MAPPING FROM NON-METRIC SMALL-FRAME PHOTOGRAPHS USING MULTI-MODEL PHOTOGRAMMETRY

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ABSTRACT:

Multi-model photogrammetry eliminates the need for specialised metric cameras. Geologists, architects and other scientists can use their own standard 35 mm or 70 mm camera for photogrammetry. Photographs are taken with a hand-held camera from terrestrial stations, helicopters, light planes or boats. The small-frame photographs are set up in an analytical plotter where multiple stereoscopic models are simultaneously orientated. Control points are measured in aerial photographs. The scientists interpret, collect and compile data continuously across the model boundaries. Accuracies are better than 20 microns at the photo scale.

The multi-model method is illustrated by examples from geological mapping of steep mountain sides in Greenland, vertical coastal cliffs in Faroe Islands and stone quarries in India and from architectural measurements in Japan.

KEY WORDS: Photogrammetry, Non-metric cameras, Geology, Geomorphology, Architecture.

1. INTRODUCTION

Photogrammetry is a complicated technology that uses expensive instruments and specialised cameras. Projects typically require photogrammetric experts. Multi-model stereo restitution (Dueholm, 1990) removes some of these barriers and allows photogrammetry to be used by geologists, geographers, architects, archaeologists and civil engineers. These professionals have a growing need for accurate three-dimensional quantification and analysis in relation to the use of new software tools such as geographical information systems and computer aided modelling and design programmes.

In geology, increasingly advanced computer modelling programmes are used to simulate the dynamics of geological processes in order,for example, to improve the prediction of petroleum recovery from reservoirs. The calibration of modelling programs requires detailed and accurate three-dimensional data which are surveyed where geological structures crop out on the surface of the earth. Exposures on steep mountain sides are a very valuable source of geological information, but they are also extremely difficult to quantify by traditional mapping and field survey procedures.

In geomorphology, the intensified study of climatic changes involves detailed investigations to be carried out in often remote arctic environments and includes comparison of different landscape elements on a time scale of days, months or years. Also, these investigations are difficult to carry out by conventional methods based on preexisting topographic maps or vertical aerial photographs.

Documentation of historical buildings is a task that has interested photogrammetrists over the years. In the near future, thousands of town renovations are to be carried out in Europe. Especially in Eastern European countries, a large amount of documentation is needed. Furthermore, three-dimensional maps are required for new computer information and design systems where urban areas or individual buildings are spatially displayed from any desired angle of view. The use of such tools involves a detailed three-dimensional survey of house facades in project areas.

While photogrammetry is an exellent tool for three-dimensional surveys, standard aerial photogrammetry is of little value in the survey of steep mountain sides or building facades. Besides, traditional terrestrial and close range photogrammetric methods are too complicated and inefficient to be used by persons without photogrammetric training.

Multi-model stereo restitution includes the advantage of free movement between stereoscopic models of different scales and angles of view and provides a versatile use of small-frame non-metric cameras. The method is developed in a cooperation between the Institute of Surveying and Photogrammetry at the Technical University of Denmark and geologists at the Geological Survey of Greenland and the U. S. Geological Survey, Geologic Division, Denver, Colorado. Prototypes based on the Kern DSR15 analytical plotter are installed at the Technical University of Denmark and the U. S. Geological Survey.

2. THE MULTI- MODEL METHOD

In traditional photogrammetry a pair of overlapping photographs are used to create one stereoscopic model. Multi-model stereo restitution uses many stereo pairs simultaneously to create a coherent block of models (multi-model block). The operator moves freely between the images and has the perception of one large stereoscopic model covering the photographed terrain or object. An automatic model change occurs whenever the floating mark is moved across the image frame line of either of the two photographs of the current model. The floating mark moves to the same point in the neighbouring model across the frame line.

The photographs in a multi-model block need not be on the same scale or taken from the same angle of view, and photographs of different origin can be used. For instance, standard vertical aerial photographs can be combined with small-format oblique photographs taken out of the open window of a helicopter and close-range terrestrial photographs taken with a hand-held camera. Thus, scale and direction of view can be changed within a multi-model block while maintaining the measuring mark in the same coordinate location.

Three-dimensional analysis, measurements, compilation and data collection are done continuously across model boundaries. Maps, cross sections and isometric or perspective views can be drawn on-line as well as off-line.

