (Fasching 2000). Besides, this data acquisition process is strongly subjective and, what is even more problematic, it is not a comprehensive documentation of the rock mass. If for any reason the rock mass is altered, e.g. by erosion or excavation work, the original conditions are lost. However, the actual rock mass conditions are preserved, if visual data at a sufficient quality are acquired (Gaich 2000).

Generally, the results from current geotechnical data acquisition are incomplete, mostly incorrect (due they do not have metrics), and often inconsistent. Anyhow, further rock mass analyses rely on these data.

2. A COMPUTER VISION APPROACH

Computer vision can be understood as connecting a computer with (digital) cameras and processing the images on it in order to get information on the recorded scene or objects. Three-dimensional computer vision (3d vision) is inspired by human perception and tries either to reconstruct objects from images or to understand the contents of a scene (Sonka et al. 1999). Figure 1 outlines the approach. An imaging system is used to generate high quality digital images. The images are processed with software components that allow an automatic reconstruction of the three-dimensional shape (surface) and to interactively annotate rock mass structures by means of a stereoscopic inspection tool.

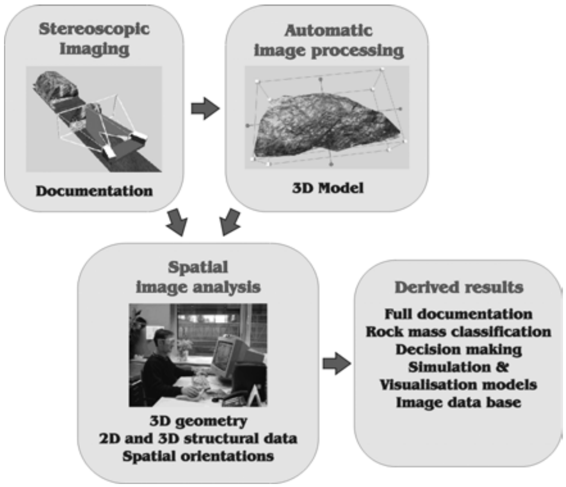

Figure 1: Computer vision principle: a panoramic camera records the rock mass. The images are evaluated by a combination of automatic and interactive processing steps which finally leads to rock mass parameters.

Various approaches for 3d vision systems were introduced in the past and many algorithms were established (Faugeras 1993) and it showed to be no universal solution for the manifold applications which themselves are strongly liable for the configuration of a 3d vision system and the used principles. As one can imagine the image quality is an essential design criterion for a computer vision system.

However, for geotechnical applications the structural data acquisition process should fulfil some basic requirements:

- Instant image processing directly at the site which brings the need for digital images
- Image resolution of about 2-3 mm on the rock surface (object space) to identify smaller structures which requires image sizes beyond customary digital cameras
- Colour information to identify lithological borders
- Stereoscopic camera configuration which is the basis for metrics
- Metric measurements with an accuracy in the cm-range
- Determination of the camera orientations which allows measurements in relation to the surroundings
- Data acquisition within minutes, important e.g. at tunnel construction sites

3. THE PANORAMIC IMAGING SYSTEM

3.1 System description

The imaging source is a digital panoramic line-scan camera. It has a single CCD-line sensor for each of the three colour channels and has to be rotated in order to get an image. This scanning principle implies that only static scenes or objects can be recorded. The camera is mounted on a tripod and controlled by standard notebook computer that is evetually adapted for the application in rough environments.

The whole system weighs less that 10 kilogramme, thus is can be transported and set up by a single person easily. No external power supply is needed, but an additional light source must be provided if the system is used in a subsurface environment. Figure 2 shows a photograph of an application at a tunnel site.

