TERRESTRIAL PHOTOGRAMMETRY FOR SUPPLEMENTARY CONTROL

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SINCE the outbreak of war at Pearl Harbor, the United States Forest Service has been constructing detailed topographic maps for the War and Navy Departments. Aerial photographs were used for all projects and the maps were required to conform to standard accuracy specifications in every case. The basic equipment used in this mapping program has been the K.E.K. Stereoscopic Plotter, an instrument devised by the Forest Service as a result of its particular mapping needs and limitations.[1] Experience during this period indicates that the K.E.K. method compares favorably with more widely used practices in overall cost, despite the necessity for establishing field control on individual stereoscopic models. An analysis of mapping expenditures showed that 68.8% of the total was devoted to horizontal and vertical control and pointed emphastically to this field as the logical subject for further improvement in procedures.

The writer's previous experience, including the Boulder Dam mapping of the Aerotopograph Corporation, and the work of R. M. Wilson, U. S. Geological Survey, suggested terrestrial photogrammetry as a profitable field of investigation. The experimental work done some ten years ago by Lage Wernstedt, Region 6, U. S. Forest Service, on the use of the photogoniometer with oblique aerial photographs also provided useful background data. A project was set up to test equipment and methods for economy and accuracy under varying topographic conditions.

The basic field equipment for such a project was not readily available at the time, and in addition it was thought that the standard photo-theodolites were too complicated and expensive to have the greatest practical value for the problem at hand. Consequently, it was necessary to devise an instrument (the camera transit) which would be capable of taking the photographs at predetermined horizontal and vertical angles with the requisite accuracy, but would still retain the desired features of simplicity of operation and rugged construction. It was also necessary to improvise a number of items of auxiliary equipment to increase the efficiency of the field work.

For the office phase of the work, i.e., the transfer of horizontal angles from photograph to compilation sheet and the measurement of vertical angles on the photographs, the Wilson Photo-alidade was available. As the work progressed, however, the photo-transit was designed and built to take the place of the photo-alidade. The photo-transit is identical with the photo-alidade in basic principles, but a horizontal circle with vernier has been substituted for the fiducial rule of the alidade, so that horizontal photograph angles may be transferred to the compilation sheet either graphically, by means of the vertical hair in the transit telescope, or by reading angles and computing geographic positions in the ordinary manner. The photo-transit can be oriented and the horizontal and vertical circles set so as to reproduce the readings of the field instrument, a definite advantage in operation, and the use of a light mountain transit in the construction of the instrument permitted a compact design and easy movement over the compilation sheet.

[1] This plotter has been described by the writer in Volume *X*, No. 4 of PHOTOGRAMMETRIC ENGINEERING.

FIG. 1. The Camera Transit.

The camera transit is exact y what the name implies; a camera combined with a transit. (See Figs. 1 & 2.) The transit used to construct this equipment was a large type K&E one minute Forest Service instrument. The telescope and standards were removed, the standards split apart at the base, and a wide aluminum plate fitted around the base of the compass box and fastened to the upper limb of the transit. This new plate enabled the standards to be separated so that the camera could be mounted between them on the axis normally occupied by the telescope. The camera consists of a sturdy cast aluminum housing and an aluminum cone placed on the front of the housing, accommodating lens adapter and lens. The lens mounting was rigidly attached to the cone so that the camera focus was fixed. The rear of the housing was fitted with a 5×7 plate adapter and ground glass viewing plate. The axes were removed from the telescope and fastened to the horizontal axis of the camera housing, which was then mounted between the widened standards in the regular horizontal axis bearings. The optical axis of the camera was located and fiducial marks placed on the frame so that they would register on the photographic negative. The telescope, with its axis removed, was mounted on the top of the camera housing and adjusted to make its optical axis coincide with that of the camera when sighted on a distant object. The level bubble from the telescope was also mounted on