A very flexible orientation programme is required when using photographs from an ordinary non-metric camera together with photographs of different scales and view angles. The most important facilities of the multi-model orientation programme are described below.

2.1 Adjustment programme

The multi-model block is orientated by a self-calibrating bundle block adjustment. Inner orientation parameters such as the focal length (camera constant), the coordinates of the principal point and the distortion parameters may be individually adjusted for each photograph in the block. Thus, photographs taken with different cameras are readily included in the same adjusted. If the inner orientation parameters are known from camera calibration, the orientation parameters are kept constant in the adjustment. Otherwise, one or more parameters may be individually hand led as unknowns. For example, small-frame cameras with continuous focusing are calibrated while focused at infinity and used for photogrammetric photography at this setting, but when an ordinary camera is used for close range photography at a focal length different from the one used during calibration, only the focal length and the exterior orientation parameters are adjusted in the bund le adjustment while the principal point and the distortion parameters are kept constant.

2.2 Templates

The small-frame photographs are grouped in strips or blocks that fit the two stage plates of the analytical plotter. The standard format stage plates will each hold at least 20 photographs taken with 35 mm cameras or 9 photographs taken with 70 mm cameras, making it possible to set up simultaneously 39 models formed by overlapping 35 mm photographs or 17 models formed by overlapping 70 mm photographs.

In order to facilitate the handling of many small-frame photographs, alternating left and right photographs of the model pairs are contact-printed onto two film sheets called templates, one for each stage plate of the analytical plotter. If equipment for contact-printing is not readily available, templates can be made by mounting the original small-frame photographs in holes cut out of stable film sheets (Fig. 2).

In the case of combining aerial photographs and small-frame photographs, the small-frame photographs can be mounted in holes cut out of those parts of the aerial photographs that are not required for the current model (Fig. 5). Thus, the aerial photographs can serve as templates for small-frame photographs as well as providing a stereoscopic model themselves.

The template sheets or the aerial photographs holding the small-frame photographs each have four fiducial marks that are used to register the multi-model block mounted on a template set to the stage plates of the analytical plotter. The image coordinate system of each photograph on a template is transformed to the coordinate system defined by the template fiducial marks. Therefore, resetting of the multi-model block is done simply by remeasuring the fiducial marks of each of the two templates involved.

2.3 Establishing the principal point

The principal point of ordinary cameras is difficult to define, because these cameras do not have fiducial marks or reseau crosses. The image coordinate system has to be defined by establishing the image corners. These, in themselves, are irregular and even vary somewhat from image to image due to film warp. The technique used in the multi-model method is to extend the frame lines by eye and measure the imaginary intersection point. This can be done with a standard deviation of 10 to 20 microns dependent on the camera frame. When this accuracy is insufficient, the principal point coordinates may be individually calculated for each photograph during the adjustment by using extra control points.

Often, a best fit solution is sufficient where the principal point discrepancies are partly corrected by adjustments to the exterior orientation parameters. Since this best fit solution is tied to the template coordinate systems, as described above, rather than the individual image coordinate systems, the same solution is reproduced each time the multi-model block is reset in the instrument. The ill defined photograph corners are only measured once, when the multi-model block is orientated the first time.

2.4 Film flatness

Another problem with ordinary cameras is that they do not have pressure or vacuum devices to keep the film flat against the camera back. Present experience shows that 35 mm film is less influenced by film warp than 70 mm film, which is probably due to the smaller camera frame reducing the free film span in the 35 mm camera. The influence on accuracy is surprisingly small, as will be discussed later under 'accuracy considerations'.

2.5 Automatic calculation of preliminary values

Because photographs of different scales and angles of view are used in the same multi-model block, preliminary values are very difficult or even impossible to estimate for a geologist or a photogrammetric operator. Therefore, an important facility of the multi-model system is the availability of automatic computation of preliminary values for exterior orientation parameters and tie point coordinates.

Preliminary values are computed by successive relative orientations within strips and spatial similarity transformations first between models and then between strips and blocks.