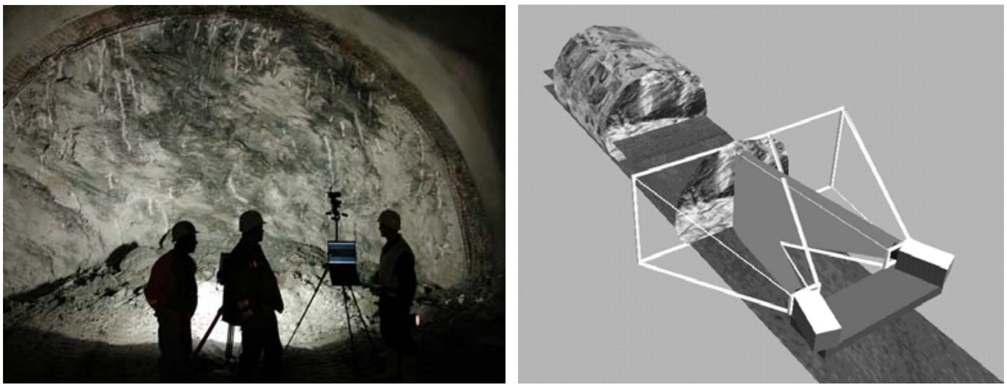

Figure 2. Imaging system consisting of a digital panoramic camera used at the Unterwald tunnel construction site, Austria (left). Basic configuration for spatial measurement needs two images from different standpoints (right).

3.2 Image quality

A panoramic camera allows to solve a contradiction: it combines high resolution in the object space which can be achieved using lenses with longer focal lengths with a large field of view which normally requires shorter focal lengths (see Figure 3).

The system can take panoramic images up to 360° field of view. In the case of the application at the tunnel site, such images have a size of about 16000x5000x6 pixel at full resolution which means a raw data size of 460 MB for one single colour image. The system was also applied in quarries where the special image format allows to record long drawn-out rock walls.

Figure 3 shows a panoramic image taken at a tunnel construction site in Austria. The panoramic image contains both the tunnel face and the already excavated area. Within the excavated area displacement monitoring targets can be identified which can be used to determine the camera standpoint. The resolution is about 2mm/pixel which allows the identification also of finer rock mass details.

3.3 Measurement from images

In order to measure from the images the perspective geometry of the cameras must be known. This so-called interior orientation of the cameras can be determined using a test field containing targets with known co-ordinates. The interior orientation include the focal length, the geometric distortion of the used lens, and the position of the principal point (Slama, 1980). Once these parameters are known metric measurements can be taken. Two kinds of measurements can be distinguished:

3.3.1 Measurement within a camera co-ordinate system:

The imaging system itself defines the co-ordinate system, i.e. measurements do not relate to the surroundings. However, relative measurements within a single image pair are valid and have physical reality. This is the simpler configuration which requires no other positioning mechanism which is sufficient for several geotechnical analyses, like the evaluation of a single rock wall that uses measurements of structures only in relation to each other.