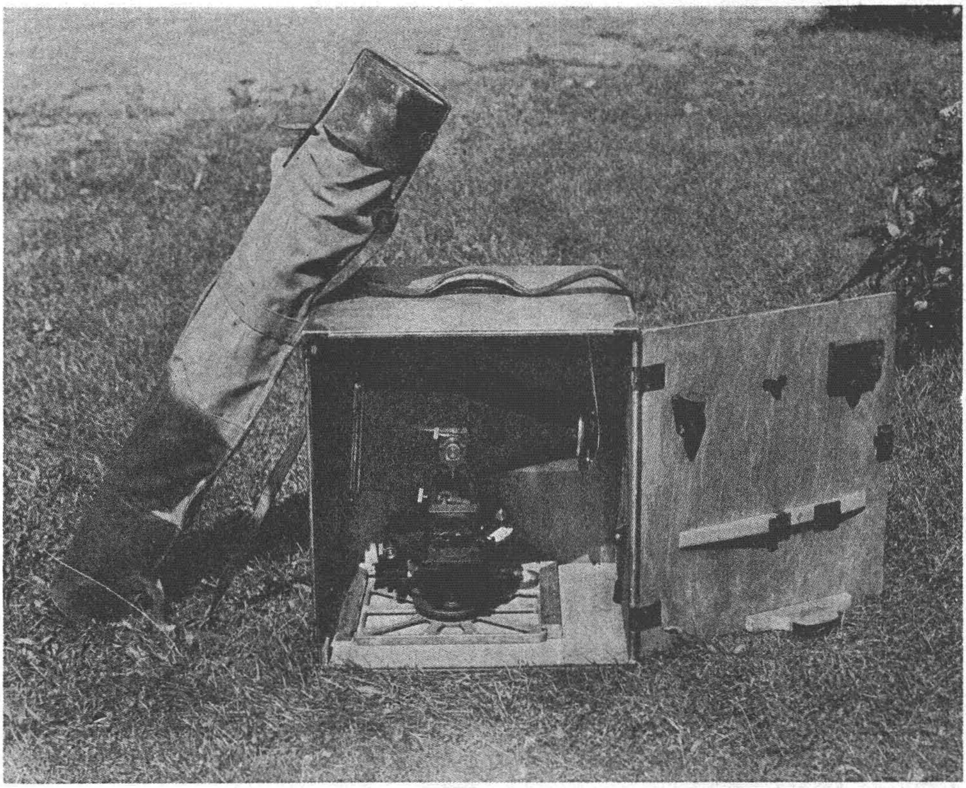

FIG. 2. The Camera Transit in packing case.

top of the camera housing and adjusted to the camera. The focal length of the lens used was about 12.9 inches, giving a horizontal angular coverage of 29° on a 5×7 plate. To insure complete horizontal coverage, the photographs were taken at 28° intervals on the horizontal circle.

The photo-transit consists of two parts: (1) the transit and base, (2) the target for holding the photograph. (See Fig. 3.) The base is a Buff and Buff heavy metal trivet about 7 inches high, with a shifting head adjusted by x and y slow motion screws. The transit used is a small K&E mountain type instrument with vertical circle, adapted to photographic work by modification of the optical system of the telescope, and provided with a new and extremely convenient optical plumbing device. The telescope was revised by removing the objective lens and replacing the focusing lens so that a focus from 3 inches to infinity is possible. The magnification of the new optical arrangement is approximately $2\frac{1}{2}$ diameters. The instrument is centered over a point by means of the plumbing device mentioned above, which consists of a 3/16″ hole drilled vertically through the pivot point of the compass box and the inner center. With this provision, the instrument can be placed vertically over a point by making the telescope vertical and sighting directly at the point. The final centering is easily accomplished by means of the delicate x and y motions of the shifting head.