The spatial similarity adjustment itself requires preliminary values for orientation parameters. These are calculated as follows: First a set of omega and fi rotation angles are guessed at by the program, and the model or strip are rotated accordingly. Then linear equations are used to compute the scale, the kappa rotation and the three translations. Based on these values, the standard deviation unit weight of the first iteration of the spatial similarity adjustment is computed and stored. This procedure is repeated with several preselected combinations of omega and kappa angles. The omega-fi combination of the smallest standard error unit weight after the first iteration is used as preliminary values in the spatial similarity transformation.

Parametres computed during the successive relative orientations and model and strip connections are then transformed to exterior orientation parameters for each image which are then used as preliminary values in the bundle block adjustment. Large gross errors are nicely trapped during this procedure, while small gross errors are located during the bundle block adjustment.

This procedure of computation of preliminary values is extremely robust. It is one of the most important preconditions for the success of the multi-model method.

2.6 Accuracy considerations

Small-frame cameras are calibrated using a test field of 120 points distributed in a spatial network of 3 x 3 x 2 meters. The points are surveyed with electronic theodolites to an RMS accuracy of about 0,1 mm.

In order to smooth the contribution from film warp, at least two photographs of the test field are used when calibrating small-frame non-metric cameras. The radial distortion is described by the standard three parameter polynomial in third, fifth, and seventh degree. Tangential distortion is ignored. RMS of residuals between 3 and 5 microns are obtained for 35 mm mirror-reflex cameras such as the Olympus OM1 or Minolta SRT101 with good quality wide angle lenses and between 5 and 8 microns for 70 mm cameras such as the Hasselblad SWC with a 40 mm lens. The higher residuals of the 70 mm cameras are probably due to the larger influence of film warp, but the subject has not been researched.

Bundle block adjustments using a calibrated non-metric camera and natural tie-points typically give RMS residuals of 6 micron on tie points for 35 mm and 10 micron for 70 mm photographs.

Metric small-frame cameras such as the Hasselblad MKWE or Rolleimetric 6006 have been used as well. The reseau glass plate built into these cameras facilitates the inner orientation measurements and highly improves the accuracy with which the principal point may be defined. On the other hand, the image is not as sharp as with a good quality ordinary camera, and the small-frame metric cameras do not give significantly better accuracies.

In geological projects, sharpness of image is very important in order to provide optimal interpretation conditions. In fact, the photograph scale is often determined more by considerations of resolution and sharpness than by requirements of accuracy. This means that any marginal accuracy gained by using metric cameras is insignificant in geological projects.

The advantages of the metric hand-held cameras, that is, the reseau glass plate and a somewhat higher accuracy very seldom make up for the disadvantages of a much higher price and an inferior image sharpness.

3. GEOLOGICAL PHOTOGRAMMETRY

The use of small-frame non-metric cameras is especially relevant in geological mapping. Field geologists always carry a quality 35 mm or 70 mm camera for documentation of outcrops, and it is a big advantage that the same camera may be used for photogrammetric purposes. Furthermore, steep mountain sides are often photographed out of the open window of a helicopter or a light aeroplane; for this operation, a lightweight, handy and easy-to-operate camera is required.

Fig. 1. *Near vertical cliff of Precambrian rocks about 1000 meters high at the north coast of Nuussuaq in central West Greenland.*

Since the spring of 1990, when the multi-model prototype was ready, a series of geological mapping experiments has been carried out. In Greenland, the small-format photographs are used in combination with vertical aerial photographs. Geological exposures on steep and otherwise inaccessible mountain sides are photographed by the field geologist from a helicopter during reconnaissance and camp shift flights. The photograph scale varies between 1:3 000 and 1: 200 000 according to the aim of the project. The lens is focused at infinity, and photographs are taken in strips with an overlap of 70 % to 80 %. The relatively large overlap ensures stereoscopic coverage on each side of cliffs and gullies along the mountain side. 64 ASA Kodachrome films for colour slides are used, because they have a good resolution and a long term stability.