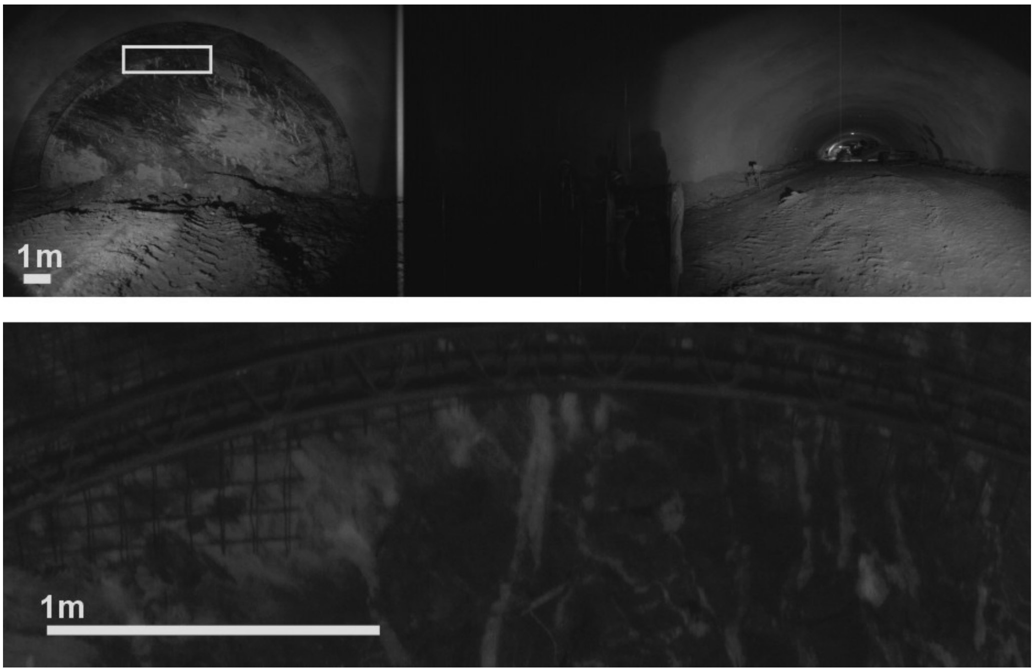

Figure 3: Panoramic image taken at the Unterwald tunnel construction site (top).
Detail showing an image section demonstrating the resolution (bottom).

3.3.2 Measurement within an object co-ordinate system

Structures are measured in relation to a given (external) object co-ordinate system. To achieve this, the so-called exterior orientations of the cameras within the object space must be determined. The exterior orientation of a camera is defined by the location of the centre of projection and the pose of the optical axis. By observing at least three non co-planar control points (points with known co-ordinates in the object space) the exterior orientation can be determined (Slama 1980). This process was adapted for panoramic line-scan cameras (Case 1967, Gaich 2000).
In the case of a tunnel construction site application, commonly used displacement monitoring targets are used to determine the exterior camera orientation. Anyhow, those targets are measured regularly in order to determine movements so it is useful to use them also for the camera orientation.

4. IMAGE ANALYSIS

Once high quality images are available, a vast number of image evaluation strategies are useful. In order to get geotechnical parameters several steps are required and briefly mentioned in the follwing.

4.1 Interactive structural analysis

A single rock mass image from a stereoscopic image pair is used to interactively annotate geotechnically relevant structures that can be identified within the rock mass. This approach was plurally used in the past in order to digitise structural (2d) information from conventional photographs, e.g. by Hagan (1980), Franklin et al. (1988), Tsoutrelis et al. (1990), or Crosta (1995). The structures are either drawn directly on the digital image or a digitiser board was used to mark the discontinuities leading to 2d structural maps.

Some approaches in the past tried to determine structural maps automatically from an image. The major problem in automatic identification of discontinuities originates from changing rock mass conditions and the task to determine the geotechnically relevant (or significant) structures. Fully automatic approaches (Reid & Harrison 2000, Fasching 2000) do not deliver satisfactory results at present. Too much parameters in a chain of processing steps influence the final results and have to be set individually. This leads to weak results that highly depend on the actual rock mass. A robust algorithm that can adapt to strongly varying rock mass conditions was not presented up to now.

Therefore an interactive analysis performed by an experienced geologist is proposed. Using a software that allows the handling of the images, traces of discontinuities can be marked and are displayed as geometrical structures overlaid the original images. These structures are grouped to manage joint sets and stored in a hierarchical manner which simplifies the computation of statistical values.

An example is depicted in Figure 4. It shows a tunnel face, the structural map of the main joints grouped into three joint sets and a regional segmentation if the tunnel face according to rock mass type. It took an experienced geologist about 10 minutes each to come to these results.