The target is a cast aluminum framework designed to place the photograph precisely in the same relationship with the photo-transit as that of the camera transit and its positive plane. A flat aluminum plate, having a small needle projecting from its center is the base used for mounting the photograph. The plate has four spring clips for holding the corners of the photograph and can be revolved by means of a tangent screw located on the right side. The plate is mounted within the framework on a threaded metal shaft, along which it can be moved to correspond with the focal length of the camera lens, and it can be moved in the vertical plane with a clamp and slow motion screw arrangement

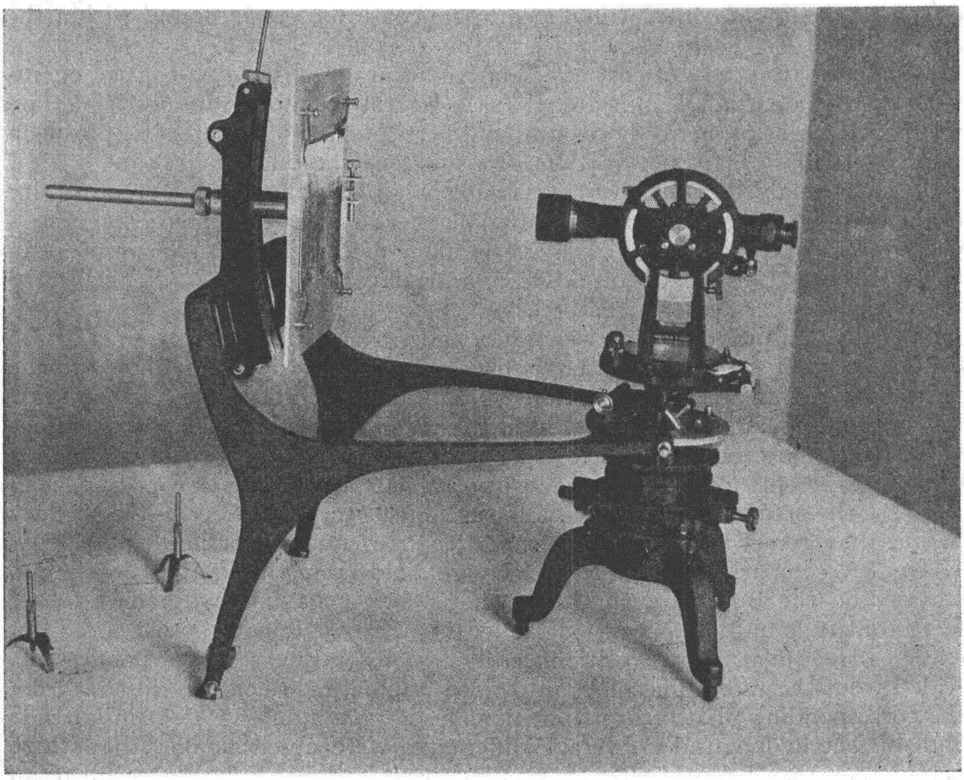

FIG. 3. The Photo Transit.

on a segmental arc. The radial motion given by the segmental arc does not disturb the focal length adjustment, as the arc is centered on the horizontal axis of the telescope. As a result of this design, a perpendicular from the center of the plate will meet the point defined by the horizontal and vertical axes of the transit at any position, making it possible to reproduce quickly the original relationship of positive plane and camera, and to measure true vertical and horizontal angles directly from the photograph. Attachment of the target frame arms to the transit is effected by means of two concentric metal rings or collars fastened to the leveling head of the transit. This method of attachment permits the entire frame to move about the vertical axis of the transit. Ball bearing feet carry the weight of the target assembly and permit easy motion over the compilation sheet. Final adjustment of the target to the correct horizontal angle is made with a tangent screw.

Two $7\frac{1}{2}$-minute quadrangles of differing topographic characteristics were chosen for the experimental work. Both have been recently mapped by the Forest Service, using field triangulation for supplementary horizontal control and fourth order leveling and stadia methods for vertical control. The first, Flat Ridge Quadrangle, lies in a mountainous and wooded area a few miles north of Gettysburg, Pennsylvania. It offers difficult problems for any type of control because of the heavy timber and brush cover and numerous valleys and ridges. Buckeystown Quadrangle was selected for the second unit of the project as a typical example of a relatively flat quadrangle in an extensively cultivated area. It is located immediately south of Frederick, Maryland. These quadrangles offer the maximum contrast in topographic conditions to be found within the area mapped by the Forest Service in this region.