Preexisting aerial photographs are available in Greenland from the National Survey and Cadastre in Copenhagen. Many areas are covered by several series of vertical aerial photographs in scales varying between 1:40 000 and 1:150 000. Even old oblique photographs from the 1940s and 50s are still available. A new series of 1:150 000 super wide angle photographs has been aerotriangulated by the National Survey and Cadastre and the Geological Survey of Greenland. By using these aerotriangulated photographs as basis for the orientation of multi-model blocks, the geologist is not required to survey control points in the field. On an average, one tie-point is measured

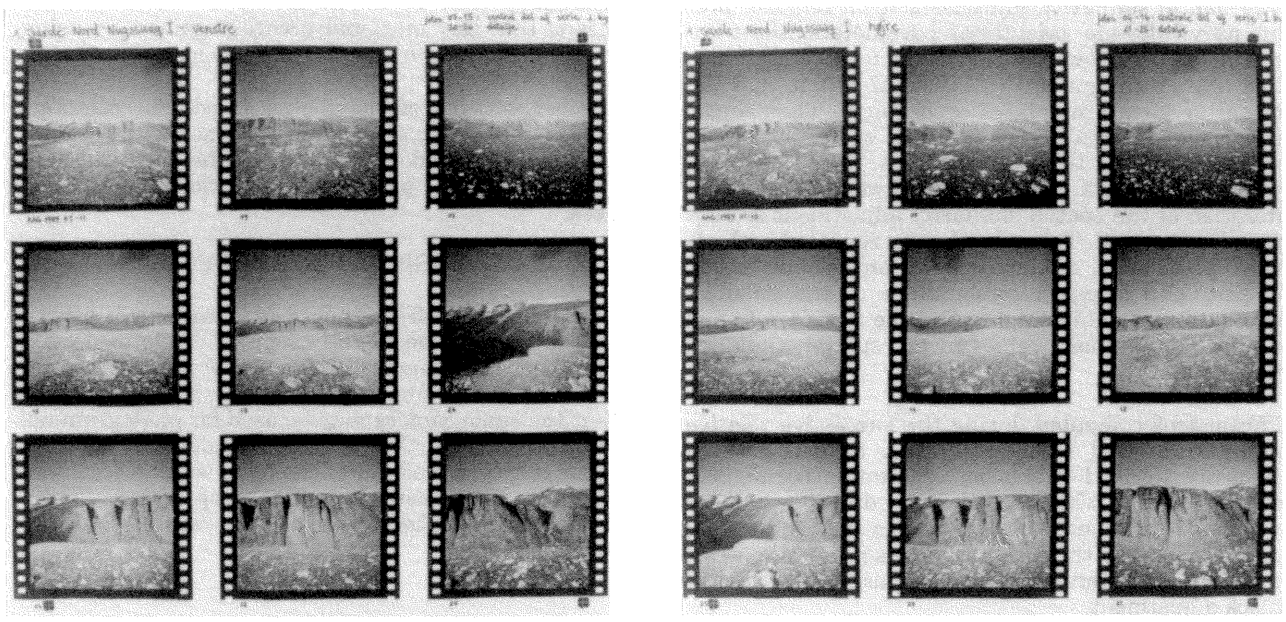


Fig. 2. A template set where small-frame photographs (originals in colour) taken with a Hasselblad camera are mounted in holes cut out of stable film sheets. Alternating left and right photographs of the model pairs are mounted on the two templates. The photographs constitute two strips. The top eleven photographs (five on the left template and six on the right) form a strip of ten stereoscopic models on an approximate scale of 1:175 000. The remaining seven photographs form a separate strip of six models on a scale of appr. 1:40 000. The two strips form one multi-model block where the 1:40 000 models are a close-up of part of the 1:175 000 strip. The crosses marked with a needle in black ink spots at the template corners are fiducial marks.

