SHORT RANGE PHOTOGRAMMETRY WITH MINIATURE CAMERA AND MULTIPLEX*

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ABSTRACT

The author gives a very interesting account of the application of photogrammetry to the survey and dimensional recovery of physical objects of limited dimensions by photographs taken at short distances and with unusual camera orientations. Equipment dug out from under the rubble of war devastated Berlin, inventiveness and manual skill produced surprising results and ideas that suggest applications in engineering fields of endeavor far beyond that of preservation of monuments of art and architecture.

HEINZ GRUNER

INTRODUCTION

HAVING dealt explicitly with theoretical considerations, functional analysis and investigation of accuracy[1] of a procedure designed to solve many timely and pressing problems dealing with reconstruction and preservation of specimens of art and engineering, the author intends to present in the following pages the practical aspects of a new method of putting photogrammetry to work in places and with equipment that yield gratifying results.

INSTRUMENTS OF TRADE

Conventional phototheodolites available for terrestrial work are frequently too heavy and too difficult to handle if the survey problem in hand requires great adaptability and ease of operation under severe conditions, in limited quarters and in places not safe or suitable for elaborate preparations. There is no field equipment of sufficient dynamic design readily available to meet the demand for photogrammetric documentation of objects of limited dimensions to be produced from camera stations very close to the scene.

A way out of this predicament is seen in the use of an amateur camera of high versatility using 35 millimeter film, the so-called MINIATURE CAMERA. This type is small in weight and dimensions and is most handy. The routine recording of the exterior orientation in the field may generally be dispensed with. Instead, the relative and absolute orientation is established in analogy with the conventional procedure practiced in aerial mapping, using control points or known dimensions of the object itself. Naturally, the miniature camera does not measure up to the big survey cameras as regards resolution and distortion properties, but it appears entirely adequate when combined with a plotting instrument of medium accuracy, such as the MULTIPLEX.† This instrument appears to be best suited because of the small diapositive plates it employs and of its depth of focus range, this being about equivalent to that of the miniature camera focused at finite distance.

Many diversified photogrammetric tasks of the short range category can be handled by this camera-Multiplex combination because of sufficiently large plotting scales resulting from short photographing distances.

FIELDS OF EXPLORATION

A typical example of lucrative application is the survey of architectural objects in congested locations, such as the fronts of historic buildings on narrow streets. The use of conventional equipment in such locations would cause technical and economic problems. The photographing distance is too short, the resulting negative scale is excessive, and the number of exposures required for coverage is higher than methodically necessary. A serious difficulty is seen in mounting heavy equip-

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† Editors note: The author refers to normal-angle equipment which was built by C. Zeiss before the war. It differs, as will be noted from the technical data appearing later in the text, from the wide-angle instrument known to our readers as the Bausch & Lomb Multiplex.

ment safely at the desirable levels.

The miniature camera affords in this situation much simpler means and less expense, since it may be set up with little effort in practically any orientation suitable for the purpose. Hence, narrow interiors, arched ceilings, cupolas, architectural details, pulpits, altars, reliefs, murals etc. can be very advantageously photographed and later on reconstructed to scale.

With photographs of this category, the photogrammetric evaluation is only one part of the task involved, the other and no less important part being the skillful interpretation of specific forms and features often requiring much art-historical knowledge. This part of the job benefits greatly from the possibility of continuous line-by-line recording during which the operator's undiverted attention remains concentrated on the guidance of his recording tool, the floating mark, along surface forms and details, thus producing a neat, interpretable design of the object viewed. This is quite in contrast with the conventional construction of plans, elevation and sections which usually are burdened with distracting auxiliary design items.

Another fruitful field of application is the survey of criminal evidence. Here, a suitable miniature camera proves particularly valuable as readiness in all critical and unsuspected situations is one of its most appreciated design features. In fact, it is the most versatile tool for scientific expeditions.

Objects of larger extent are not necessarily excluded from these considerations if exposure stations can be established sufficiently close, and if the resulting large number of photo pairs for full coverage is acceptable. If the identifiable detail is sufficient for the task at hand (it should be understood that fine grain emulsions are used exclusively), the convenient and comparatively simple method of projection by the Multiplex plotting instrument offers striking advantages.