Comparative study of cost and relative accuracy of the two control operations on each quadrangle indicates that the terrestrial photogrammetric method will provide a dense net of horizontal and vertical control of sufficient precision to meet standard map specifications at a substantial reduction in cost.

A sharp analysis of relative costs is not possible at this time, as the novelty of the photogrammetric method resulted in considerable experimentation in field procedures. In addition, an excessive number of camera stations were established to test consistency of position and elevation determinations by the terrestrial photogrammetric method.

Relative accuracy can be determined more easily, however, by comparison of the results on duplicate points. On the Flat Ridge Quadrangle photo-alidade positions on three stations previously located by fourth order triangulation differed by a maximum of 14 feet in latitude and 11 feet in longitude. Positions on 13 stations were determined from a radial line plot laid to photo-alidade control and compared with previously established triangulation positions; in this case the greatest error in latitude was 26 feet, the remainder of the stations having an error of less than 20 feet, and the maximum error in longitude was 18 feet. A comparison of photo-transit and field triangulation positions for 6 stations on the Buckeystown Quadrangle shows a maximum difference of 17 feet in latitude and 22 feet in longitude, but the remaining differences did not exceed 10 feet in any case. Positions on 14 stations on Buckeystown Quadrangle, scaled from the radial line plot laid to the original field control, differed from the corresponding photo-transit positions by a maximum of 19 feet in latitude and 46 feet in longitude. Average differences were much smaller than these maximums; the 46 foot discrepancy in longitude appears to be the result of an error, since the next largest difference is 22 feet. Comparative elevation figures are available for 284 points on the Buckeystown Quadrangle. Here the maximum difference in elevation was under six feet and 50% of the differences did not exceed two feet.

The process of establishing supplementary control by terrestrial photogrammetry is in every respect analogous to that used in establishing an intensive net of triangulation. The procedure is broken down into two distinct operations—field work with the camera transit, and office work with the photo-transit. The field operation consists of the occupation of known positions with the camera transit for the purpose of making photographic exposures at accurately determined azimuths and angles of elevation or depression. The office work with the photo-transit involves the graphic reproduction of the horizontal angles recorded by the photographs, and measurement of vertical angles for the determination of elevation. This method of obtaining control makes necessary more careful office planning than is customary and demands of the field engineer a thorough knowledge of the photographic techniques necessary for making exposures of the best quality, but requires far less manpower and time in the field.

The essential phases of the work are perhaps best presented by describing the sequence of operation a 15-minute quadrangle. It is assumed that the quadrangle will be mapped on a manuscript scale of 1/31,680 with a contour interval of 50 feet, that 1/24,000 vertical photographs meeting standard accuracy specifications are to be used for stereoplotting, and that horizontal and vertical control must conform to the pertinent Forest Service specifications, which are as follows:

Horizontal Control—3rd or Higher Order

There shall be three 3rd or higher order horizontal stations within the boundaries of each 15-minute quadrangle and their distribution shall be such that at least one of these stations will fall in the north half, one in the south half; and if practicable, the third station shall be placed so that there is a station in both the east and west half. The east and west half distribution is not compulsory.

Horizontal Control—4th Order

At least one positively identifiable point shall be established so as to appear approximately midway within the overlapping area of adjacent flights, approximately opposite the center of every fifth photograph. Wherever possible, these points shall appear on six photographs Along the boundaries of the project area, the same intensity and spacing of control is required for the last flight of photographs even though it necessitates the establishment of control outside the project boundary. Wherever possible, these points shall appear on three photographs and be approximately midway between the center and the edge of the pictures. Any 3rd or higher order control that meets these requirements will, of course, supplant the 4th order.