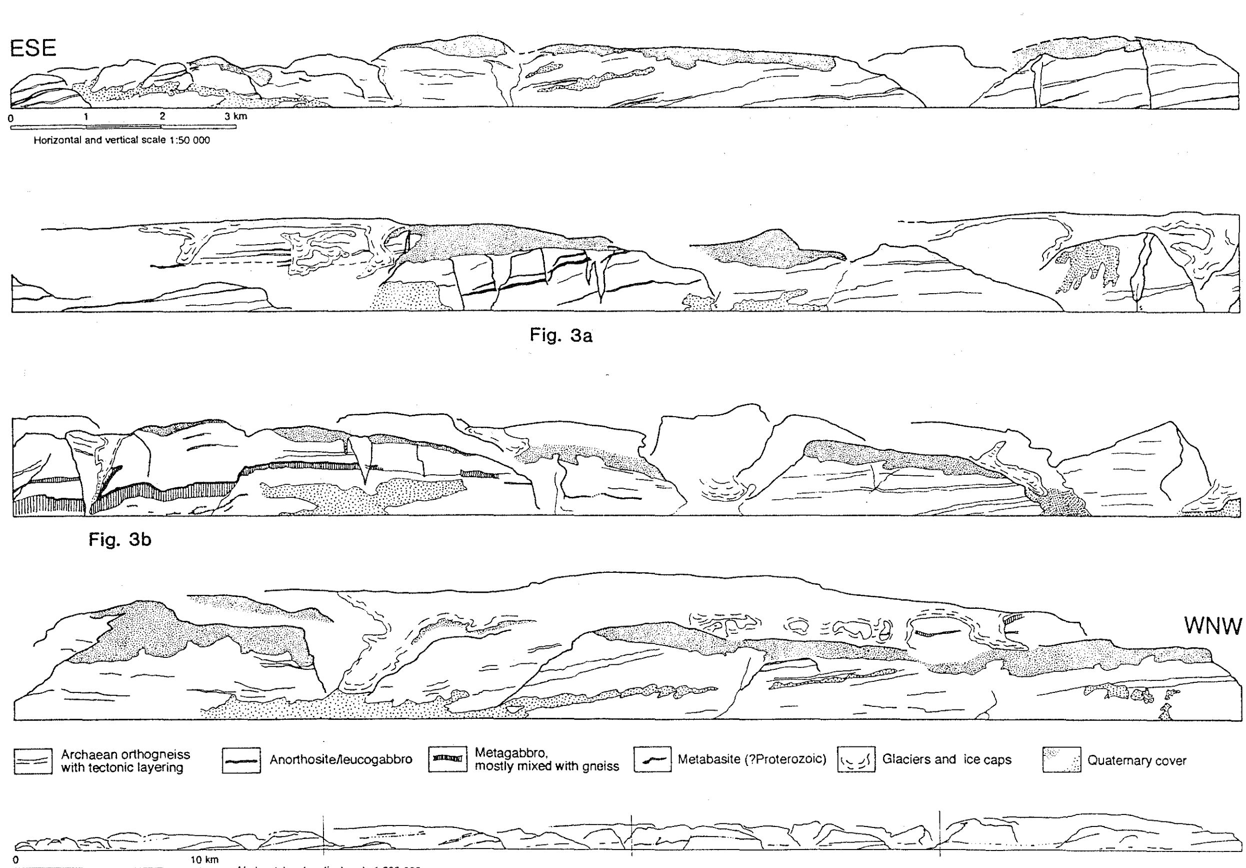


Fig. 3. *Geological cross section compiled from the template set in fig. 2 and two similar sets. Reduced copy from Garde, 1992a.*

between each small-format oblique photograph and the vertical aerial photographs, and the entire block is adjusted together.

When the field photographs are on a relatively large scale (1:3 000 - 1:30 000), it is difficult to identify common points between the 1:150 000 vertical aerial photographs and the oblique field photographs. In this case, 1:40 000 vertical or oblique aerial photographs are used as an intermediate link. The rather time-consuming procedure of measuring tie-points between three series of photographs of different scales and angles of view is well justified. The geologist, in his task of interpreting and compiling data, find it very useful to be able to switch from the regional bird's-eye view of the two different aerial series to the more detailed, high resolution oblique view in colour of the field photographs.

To further illustrate the use of multi-model photogrammetry in Greenland, four project examples are given below:

3.1 Reconnaissance mapping in Central West Greenland

The first example illustrates geological reconnaissance mapping along a 65 kilometers long coastline in north-eastern Nuussuaq. Steep, in some places vertical cliffs rise from sea level to a maximum height of 2 kilometers (Fig. 1). The cliffs are in shadow except for early mornings during the arctic summer. Access by boat is very difficult because of calving ice and many icebergs. Consequently, the geological mapping of this coast line has been a challenge for many years.

An early morning in the summer of 1989, when weather conditions were optimal, the coastline was photographed from a helicopter hired by the geologist in Umanaq (Garde 1992a) on a scale of 1:175 000 with selected areas covered on a scale of 1:40 000 using a Hasselblad SWC camera with a 40 mm wide angle lens.