Camera Characteristics

The main features of a miniature camera that make it suitable for survey purposes are a solid metal body and exchangeable lenses assembled in focusing mounts. The focal length of the lens may be chosen between 40 and 50 millimeters ($1\frac{1}{2}$ to 2 inches). Several brands of black and white emulsions are coated on a dyed film base for suppression of halation. Their use requires that diapositives be made either on clear base positive film or on glass plates in order to obtain optimum density distribution and gradation of the work material. Because of this intermediate step it is not necessary to maintain the camera focal distance constant and equal to the principal distance of the Multiplex projectors, and to forego the focusing of the camera for finite object distance. The employment of a photographic focal length shorter than the "Multiplex principal distance," henceforth termed "Multiplex constant," will not be considered. Wide-angle photography will rarely offer advantages since for complete topographic coverage the object's surface must be imaged gaplessly on the two photographs from which the stereomodel is formed.

The focal distance of the camera, hereafter termed "camera constant" usually departs from the nominal focal length of its lens. The correct numerical value will be established as follows: With the camera focused at infinity, an object of known length extending parallel with the focal plane is photographed from a known distance. Then

$$\text{camera constant} = \frac{\text{image length}}{\text{object length}} \times \text{distance}.$$

The numerical value of the camera constant increases as the camera is focused upon a finite distance. The differential may be easily determined by the lead of the thread of the focusing mount.

If the camera is well constructed, the photograph principal point will be found to be sufficiently close to the geometrical center of the film window. This can be shown if the camera itself is photographed through a mirror whose reflecting surface is set parallel with the focal plane. To facilitate the experiment a vertical setup is used. Focal plane and mirror are horizontalized with a level bubble. The image of the objective's center denotes the principal point.

Flatness of the emulsion[1] within the window of a well constructed camera can be considered satisfactory, as ascertained by the results of previous investigations.

Several brands of miniature cameras are equipped with a dove-tailed bracket to hold a variety of attachments. This will be used for a very simple and helpful aiming device. It consists of a suitably shaped piece of metal with a highly polished vertical surface bounded by a sharp horizontal edge. It is adjusted to be precisely parallel with the focal plane. When held at a sufficient distance from the eye, the reflected image of the observer's pupil appears projected forward into the object space. It serves to aim the camera accurately at the target. The accuracy obtainable by this implement was found of the order of 2/1,000 of the target distance. For close-up photography it will be necessary to take the offset between lens center and mirror into consideration.

Favorable photo stations from windows across the street are lucky exceptions when high building fronts are to be surveyed. It will more often become necessary to improvise high supports, from whatever portable material can be found, upon which the camera is securely fastened. An auxiliary aiming sight and a circular level will assist the desired camera orientation. The loading capacity and the small picture size of 24×36 mm. permits taking continuous series of photographs. Experience has shown that this is also possible under the adverse condition of high pole or support mounting. With some inventive talent and skill, the camera may be remotely operated by string and pulley winding of film and shutter and exposing with a long cable release.

Planning of Photo Stations

As discussed before, there is no need to observe the stringent specifications regarding the exterior orientation as commonly exercised with phototheodolites. The aim of the following directions is to emphasize those measures which will assure optimum and gapless evaluation of the photo-pairs.

Reasonably close observance of the required distance from camera lens to target is important inasmuch as the plotting operations at the given scale should take place nearest to the plane of critical focus, which is at a distance of 31 cm. from the projector lens. For a given plotting scale $M=1:m$ the target distance $e=.31$ m. (meters)

Scale	1:2	1:5	1:10	1:20	1:50
Target distance from entrance pupil of lens	0.62 m. 2 ft.	1.55 m. 5 ft.	3.1 m. 10 ft.	6.2 m. 20 ft.	15.5 m. 50 ft.

The minimum spacing of neighboring projectors is 9 centimeters. This limits the freedom of choosing the base length (distance between the respective exposure stations) at the short end of the range. There is also a limitation at the long end if a series is to be made of (more or less) parallel exposures which shall provide continuous stereoscopic coverage of the scene. This condition resembles that of aerial photography, where at least 50 per cent forward overlap between consecutive pictures is needed for continuity of mapping. The 36 mm. side of the picture format will preferably be turned into the direction of the base line. Considering a camera focal length of 50 mm. and the standard miniature format of 24×36 mm., these limitations demand a careful planning of the base lengths and the parallelism of the exposure axes. As a matter of fact, the resulting tolerance is only ±9 per cent of the base itself.

