DEVELOPMENT OF THE ORTHOPHOTOSCOPE*

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ABSTRACT

The Orthophotoscope is a newly-developed device for converting conventional perspective photographs to the equivalent of orthographic photographs. With this instrument, photographs are produced having no displacements of images due to tilt or relief, so that horizontal distances can be measured accurately on the photographs. Such uniform-scale photographs have many important uses in engineering, geology, forestry, and other scientific fields. There have been previous attempts to accomplish the same objective, notably the Gallus-Ferber apparatus; the Orthophotoscope is much simpler and more feasible from an operational or economic standpoint. The new instrument is operated in conjunction with an oriented model formed by any type of double-projection stereoscopic plotter using the anaglyphic principle. A sensitized film is "scanned" by a slit in a screen on which the model is projected. The elevation of the film is varied according to the terrain as the scanning proceeds. The sensitized surface is an orthographic film which is sensitive only to the blue light and not to the red light of the usual anaglyphic projection. When the scanning is complete, the film is developed as a negative and the "orthophotographs" are printed from this negative in any quantity or scale.

THE Orthophotoscope is a device for converting conventional perspective photographs to the equivalent of orthographic photographs, for practical purposes. In a hypothetical orthographic aerial photograph (See Figure 1) the image plane (or projection plane) in the camera would be parallel to the datum plane and all image rays would be perpendicular to these two planes. There would be no displacement of images due to tilt or relief, and the resulting photograph would be a true map having a uniform scale. Horizontal distances measured on such a photograph would be correct, regardless of the relief of the terrain. This is in marked contrast to the well-known relief displacements of conventional perspective photographs. If a perspective photograph is tilted, there is a further distortion of the scale. The orthographic photograph, by definition, has no tilt and therefore no scale distortion due to tilt. It is emphasized that the Orthophotoscope does not produce actual orthographic photographs of the terrain; rather it is a means of producing the *equivalent* of orthographic photographs from perspective photographs of the terrain. The equivalent photographs produced by this method are called "orthophotographs."

THE NEED FOR ORTHOPHOTOGRAPHS

There has long been a need for photographs on which data can be plotted or measured directly without the necessity of making adjustments for a varying scale due to tilt and relief. The problem of tilt alone, in areas where relief is not a significant factor, has been solved to a degree by excellent rectification procedures. But the need for aerial photographs having a uniform scale despite ground relief has not been met heretofore by any simple practicable method. Given an orthophotograph, the engineer, surveyor, forester, geologist, or any other person needing such information can correlate points imaged on the orthophotograph with points observed on the ground, and knowing the scale, can make direct measurements on the orthophotograph to determine distances between points. This cannot be done with conventional photographs because of scale distortion, and is often difficult to do even with good topographic maps because the map does not bear the wealth of detail found in the orthophotograph. Furthermore, the geologist, forester, or other scientist, can plot scientific field observations in their correct positions and orientations directly on the orthophotographs without the necessity of first making a conventional base map himself, or delaying the work for a lengthy period until a base map becomes available from another source.

Some of the specific potential uses of orthophotographs are as follows:

The orthophotograph can be used as a

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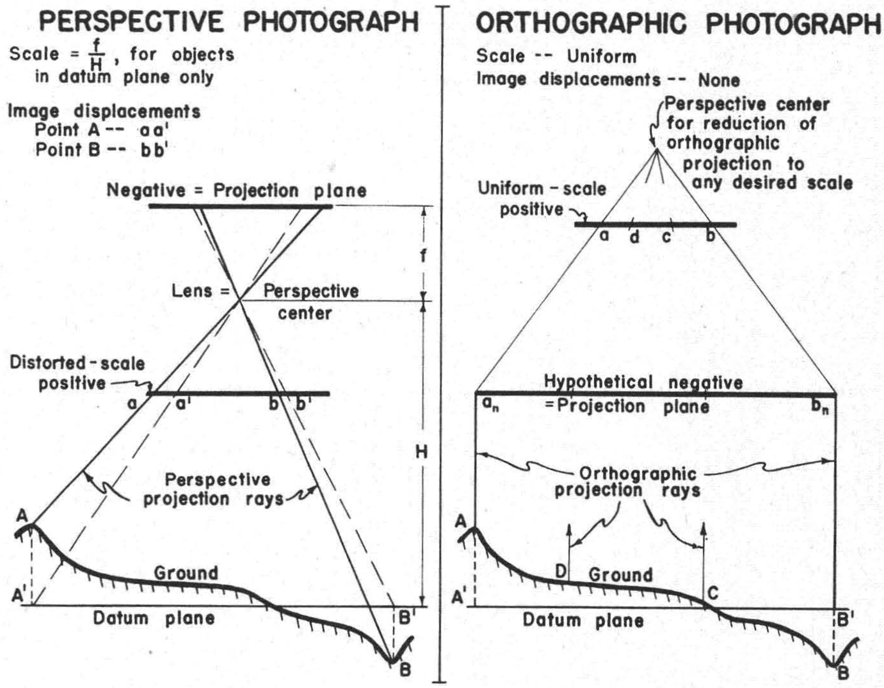