Fig. 2 shows a template set that combines a strip of 10 models (11 photographs) at 1:175 000 with 6 models (7 photographs) covering a key area at 1:40 000. The template set constitutes one multi-model block. The block was adjusted together with the above-mentioned 1:150 000 aerotriangulated vertical aerial photographs. RMS accuracies of approximately 3 meters on tie-points between the vertical aerial and the oblique Hasselblad photographs were obtained. The 65 kilometers coast line is covered by three sets of templates.

Fig. 3 shows the 65 kilometers long cross section compiled within few days of laboratory work at the DSR 15 analytical plotter.

3.2 Detailed basin analysis in Central West Greenland

Pedersen and Dueholm (1992) describe a geological compilation of an approximately 80 kilometers long section along the south coast of Nuussuaq based on helicopter photographs on the scale of 1:20 000 to 1:40 000. This study traces the infilling pattern of a basin with almost horizontal volcanic rocks and clastic sediments and documents both syn- and post-volcanic basin movements. Detailed geometrical analyses of fore-set bedded lavas are performed, and block diagrams of selected areas are constructed. Olsen (1992) analyses a Cretaceous delta complex at the south coast of Nuussuaq on the basis of photographs on the scale of 1:5 000 to 1:30 000. By combining detailed field observations with multi-model photogrammetry, a three-dimensional analysis of facies variations throughout the delta is obtained which is used in analogy studies for reservoir evaluation. Pedersen (1992) studies the detailed facies variation of Tertiary lake sediments from Disko on photographs on the scale of 1:3 000 to 1:10.000 and shows how detailed sedimentary logs can be remeasured and extrapolated in the laboratory.

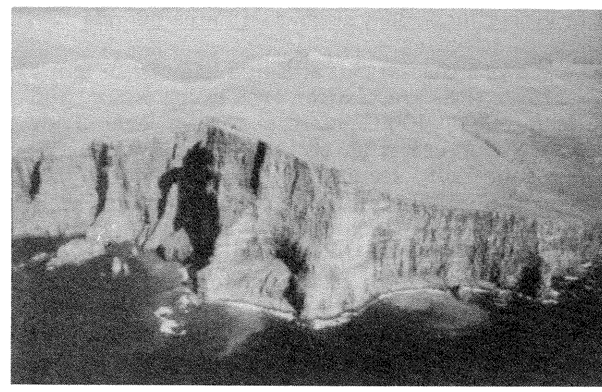


Fig. 4. *'Bird cliff' at Faroe Islands exposing a 500 meters high section through the volcanic formations that make up the islands.*

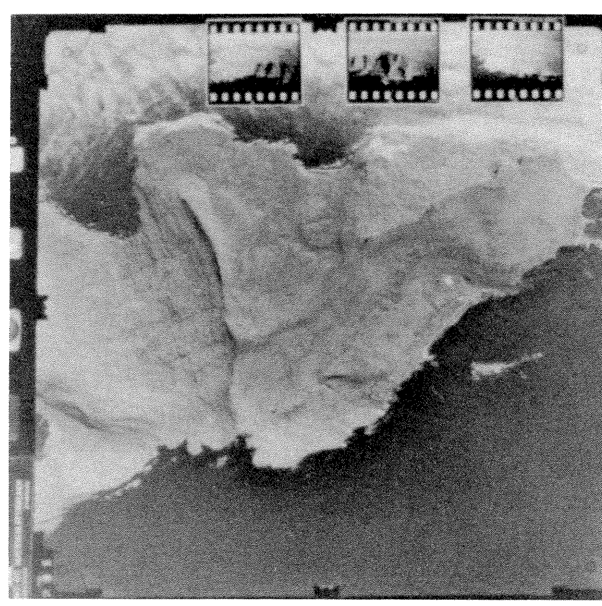


Fig. 5. *The left template of a multi-model block where small-frame photographs (originals in colour) are mounted in holes cut out of vertical aerial photographs. The vertical aerial photographs thus serve as templates for the small-frame photographs, and at the same time provide a stereoscopic model themselves in the uncut areas. The right template holding the stereo partners is not shown in the figure. The multi-model block consist of six stereoscopic models: one model formed by the overlapping aerial photographs and a strip of five models formed by six oblique 35 mm photographs which were taken from a helicopter.*

3.3 Three-dimensional field documentation

Garde (1992b) analyses quarries in India with Precambrian metamorphic rocks on a very large scale (1:25 - 1:200) from close-range small-frame photographs taken from distances between 3 and 10 meters with a 35 mm camera. With the aid of a simple local control system, he is able to document very detailed field relations. A two metre rule, a geological compass and a hand-held level were used for control measurements. The method demonstrates three-dimensional quantitative studies with a precision down to centimetres or millimetres which is also very useful in archaeological studies.