The most desirable separation of the Multiplex projectors on the base bar is 10 centimeters. This results in the following set of data:

Plotting Scale	1:2	1:5	1:10	1:20	1:50
Base length	0.2 m. 8″	0.5 m. 1′8″	1.0 m. 3′3″	2.0 m. 6½′	5.0 m. 16½′

The base length equals the neat model width or increment furnished with each additional photograph in the series. The dimension of the model in the direction of the short format side is slightly in excess of 40 per cent of the first.

In taking photographs with the exposure axes elevated or depressed (the normal case with tilted axes), consideration must be given to the mechanical tilt limits of the projectors and their tilted depth zone. For reasons of vertical coverage, which corresponds to sidelap in aerial photography, it is recommended that the camera tilt measured from the perpendicular upon the plane of projection do not exceed 20 degrees (a gradient of 1:2.7).

Convergent Photography

Under certain circumstances the use of convergent axes has advantages. Two exposures aimed at the center of the scene may cover its full width, while coverage with parallel axes would require 3 pictures, of which the first and the third would contribute with only one half of their format area. Consequently, convergent axes will be preferred if, from the given object distance, the target width is fully covered, and if both pictures present its modulated surface without discontinuity.

Beyond these considerations all valid rules for obtaining good photographic negative quality should be observed.

The Midget Printer

The obvious advantage of using diapositives as work material justifies the use of a special printer by which the photographs are reduced to match the Multiplex characteristics. Because of the relatively small latitude (about 1:2) of the diapositive emulsion and of the density requirements for Multiplex projection, a close check on the appropriate exposure time must be maintained. Film was found adequate and more convenient for use if series of diapositives are to be produced. These considerations lead to a printer design, which is relatively simple to build and satisfies all conditions.

The miniature camera itself is used to furnish the lens, the diapositive stage and the film transport mechanism. An adapter ring is inserted between the housing and the lens, which increases the stage to lens distance by the measure of the Multiplex constant. The adapter ring also supports the negative stage in front of the lens. The plane of the negative stage is strictly parallel with the diapositive stage and is axially adjustable to permit the focusing and setting of the proper reduction ratio. A few test exposures at full aperture of the lens are made to ascertain the calibration. The setting arrived at will generally suffice in those cases where the same lens was used in the field. In order to compensate for the change of the camera constant due to finite focusing, the respective setting of the focusing amount used in the field is repeated when making the reduction setting of the printer. It is advantageous to mount a thin glass plate into the negative stage. This plate is marked with lines bordering the format and serving to center the negative, and with a center dot denoting the principal point. This point will be transferred to the diapositive in the printing process.

The assembled unit is placed upon a light box with an opal glass forming its window. It is important that light not contributing to image formation be carefully screened out by masks below and above the negative.

Fine grain positive emulsion on clear film base is used. It is placed into the camera in the conventional manner. The exposure time at lens stop 12.5 is of the order of several seconds. If the emulsion side of the negative faces the lens, the resulting diapositive will later be placed in the Multiplex projector with its base facing the projector lens to avoid side-inverted imagery.

The Multiplex constant equals 45.6 mm. If cover glass plates 0.9 mm. thick are used to protect the film diapositives, the optical path in the projector is lengthened by 0.9×0.66 mm. This will increase the thickness of the printer spacing ring to 46.2 mm. or will require the use of the focusing mount to offset the difference of 0.6 mm. Assuming a depth range of 80 mm. in the Multiplex model and a depth setting precision of the floating mark of 0.4 mm., then the constant should be established within 0.5 per cent in order to avoid systematic errors due to model deformation. As a check of the correct reduction ratio, a distance of 30 mm. measured on the diapositive should be correct within 0.15 mm. For details concerning accuracy of formulae and pertinent data refer to Bibliography.[1]

Use of the Sterogram

Methodically there is no departure from the routine procedures used in aerial survey and mapping. It suffices to refer to existing manuals of operation of the plotting instrument. We shall only point to particular circumstances significant for short range photogrammetry and to some peculiarities encountered with the use of miniature camera photography.

To establish the interior orientation the principal point should be centered in the projector. Since this point has been copied into each picture, centering offers no problem. The possibility of using the original negatives for plotting, and the effect of using a photograph principal distance departing from the Multiplex constant have been thoroughly investigated.[1] It will be assumed in the following that all spatial measurements result from undistorted pencils of rays if the diapositives meet the Multiplex constant.