Vertical Control—3rd or Higher Order

Third or higher order level lines shall be so spaced that they shall pass through portions of at least three quarters of each quadrangle.

The preliminary phase of investigation of existing basic control is, of course, independent of the supplementary control methods to be used. If this investigation shows that existing basic control is not adequate, it will be necessary to establish the required additional triangulation station or level lines by conventional methods.

The engineer must first plan a net of camera transit stations for horizontal control, bearing in mind the purpose for which the stations are established. The distance at which objects can be identified on oblique photographs, the fact that photographs will also be used for vertical control, and the fact that it is not necessary that these photographs give complete three-point coverage of the entire terrain, but only of salient topographic and man-made features which can readily be identified on aerial and terrestrial photographs, are primary considerations in selecting camera transit stations. With this plan in mind, the engineer should first visit each proposed camera station and construct any towers or targets needed to insure the identification of the station on photographs taken from nearby camera stations, and make positive identifications of the stations on the aerial photographs. The number of such stations will depend largely on the topography and cover of the country but can be expected to range from 12, under ideal conditions, up to as many as 35. It will not be necessary to consider the location of these stations in relation to the photographs to be controlled, as this problem takes care of itself in the office procedure. The major concern is to be sure that the horizontal camera stations form a strong breakdown net of triangulation and are appropriately spaced to obtain the results required. Each station should be perpetuated and plainly marked so as not to be confused with triangulation stations of higher order.

The engineer then occupies each of these stations, adhering to the procedure described immediately following for his observing program. The camera transit is set over the station and a known and distant triangulation station is selected as the orientation point. The vernier is then set on the correct azimuth to that station (obtained from previous observations, or triangulation data). When the instrument has been properly oriented, the upper motion is unclamped and the camera rotated to the 00° mark (South) for the first exposure. Photographs are then made at 28° intervals in a clockwise direction until the complete horizon has been covered. This requires a minimum of 13 photographs. The angle of depression or elevation at which the exposure is made is determined by the nature of the terrain; in some cases it may be necessary to make two or more exposures at the same azimuth to obtain complete coverage. Each exposure is identified by a marking device which is recorded on the negative. After all exposures have been completed, the telescope is again pointed at the initial station and the vernier read to detect any error which may have crept in during the operation. After checking the orientation, the observer reads the azimuth to all visible camera stations, repeating the orientation check after each reading, and performing the entire operation at least twice to guard against error. These azimuths to visible camera station are later used to aid in the identification of the stations on the terrestrial photographs, and can be used for determining their geographic positions.

Since reliable identification of objects for vertical control on the terrestrial photographs is limited to about three miles, it is necessary to establish additional camera stations to complete the coverage for vertical control. A sufficiently accurate position for the vertical control stations can be obtained by identifying the stations on the aerial photographs and locating the identified point on the compilation sheet by means of the radial line plot. For this reason it is possible to omit the azimuth determination and pointings to other camera transit stations, an assumed azimuth being used in measuring the proper horizontal interval for exposures. The shortened observing program can usually be completed in from 30 to 45 minutes. This freedom from restriction on location of the supplementary camera stations frequently makes it possible to place them at points of easy access and identification, and materially increases the speed of the field world. A portable tower 25 feet in height was used with marked success on the Buckeystown Quadrangle, with an average of eight to ten stations occupied per day. The roofs of buildings were also utilized to obtain the necessary clearance. Camera stations are located on or near bench marks whenever practicable, as the elevation of each station must be determined by some instrumental method which permits consistent closures of not more than two feet. In the case of stations used for horizontal control also, this consideration must be subordinated to the requirements of the triangulation net, but for the stations established purely for vertical control it is of primary importance.

From this point on the operation becomes an office procedure. The photographic plates are developed and two sets of contact prints made, the first on single weight paper for use if further field identification becomes necessary, and the second on double weight positype paper for the photo-transit work. Projections are constructed on the manuscript sheets and the basic control stations are plotted. Concurrently with this work the vertical photographs are laid out and inspected to determine the proper locations for fourth order horizontal control, the selected points are marked on the vertical and photo-transit prints, and all field identifications are transferred to the positype prints to be used in the templet laydown. This operation requires a high degree of care and skill, and should always be performed by a highly trained engineer and photogrammetrist. The prepared oblique prints are then delivered to the photo-transit operator for the control plotting.