3.4 Engineering geology studies on Faroe Islands

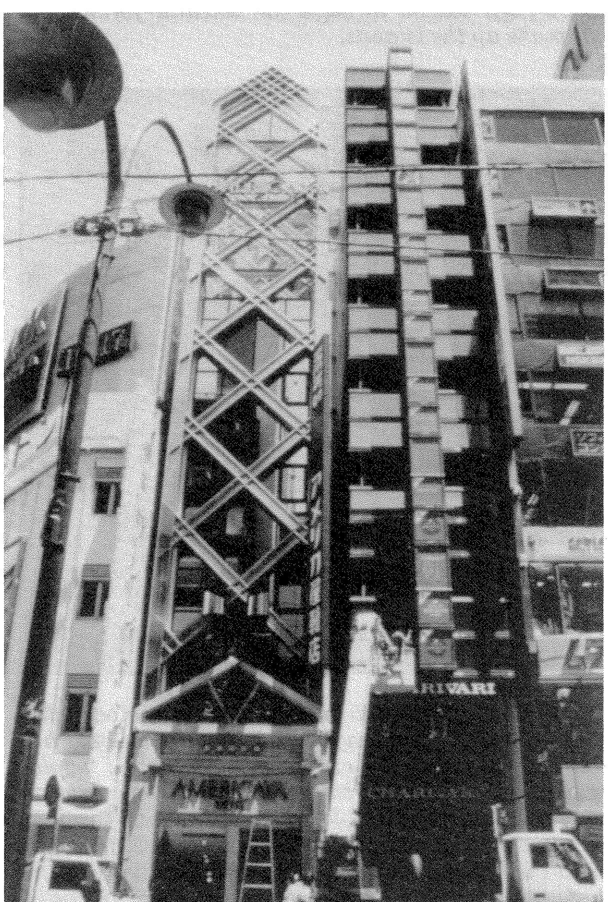
Fig. 4 shows a coastal cliff at Faroe Islands. In many places these cliffs are vertical, even overhanging, and rise from 500 to 1000 meters above sea level. They form excellent resorts for seabirds as well as displaying an impressive section through the lava benches that constitute the small North Atlantic islands.

A road tunnel was to be constructed through the mountain in the center of the photograph of Fig. 4. Information on stratigraphy and water-bearing fractures of importance to the project could be analysed and quantified through a detailed survey of the coastal cliff. Therefore, 35 mm photographs were taken from a helicopter by the geologists on a scale of approximately 1:20 000. An Olympus OM-1 camera with a 28 mm wide angle lens was used. The photographs were mounted in holes cut out of vertical aerial photographs on a scale of 1:30 000 (Fig. 5). The geology of the the vertical cliff was analysed in detail in the 35 mm photographs, after which the mapped units could be traced into the hinterland by switching to the vertical model.

4. ARCHITECTURAL SURVEY

René Kural, an architect from The Royal Danish Academy of Fine Arts studies modern metropolitan architecture. On a short expedition to Tokyo, he needed to document and survey new buildings by photogrammetry using uncomplicated photography procedures. Building facades along business streets were photographed from the opposite pavement using a 35 mm Nikon FM2 camera with a 28 mm wide angle lens. The camera axis was tilted upwards so that relatively high buildings (10 storeys) were pictured in one image. 70 % overlap and upright format was used. Fig. 6 shows one of these images.