The reciprocal orientation of the stereo pair follows the familiar pattern. Because of the small angular coverage of the taking camera, the overcorrection factor for parallax due to lateral tilt is about 15. A very convenient solution for the adjustment of convergent photographs[2] will facilitate their employment.

Short range photogrammetry is mainly concerned with targets that frequently display geometrical patterns, which are repetitive or related by symmetry. This particularly applies to architectural and ornamental structures. They often furnish an abundance of control data helpful to the exterior orientation of the stereo pair. On the other hand, the acuity of intersection of conjugate pencils of rays favors the propagation of errors in joining adjacent models by stereoscopic control. To avoid the rapid accumulation of errors, model extension through a series of photographs should be strongly supported by supplementary lines of control to be established on the object surface. Therefore, prominent vertical contours of long fronts of buildings are fixed by taped lines run at shoulder height along the structure. These measurements will check the scale of each component model. If the vertical dimensions of house fronts are such that several parallel series of photographs are needed for coverage, geodetic methods for control point fixation may be called upon to supplement the control pattern in the higher region. Radial line and slotted templet methods may also occasionally prove their value using enlarged prints as a base.

The tracing table performs the task of transferring the surface detail of the model upon the mapping plane in orthogonal projection. A vertical wall of a building will be presented in parallel projection upon a vertical reference plane. This is exactly what the architect needs and considers as the standard presentation of his design. The conventional procedure of plotting topography, therefore, applies without change. It is, however, necessary to establish parallelism between this wall and the mapping surface. This, the exterior model orientation, is accomplished in the usual manner by tilting and tipping the projector supporting frame over the mapping surface. The well-known control triangle, the corners of which are tied by coordinates to the vertical reference plane, is the minimum requirement by which the correct relationship can be established. While the planimetric plot shows the structural detail in vertical plan, the readings on the tracing table counter mean depth measures of detail points in front or behind the datum plane. The plotting of structural lines in space is continuous as usual by stereoscopic guidance of the floating mark over the model surface and lifting or lowering the platten in conformity with its relief.

Profiles parallel with the datum plane correspond with contours in aerial mapping. Profiles in planes perpendicular upon the datum plane may be constructed from point by point plottings, unless use is made of a profile attachment to the tracing table.[1] The trace (a straight or curved line) of the profile to be developed is first laid out on the map sheet, then all prominent detail points along this trace are spotted on the model surface, marked on the map sheet and labeled with the respective counter reading. The profile is subsequently constructed by plotting the counter entries as ordinates perpendicular to the trace.

Chord lengths of common curves of intersecting surfaces may be obtained indirectly from plan and profile measures, or directly by introducing a sheet of coordinate paper holding it in such orientation that its plane cuts through the model surface at the terminals of the chord, and that one set of the grid lines runs in the direction in which the length of the intercept shall be read. As an expedient the side scale of a slide rule held over white paper may serve the same purpose.

Developed surfaces, for example, of cylindrical or conical shapes, may be obtained immediately if the respective surface molded of white paper is inserted into the model space. Surface detail may then be directly drawn on it with a pencil.

Ceilings of buildings are readily mapped, too. The stereo model is produced as usual from photographs taken with the camera placed and oriented on the floor pointed straight up. The graphical plot may present the detail as seen from beneath or, if desired, as projected down into horizontal plan. In the latter case the diapositives are placed in the projectors in an inverted position.

Significant By-products

Rectified prints of single pictures may

be obtained through Multiplex projection with satisfactory quality if the copying easel is placed at or near the projector's optimal projection distance. Pass point templets are used to orient the projector. The use of the original negatives in this application will be of obvious advantage. To comply with theoretical requirements the negative principal point is to be displaced as the angle of tilt of the projection axis increases. The measure of displacement will be found by computation[1] from a relatively simple formula. The value of the reduction factor is in our case

$$k = \frac{\text{Camera constant}}{\text{Multiplex constant}}.$$

It will also be necessary to fix the location of the foot of the perpendicular from the lens center on the easel. A primitive implement is adequate for doing this with satisfactory accuracy. A mirror with a small center hole and with several circles scribed around it into the reflecting coating, is placed upon the easel. It reflects the light from the projector onto the room ceiling. At the correct position of the mirror, the shadow images of the circles are observed concentrically with the silhouette of the yoke supporting the projector. The plumb point is plotted through the hole in the mirror. Its distance y from the principal point projected on the easel is measured. The required displacement Δy of the photograph principal point along the line and in the direction plumb point—projector principal point will now be computed as

$$\Delta y = \frac{k^2 - 1}{2} \cdot y.$$

Example: given the camera constant 52 mm. and
the Multiplex constant 46.2 mm.
then: $k = 1.12$, $\Delta y = 0.13y$.