This procedure is initiated by setting and adjusting the photo-transit over the most favorably located basic control points. A photograph exposed at this station is placed on the target plate with its principal point exactly over the needle on the center of the plate and its fiducial marks coinciding with lines ruled on the horizontal and vertical axes of the plate. The approximate focal length is set off by moving the plate in or out along the threaded shaft until the distance from the center of the plate to the horizontal axis of the telescope corresponds to the focal length of the camera. The final and precise focal length adjustment is made by moving the plate until the angle turned between the horizontal fiducial marks agrees exactly with the correct angle as obtained by computation. The final adjustment corrects any error due to print shrinkage or expansion. The vertical angle at which the photograph was made is next set on the vertical circle and the plate moved on the segmental arc until the telescope cross hairs rest on the principal point of the photograph. The final adjustment consists of revolving the plate with the tangent screw so that the horizontal hair will cut the right and left fiducial marks when the telescope is turned on its vertical axis.

After the photograph has been properly set up, the horizontal vernier is set to the orienting azimuth used by the camera-transit and clamped; the telescope is then sighted on the orienting station on the compilation sheet and the lower motion locked in this position. The upper plate is then released and set to the azimuth of the photograph to be used, and the target is brought into true orientation by moving it until the principal point of the photograph is cut by the vertical hair. The target is then locked. The photograph in now in its proper position and horizontal angles to any point desired can be transferred to the compilation sheet by depressing the telescope and marking the line defined by the vertical hair. This procedure is repeated for each camera station, thereby determining the position of all camera and fourth order stations by means of three or more intersecting lines.

When all horizontal control work has been completed, the vertical control operation is begun. Horizontal and vertical photo-transit work are not carried on simultaneously unless more than one photo-transit is available. The first step in vertical control is a new laying out of the vertical photographs used in the templet laydown and K.E.K. Plotter to determine the number and proper location of spot elevation points necessary to control each stereoscopic model. The selected points are then marked and transferred to the olbique photographs for use in the photo-transit. Their horizontal positions, as well as those of the auxiliary camera stations, are found by radial line plotting on an acetate control overlay sheet. The horizontal distance from camera station to elevation point is scaled in feet on the control overlay and the result recorded on a standard form provided for each camera station. These forms, together with the photo-transit prints on which the elevation points have been identified, are then submitted to the photo-transit operator for the vertical angle readings.

The prints are set up in the photo-transit at the proper angle of depression or elevation as indicated in the camera-transit notes for the station, and vertical angles are read to all identified elevation points and recorded on the standard form. This procedure is carried on systematically, station by station. Scaling of horizontal distance, the photo-transit set up, and the vertical angle reading are repeated by independent operators, resulting in two sets of vertical angle forms for each camera station. Both are submitted to the computing section for averaging and computation.

A general appraisal of our experience with terrestrial photogrammetric control indicates several inherent advantages and one particular defect. An outstanding feature of the method is the flexibility of the field work program after the detailed planning has been completed. A varying number of crews can be employed without any loss of time, since the work of one crew does not depend upon that of another. The photographs and notes made at each station constitute an extraordinarily complete record, and are available for use at any future time. The process of establishing vertical and horizontal control points is so simple and rapid that any unusual requirements developing during the course of the stereoplotting or templet laydown are handled without delay, and a rigid check can be placed on the manuscript by utilizing the same basic material. The most serious defect noted is a strong tendency to establish an excessive amount of control. This can be corrected only by experience.

The question of the applicability of the method to varying topographic conditions cannot be answered with any great degree of precision. The writer believes, however, that some 60% of the area of the continental United States can be worked advantageously with the equipment described above.