The application of multi-model photogrammetry in geology – status and development trends

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The use of multi-models in geological photogrammetry enables free movement between stereoscopic images of different scales and angles of view. The method can be used for detailed analysis and three-dimensional mapping in a diversity of geoscience studies. Multi-model blocks can be stored and later reset easily and rapidly, which allows the gradual build-up of an archive of orientated stereo photographs that can be shared by many scientists. Further development of the multi-model method involves digital photogrammetry, digital image processing, computer modelling, and geographical information systems.

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Introduction

In traditional photogrammetry a pair of overlapping photographs is used to create one stereoscopic model. Multi-model stereo restitution (Dueholm, 1990) uses many photographs simultaneously to create a coherent block of models (multi-model block). The operator moves freely between the models and has the perception of one large stereoscopic model covering the photographed terrain or object. The photographs in a multi-model block need not be of the same scale or from the same angle of view, and photographs of different origin can be used. The method includes efficient and accurate procedures for the handling of photographs taken with ordinary hand-held 35 mm and 70 mm cameras. Photographing procedures in the field are flexible and can be carried out by the non-specialist with a minimum of instruction (Dueholm, 1992).

Multi-model stereo restitution is developed for the Kern DSR 15 analytical stereo plotter. Present installations at the Technical University of Denmark and the U.S. Geological Survey, Denver, Colorado are prototypes. The method has been tested through a number of independent projects within a broad range of the geological sciences, comprising Precambrian gneisses, a Tertiary volcanic province, clastic sediments from a regional Cretaceous delta complex, Tertiary lake sediments and geomorphology of arctic terrains. In this paper general conclusions are summarised and the potential of multi-model photogrammetry as a new interdisciplinary tool in geoscience is discussed.

In geological work, standard aerial photographs may conveniently be combined with small-format oblique photographs taken from an aircraft and terrestrial close range photographs. Thus, an area of interest can be viewed and measured in stereo from horizontal, oblique and vertical directions. The operator can change scale and direction of view within the same block by changing model. Three-dimensional analysis, measurement of geological structures, and data collection, is performed continuously across model boundaries. Maps, cross sections, and isometric or perspective views can be drawn. Orientated multi-model blocks can be removed from the stereo plotter and re-introduced within a few minutes.

Photogrammetric ground control

For large areas that have to be tied to geographical coordinates aerotriangulation using standard vertical aerial photographs is the most convenient source of control points for the orientation of multi-model blocks (Pedersen & Dueholm, 1992). If aerotriangulated aerial photographs are unavailable the block can be orientated using points measured in accurate topographic maps. Simple local measurements taken in the field by the geologist (Garde, 1992b) can also be used. Satellite-based GPS (Global Positioning System) measurements provide a new and alternative method for acquiring accurate control points in connection with hand-held photography which has not yet been tested.

Data transport facilities

Three-dimensional data compiled with the multi-model system are stored in ASCII format and are easily transported to various other computer platforms. For example, Humlum (1992) uses a DOS-based spreadsheet programme to transfer the ASCII files into PC-based geographical information systems for geomorphological data manipulation, and Garde (1992b) transports his data to a Macintosh drawing programme where maps and sections are made ready for publication.

Summary of applications in geology

Multi-model photogrammetry provides a supplementary tool to traditional field investigations enabling the detailed study of any terrain, irrespective of topography, at any scale, and any angle of view. By providing means for detailed quantitative analysis of inaccessible but well-exposed terrain the method offers possibilities for a range of new studies. Field observations and sample collection can be integrated with photogrammetric extrapolation and quantification allowing field measurements to be refined and extrapolated in the laboratory. In many areas it is not necessary to perform geometrical measurements (such as dips and strikes) in the field as these may be more accurately undertaken in the laboratory. Systematic employment of multi-model photogrammetry leads to more efficient field work and utilisation of transport facilities (such as helicopters).

The preceding articles in this report illustrate how the multi-model method has been applied to diverse geological problems ranging in scale from 1:25 to 1:200 000.