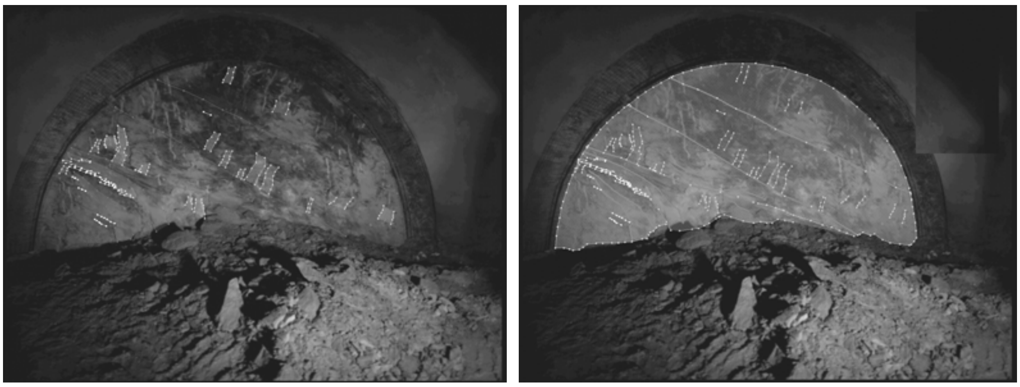

Figure 4: Evaluation of the main structures identified by an experienced geologist. Main structures (left) and identified lithological regions (right).

4.2 Stereoscopic vision

A major support for the interactive analysis is the use of stereoscopic vision that allows to inspect the images three-dimensionally on the computer. Two images of the rock mass exposure are displayed simultaneously and separated for each eye by means of graphic's hardware (e.g. synchronised shutter glasses or anaglyph glasses) which enables three-dimensional perception (Foley et al. 1990). Using this principle improves the interactive assessment of a rock mass as ambiguous regions or weakly determinable discontinuities or orientations get more conspicuous. In the working process the mode is switched between two-dimensional annotation and three-dimensional vision.

Figure 5: Stereoscopic vision enables a spatial inspection of the recorded rock mass which significantly improves the geotechnical analysis (left). Interactively determined structural map draped over the automatically computed surface bringing the structures into 3d (right).

4.3 Automatic surface reconstruction

Surface reconstruction allows to recover the three-dimensional shape of the recorded rock mass exposure which is nowadays a standard procedure. Realisations differ in speed, accuracy, and capability to deal with large image. Going out from a stereoscopic image pair, three steps are performed:

1 Matching: This is the process of identifying corresponding points within the image pair. This task is an important basis for the quality of the reconstructed surface: the denser and more accurate the point correspondences are detected, the more reliable are measurements derived from the surface model.

2 Three-dimensional point reconstruction refers to the computation of the three-dimensional object co-ordinates of a surface point based on the corresponding image points and the orientation of the cameras. The results is an unorganised set of 3d points (point cloud)

3 Mesh generation ensures a connection between the single points of a point cloud. Often used are triangulated irregular networks (TIN) like the Delaunay Triangulation which results in a surface description exclusively composed by triangles.

4.4 Fusion of results

The resulting structural maps from the interactive analysis can be aligned geometrically with the automatically computed surface reconstructions, if both results base on the very same images (cf. Figure 5 right). With that, two-dimensional structural maps become a three-dimensional existence and therefore enable the derivation of spatial magnitudes of the structures, like the true length of discontinuities or distances between them.

The resulting geotechnical surface models consists of 3d points, their connection among each other and the 3d structural data. The models are handled in a standard graphics file format, like the so-called virtual reality modelling language (VRML) which is virtually supported by any internet browser. This allows easily to interchange such models using the world wide web.

4.5 Discontinuity orientations

The results so far enable 3d point measurements either in relation to the camera co-ordinate system or to an external object co-ordinate system. The measurement of spatial orientation information can be derived from single 3d point measurements: suppose a spatial triangle determined by three surface points. If the surface points are chosen to lie on a discontinuity then the normal vector to this surface triangle represents the orientation of this discontinuity. This principle was already used in geotechnical analyses based on conventional photographs (Linkwitz 1963, Rengers 1967).

5. BENEFITS

The system provides a rapid, comprehensive and unbiased documentation of the rock mass. The high image quality provides decision-making concerning construction, support, or planning, respectively. It provides an improved analysis including: spatial rock mass observations on the computer, three-dimensional measurements, and simply changing the observation scale which additionally supports the assessment. Since the analysis is performed indirectly, the safety of the data acquisition is increased, as well as work in hazardous areas can be omitted. Time to get the data is decreased and the rock mass conditions can be inspected at a later time if needed.

6. CONCLUSION

Geotechnical data acquisition using an image based approach overcomes problems of the current practice. Using a special panoramic camera allows a detailed, thus comprehensive documentation of the rock mass within a wide field of view. Since images of 360° are possible, the exterior orientation of the camera can be determined at a tunnel construction site without an additional external positioning system.