FIG. 1. Comparison of perspective and orthographic photographs, showing effect of relief.

base for plotting in their true positions, by correlating objects on the ground with their images on the photographs, such geologic features as fault lines, lithologic contacts, prominent resistant beds, linear features, and axes of anticlines and synclines. Strikes and dips of formations can be determined by the usual field methods and plotted directly on the orthophotograph in their proper positions, both relative and absolute.

In the same way, agronomic data, such as woodland boundaries, timber classification, soil classification, and crop inventory can be expeditiously plotted directly on the orthophotograph with an accuracy sufficient for a reliable determination of the acreage of tracts within a given category.

Property surveys can be based on corner monuments or accepted fence lines that can be definitely identified in the orthophotograph. A plot based on an orthophotograph would show the true plan of the tract of land at a uniform scale, as long as the corners or boundaries were visible and correctly identified.

Distances scaled on an orthophotograph can be used in combination with vertical angles determined in the field to calculate the difference in elevation between any two points. This would expedite the procedure for obtaining supplemental control, known as "photo-trig."

The orthophotograph can serve as a base for the compilation of a contoured photomap by using it, at a suitable scale, on a planetable or with a stereoplotting instrument, thus replacing the conventional base sheet.

The orthophotograph can be used without further treatment as a general-purpose substitute for a planimetric map, for compiling such data as place names, political boundaries, and so on.

Large numbers of orthophotographs can be assembled into a uniform-scale mosaic with no distortions due to tilt or relief.

A profile of the terrain along any line on the orthophotograph can be drawn automatically, if desired, by means of an attachment for recording the vertical motion of the Orthophotoscope as the line is scanned.

THE PRIOR ART

The desirability of converting conventional perspective projections of photographs into orthographic projections has long been recognized, and attempts have been made previously to solve the problem. The most notable attempt of which there is general knowledge is the use of the Gallus-Ferber photorestitution machine.[1] The general principle of the Gallus-Ferber apparatus is similar to that used in the Orthophotoscope, but the structural arrangement and method of execution are completely different. Detailed differences between the two systems are discussed further along in this paper. Suffice it to say, at this point, that the Gallus-Ferber apparatus is clearly acknowledged as the forerunner of the Orthophotoscope, in general concept. The important advance is that the Orthophotoscope is a relatively simple apparatus which obtains the desired results directly from conventional plotting equipment in everyday use, and is quite practicable from an economic standpoint.

History of the Development

The ideas embodied in the Orthophotoscope were conceived by the author as far back as 1936, but no steps were taken towards its development until October, 1950, when the first experiments were performed by the Photogrammetry Section of the Geological Survey in Arlington, Va. The principle is shown schematically in Figure 2.

The initial experiments were performed with a relatively crude arrangement of sensitized paper, a mobile paper screen with a hole serving as the scanning slit, and Multiplex projectors. The early experiments showed that it was possible to obtain a continuous photographic image on the sensitized paper by exposing it piecemeal to the rays projected by the Multiplex projectors; piecemeal exposure was effected by moving the screen over the sensitized paper so that the hole scanned the entire surface. It was also shown that if conjugate images were projected to the sensitized surfaces, one in blue-green light and one in red light, the blue-green image only would affect the sensitized surface.

Further development work on the device was tabled because of the pressure of other research efforts by the Section. Early in 1953, however, the U.S.G.S. Inter-Division Committee on Application of Photogrammetric Techniques to Geology expressed an acute need for a device of this nature to facilitate the compilation of geologic data in the accelerated search for strategic minerals. Spurred on by this need, the Photogrammetry Section renewed its efforts towards producing a practicable means of making orthophotographs.