Garde (1992a) shows how critical structural information about Precambrian rocks can be acquired from photographs on the scale of c. 1:175 000. A 65 km long and almost inaccessible section along the north coast of Nuussuaq was photographed, and subsequently mapped on the scale of 1:200 000 with only a few days of laboratory work. Although the laboratory work left a number of unresolved questions much information was acquired which aids the understanding of the structural development in the region.

Pedersen and Dueholm (1992) describe a geological compilation of a c. 80 km long section along the south coast of Nuussuaq based on photographs on the scale of 1:20 000 to 1:40 000. The study traces the infilling pattern of a basin with almost horizontal volcanic rocks and clastic sediments and illustrates both syn- and post-volcanic basin movements. Detailed geometrical analyses of foreset bedded hyaloclastites are performed, and block diagrams of selected areas are constructed. On the basis of the study a detailed sampling programme is planned based on preselected helicopter landing sites in difficult terrain that had not previously been visited.

Olsen (1992) combines detailed field observations with multi-model photogrammetry and obtains a three-dimensional analysis of facies variations through the Cretaceous delta complex on the south coast of Nuussuaq based on photographs at scales of 1:5000 to 1:30 000. Very detailed and accurate cross sections are measured and horizontal maps of individual sand-bodies constructed. Width/thickness ratio, sinuosity, and shape of sand-bodies and palaeochannels are quantified.

Pedersen (1992) shows how detailed sedimentary logs can be remeasured and extrapolated in the laboratory during a study of the detailed facies variation of Tertiary lake sediments from Disko using photographs on scales of 1:3000 to 1:10 000.

Garde (1992b) analyses Precambrian metamorphic rocks on a very large scale (1:25–1:200) from outcrops in quarries. With the aid of a simple local control system he is able to document very detailed field relations. The method opens up for three-dimensional quantitative studies with precision down to centimetres or millimetres.

The method is also applicable to geomorphological features. Humlum (1992) analyses a steep alpine terrain in eastern Disko as part of a combined geomorphological and climatological study. This study also exemplifies the re-use of a multi-model block which had earlier been orientated for the study of the Tertiary volcanic rocks.

Applications in related fields

Multi-model photogrammetry has been successfully applied to engineering geology projects. Geological mapping of walls and roof in underground tunnels are described by Coe & Dueholm (1991a, b), and excavated trench walls were studied by Coe *et al.* (1991). Here the method is used under extremely controlled and precise conditions focussed on the mapping of fractures to evaluate the dynamics of bed rock deformation and fracture patterns.

The monitoring of active dynamic processes within the geosciences is another field where hand-held oblique and close-range photographs can supplement traditional aerial photogrammetry. By comparing multi-model blocks of the same area, photographed at different times, the changes with time can be quantified. This could be applicable to the study of volcanic eruptions, movement of the crust in earthquake zones, development of landslides and the study of snowfields or the movement of glaciers.

The method is not restricted to the geosciences. It is being explored in architectural surveys and studies of historical buildings and in archaeology though, as yet, none have published experiences from these projects.

Development of new methods for geological mapping

During the study of the Tertiary volcanic rocks in West Greenland (Pedersen & Dueholm, 1992) a large number of photogrammetrical models covering many thousands of square kilometres on Disko and Nuussuaq have been orientated and stored in a stereo model archive that comprises photographs of varying age and scale. Up to now the still expanding archive includes 98 models of vertical and oblique aerial photographs and 561 colour stereo models mounted on 38 sets of templates. The orientation of multi-model blocks is time consuming, but because orientated models and blocks can be reset and made ready for new measurements within a few minutes, the existence of this archive has become a huge source of geological information from which both qualitative and quantitative observations can be quickly extracted.