The images are processed using software components customised for geotechnical analysis. They enable spatial measurement of geometric rock mass structures, such as lengths of discontinuities, the size of an region, or discontinuity orientations. This indirect observation and measurement solve current problems like pressure of time or the need for tactile access in order to perform measurement. Additionally, a stereoscopic vision tool improves the impression and therefore the capabilities for the rock mass analysis significantly. Another support is the possibility of changing the observation scale rapidly by zooming the image. This altogether makes the geotechnical assessment easier.

Summarising, the computer vision system is a supplement for the current field work of the geologist. It improves the present geotechnical data acquisition process completed by measurement and analysis possibilities not existing so far.

The results can be processed in order to serve as input for numerical simulations, for 3d visualisations of the rock mass and for documentation purposes. It allows the computation of additional magnitudes describing the rock mass, like discontinuity roughness or surface roughness parameters. This results in geotechnical data of a new quality and should lead to a new standard for geotechnical data acquisition not only on tunnel construction sites.

REFERENCES

Case, J.B. 1967. The analytical reduction of panoramic and strip photography. Photogrammetria :127-141.

Crosta, G. 1997. Evaluating Rock Mass Geometry From Photogrammetric Images. Rock Mechanics and Rock Engineering 30 (1): 35-38.

Fasching, A. 2000. Improvement of Data Acquisition Methods for Geological Modelling. Phd thesis. University of Technology, Graz, Austria.

Faugeras, O. 1993. Three-Dimensional Computer Vision: A Geometric Viewpoint. Cambridge, Massachusetts: MIT Press.

Foley, J.D. & van Dam, A. & Feiner, S.K. & Hughes 1991, J.F. Computer graphics, principles and practice, 2nd ed. Reading. MA: Addison-Wesley.

Franklin, J.A. & Maerz, N.H. & Bennet, C.P. 1988. Rock mass charactersation using photoanalysis. Int. Journal of Mining and Geological Engineering 6: 97-112.

Gaich, A. 2000. Panoramic Vision for Geotechnical Analyses in Tunnelling, Phd thesis. University of Technology, Graz, Austria.

Hagan, T.O. 1980. A Case for Terrestrial Photogrammetry in Deep-Mine Rock Structure Studies. Int. Journal of Rock Mechanics & Mining Sciences 17: 191-198.

Linkwitz, K. 1963. Terrestrisch-photogrammetrische Kluftmessung. Rock Mechanics and Engineering Geology I:152-159.

Reid, T.R. & Harrison, J.P. 2000. A semi automated methodology for discontinuity trace detection in digital images of rock mass exposures. Int. Journal of Rock Mechanics & Mining Sciences 37: 1073-1089.

Rengers, N. 1967. Terrestrial Photogrammetry: A Valuable Tool for Engineering Geological Purposes. Rock Mechanics and Engineering Geology V: 150-154.

Schubert, W. & Klima, K. & Fasching, A. & Fuchs R. & Gaich, A., 1999. Neue Methoden der Datenerfassung und Darstellung im Tunnelbau, In: Beiträge zum 14. Christian Veder Kolloquium – Die Beobachtungsmethode in der Geotechnik,: 13-27. Graz: University of Technology.

Slama, Ch.C. (ed.) 1980. Manual of Photogrammetry. Fourth Edition. Fall Church, Va.: American Society of Photogrammetry.

Sonka, M. Hlavac, V., Boyle, R. 1999. Image Processing, Analysis, and Machine Vision, 2nd ed., Pacific Grove et al.: PWS Publishing.

Tsoutrelis, C.E. & Exadactylos, G.E. & Kapenis, A.P. 1990. Study of the rock mass discontinuity system using photoanalysis. In Rossmanith (ed.), Proc. int. conf. on Mechanics of Jointed and Faulted Rock. Rotterdam: Balkema.

Wallbrecher, E. 1986. Tektonische und gefügeanalytische Arbeitsweisen. Ferdinand Enke Verlag.