The value of y is derived from a preliminary orientation of the projector. After applying the displacement Δy to the photograph principal point, the final orientation of the projector is made. The effect of a residual error of this displacement is an affine geometrical distortion in the rectified print.[1] The corrective settings used for the projector orientation are: height change, longitudinal and lateral tilt. Only three pass points are needed. Neighboring rectified prints may be joined together following the practice of aerial mosaic making.

Rectified stereo pairs may be produced by this method of rectification. The examination at large scale and without interference of y-parallax under a mirror stereoscope offers a convenient method for study and investigation. A simple pocket stereoscope may be used for sectional examination. Rectified series of overlapping photographs may also be processed to furnish mosaics observable in three dimensions.[1]

Controls and Supplementations

Similar to architectural targets where geometrical coordination of detail offers ample control for scaling and orientation, many targets in other fields of short range photogrammetry possess properties which provide guides and checks that simplify the control problem. Besides, it will seldom be difficult to establish them on the object or its immediate surroundings before taking the photographs.

After the plotting operations, a number of imperfections will usually remain, which stem either from lack of identification of rich detail or from the hand guided movement of the floating mark against static and dynamic friction between the tracing table and the mapping surface. But the skeleton drawing is generally sufficient for accurate fair drafting, if it is aided by simultaneous stereoscopic checking of the work photos. A special small stereoscope was found to be very helpful in this phase of operations. It consists of two magnifiers 12× mounted in front of across slide, which holds the film negatives for observation in transmitted light. The cross slide permits placement of conjugate sections of both negatives into the field of stereoscopic vision. The inter-pupillary distance is adjusted by lateral displacement of one of the magnifying lenses. Vertical offset of conjugate imagery is corrected by vertical shift of the other magnifier. Focusing is provided for both lenses individually. Where possible, field inspection of the object should furnish a final check on the end product.

Practical Applications

The equipment described lends itself very favorably to many problems of reconstruction. It makes possible the photographing with little preparation of many experimental setups in research laborato-