The three-dimensional analysis of sedimentary facies in the delta deposits of southern Nuussuaq (Olsen, 1992) and the analysis of the infilling pattern of hyaloclastite basins in southern Nuussuaq (Pedersen & Dueholm, 1992) are examples of new types of quantitative geological studies which have become possible in sedimentary and volcanic terrains. The existence of a large model archive greatly increases the possibilities of studies of the evolution of such areas. As an example, the geologist might become interested in mapping the position of the shore at the time of a volcanic eruption. By working with the model archive, the shore position may be followed through several valleys within a few hours. Outcrops of interest can be analysed in the high resolution and oblique view of the colour field photographs and in between the landscape may be surveyed in small scale from aerial photographs. By the end of the day the geologist might have moved through the models, as if he had been flying several hundred kilometres in a helicopter with the additional advantage of having been able to collect and digitise a dense set of accurate three-dimensional data that locate the shore and measure the dips and strikes or other structural parameters of the hyaloclastites derived from that eruption.

For these reasons multi-model photogrammetry has already changed the way field work is carried out in the sedimentary and volcanic areas in West Greenland. High field priorities are being laid on stereo photography flight missions and selected sampling and much less on traditional mapping. There is little doubt that in the future the method is likely to have a great impact on the way field geology is undertaken in well exposed sedimentary and volcanic terrains.

Garde (1992a,b) has demonstrated that multi-model photogrammetry can also be used with many advantages in Precambrian terrains both on the small and the large scale, and his work indicates, that the method has potential in the structural and lithological analysis of the crystalline basement in areas with moderately deformed and well preserved supracrustal belts.

Interdisciplinary model archive

A gradually expanding archive of orientated stereo models can, if administered under suitable conditions, become a unique source of information for interdisciplinary natural and technical scientific investigations. As an example, Humlum (1992) uses multi-models from a geological model collection for geomorphological analysis.

Future developments

Multi-model photogrammetry is a versatile means of collecting geological data for computer data bases and modelling programmes, and for the combination of geological data with parameters such as digital lithological, geochemical and geophysical data. Thus, multi-model photogrammetry can provide the basis for the geological part of a modern geoscientific information system.

In the near future, high resolution photographs may be stored and even taken digitally. Also, computer screens with three dimensional display have been developed. These screens allow stereoscopic viewing of images supplied from scanners or digitised photographs. Digital photogrammetric systems (Dowman *et al.*, 1992; Miller *et al.*, 1992) for accurate stereoscopic measurements have been explored based on the traditional single model technique and using both satellite data (for instance from the SPOT satellite) and digitised aerial photographs. Today, these systems have very low data capacity and resolution compared to the requirement of the detailed studies dealt with in this volume.

The multi-model method may be transferred to enhanced digital photogrammetric systems and modified to include free movement between as many models as can be stored digitally in the system. Continued rapid growth in computer technology will eventually solve the capacity and resolution problem. Digital image processing techniques, today known from the analysis of scanned two-dimensional satellite images, can be integrated and applied to the three-dimensional models. The combination of vector and raster techniques will allow already recorded data and digitised maps to be superimposed on the three-dimensional models.

By combining the multi-model software with the new digital photogrammetric systems, it will be possible to move freely, and with controlled geometry, between three-dimensional scanned satellite images, models formed by digitised vertical and oblique aerial photographs, digital small-frame colour photographs, computer modelled data of any kind, and digitised map data. Development towards such a system requires an interdisciplinary team of scientists that can combine the geoscientific requirements with advanced computer technology, photogrammetry, digital image processing, information systems, and computer modelling programmes.

Conclusion

Through a series of mapping experiments the multi-model photogrammetric method has been established as a new powerful tool in detailed geological and geomorphological analysis and mapping. It provides increased versatility and efficiency to field work, and it allows scientific problems to be formulated and investigated in a way that was not previously possible.

An ongoing study of the continental margin in central West Greenland has established an archive of orientated stereo models covering large areas that may be used for other purposes and is a rich source of information for interdisciplinary natural science investigations.

A modern geoscientific information system, which includes several parameters such as lithological, geochemical, and geophysical data, may usefully utilise multi-model photogrammetry to interface geological data.

The potential of using multi-models in geological photogrammetry has not yet been fully employed. Further development must proceed through an interplay between the requirements of the geosciences and the new digital methods.

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