For scaling of the models, distances were tape measured on the facades. Leveling of models was established by anticipating whether selected building lines were vertical or horizontal. A north direction was composed from shadows in the photographs combined with knowledge of the exact time of photography. The largest problem encountered was the intensive Tokyo



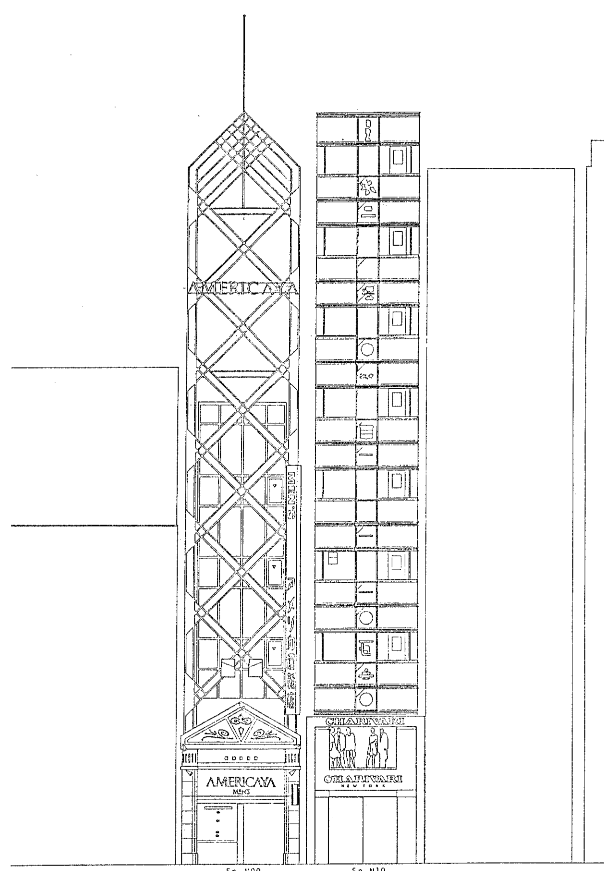


Fig. 6 (left). *New buildings in a business street in Tokyo. The photograph (original in colour) is taken with a 35 mm camera with a 28 mm focal length and used for photogrammetry. The lift in the centre of the image is there by coincidence. It was not used as a platform for photography in the described project.*
Fig. 7 (right). *Reduced copy of the architect's compilation of the two buildings shown in the centre of Fig. 6.*

traffic that covered the ground floor of the buildings in many images. For expedition purposes, however, the method described gives valuable results that could not have been achieved in other ways. In other projects, photography from a lift may be an alternative solution.

Fig. 7 shows the architectural study and survey of two of the buildings of Fig. 6.

The multi-model method can be used for town surveying in combination with aerial photographs as described above under geological mapping. In Danish cities, buildings are generally lower than 6 storeys and aerial photographs on a relatively large scale (1:5 000) are often available. Tie-points between the aerial photographs and small-frame street photographs are measured on eaves or dormers that can be identified in both sets of images. Alternatively, oblique photographs may be taken from a helicopter as a supplement to the aerial photographs, or in order to cover the upper floors in narrow backyards.

5. CONCLUDING DISCUSSION

In areas where vertical aerial photographs are insufficient, the multi-model method is a versatile photogrammetric alternative that provides means for detailed analysis and accurate measurements in overlapping strips and blocks of small-format colour slides taken with non-metric cameras.

The method complies with a growing demand for accurate three-dimensional surveys within geoscientific analysis and architectural studies. Vertical or near vertical features such as mountain sides and building facades are photographed with hand-held cameras, and blocks of models, often combined with vertical aerial photographs, are simultanously set up in an analytical plotter.

The increased demand for spatial data will probably create a new market for oblique photography. Small-frame photographs are not necessarily the best response to this demand. In geological analysis, the advantages of having the field geologist take his own photographs are many, but in town surveys, it might be easier to map from oblique large-frame photographs. Today, however, very few photo gram me tric flight operations are equipped for oblique large-format photography.

The multi-model method allows both the photography and the compilation in the laboratory to be carried out by photogrammetric laymen such as geologists, geographers, architects, archaeologists and civil engineers. The bottle-neck of the method is the expensive and technology-heavy analytical plotter. In future, the multi-model method may be combined with digital photogrammetric systems (Dowman et al., 1992; Miller et al., 1992) and modified to include free movement between as many models as can be stored digitally in the system. Geoscientific analysis procedures are going to experience a revolution if it becomes 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.

When the continuing rapid growth in computer technologies has solved today's capacity and resolution problems, one can expect advanced photogrammetric software programmes to be generally available for 'personal' computer work stations with the potential of moving the entire photogrammetric procedure into the hands of laymen.

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