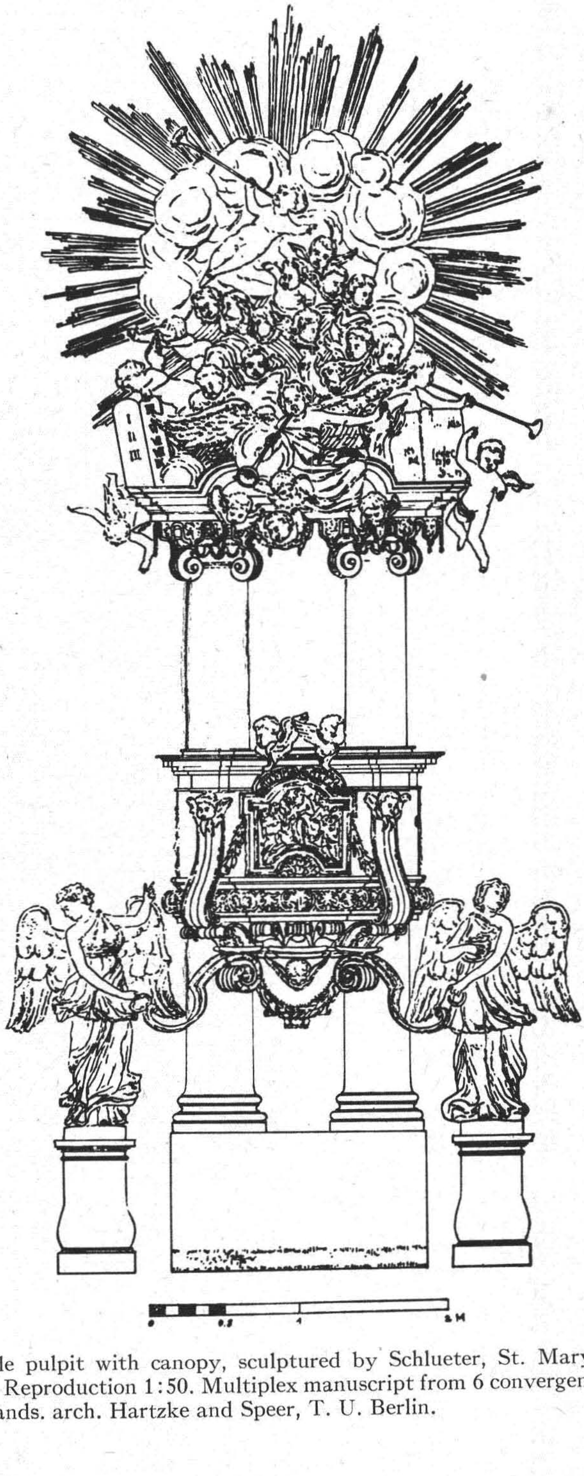

FIG. 1. Marble pulpit with canopy, sculptured by Schlueter, St. Mary's Church, Berlin. Original plot 1:25, Reproduction 1:50. Multiplex manuscript from 6 convergent miniature camera photographs by Cands. arch. Hartzke and Speer, T. U. Berlin.

ries and convenient evaluation of the photographic records at a later date. The archaeologist and explorer is confronted with the task of photographing his discoveries in a way that they can be presented in good pictorial quality for publicity purposes, as well as in figures, plans and profiles for scientific investigation. The potent advantage in these instances is the immediate readiness of a miniature camera for the shot, which is a convenience not offered by other equipment. Many objects have, thereby, been brought into the measuring control of photogrammetry, which otherwise would have been dropped because of lack of equipment or of complications in handling it. Another decided advantage is the availability of film and accessories most anywhere.

Several samples of many interesting applications produced at the Institute of Photogrammetry of the Technical University of Berlin under the direction of Professor Dr. O. Lacmann may be given. Figure 1 shows a pulpit with canopy, 24 ft. high, sculptured in marble. Three convergent pairs of photographs were taken at three levels from a distance of 25 ft. and plotted at a scale of 1:25. The plotting was done by students of architecture. Revision work with the stereoscope followed the manuscript drawing. Further supplementation was carried on during field inspections. This example brought forth the great advantage of continuous line plotting from models with extreme wealth of forms and details.

A series of overlapping photographs with parallel axes served to construct the plans of a palace front 150 feet long, 43 feet high. Three series of 16 exposures each at three different levels, and 2 series of 5 exposures each, making a total of 58 pictures, were necessary for total coverage from across the street, affording an object distance of only 24 feet. Three students of architecture accomplished the plotting at 1:25. The control traverse was a taped line at shoulder height. Discrepancies in joining the upper series pointed out the advisability of observing with a transit instrument several additional control points in the higher region of the long structure.

A richly ornamented arched ceiling was surveyed with three series of 4 exposures each with the camera placed on the floor. The artificial lighting had to remain unchanged during the photographic operation to avoid errors in the stereoscopic interpretation which arise when shadow contours change their positions between exposures.

When the project is completed the deposition of 12 million cubic yards of rubble to be removed from Berlin's business and residential sections after the war will result in a dump 220 feet high covering an area of half a square mile within the city. For planning this operation a relief model 1:200 of the proposed hill was built by landscape architects. To permit a prestudy of its design, it was photographed from the ceiling of the exhibition hall with 40 exposures and plotted with the Multiplex at a scale of 1:10, corresponding to 1:2,000 in nature. The resulting topographic map was subsequently enlarged to 1:1,000. It serves to transfer and control the topographic shape in the terrain, where the dumping operations started from the perimeter and progress toward the center.

Investigations of the acoustical properties of the stage drapings of Berlin's Titania Auditorium required data on the configuration of the stage envelope, profiles, elevation plans, developed surfaces and spans. Without interfering with other activities on the stage convergent photographs were taken. Evaluations were made at a scale of 1:100, and a scale model 1:50 of all stage features was constructed, which helped to solve the problems involved.

Similar tasks are currently being studied and solved. They confirm the above findings and statements that the procedures so economically practiced in aerial photogrammetry can successfully be employed in a wide sector of short range photogrammetry by the use of the miniature camera and the Multiplex.

Bibliography

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