By the fall of 1953, a workable mock-up

[1] Talley, B. B., Aerial and Terrestrial Photogrammetry. Pitman Publishing Corporation, New York, 1938, pp. 519–521.

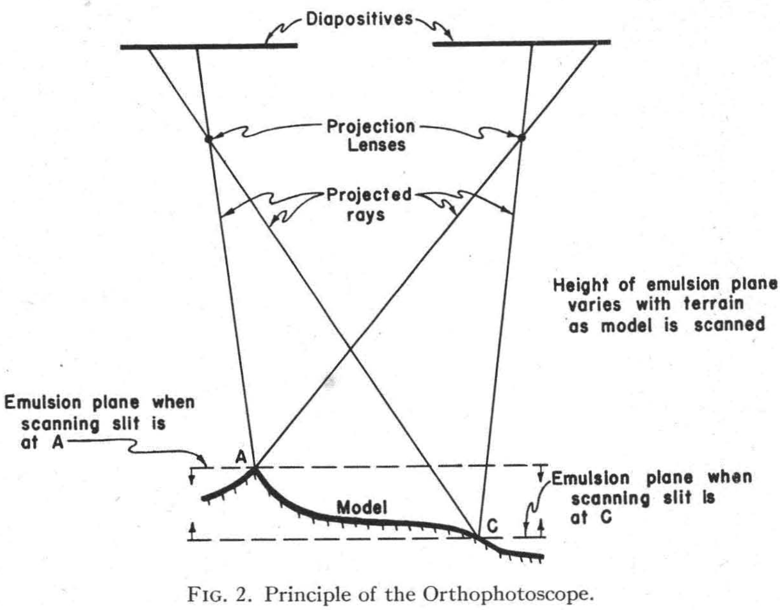

FIG. 2. Principle of the Orthophotoscope.

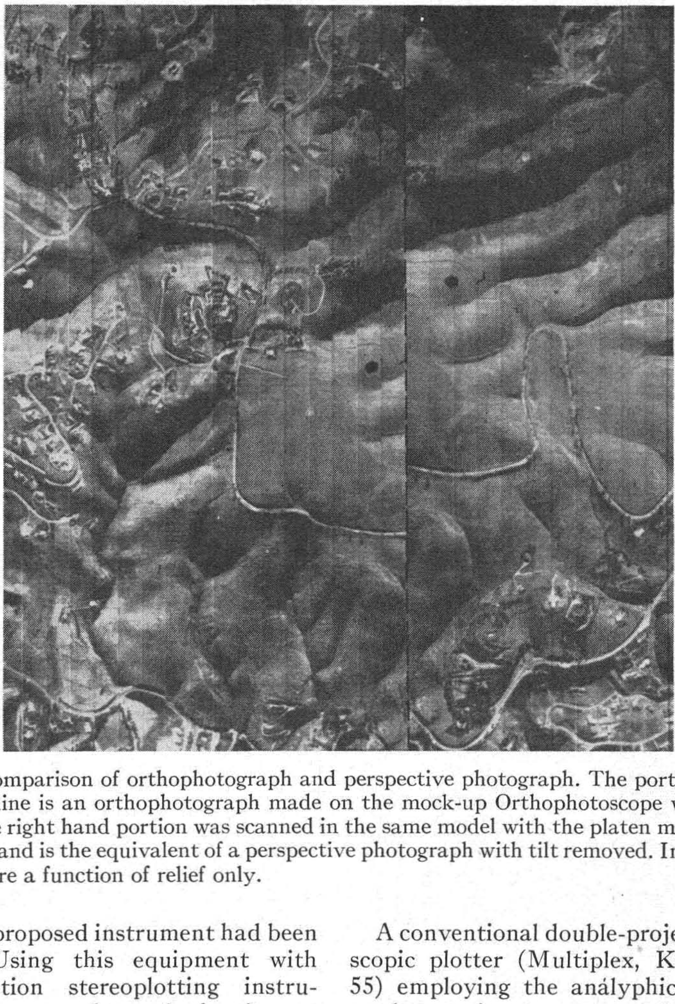

FIG. 3. Comparison of orthophotograph and perspective photograph. The portion to the left of the dashed line is an orthophotograph made on the mock-up Orthophotoscope with full relief correction. The right hand portion was scanned in the same model with the platen maintained at a fixed elevation and is the equivalent of a perspective photograph with tilt removed. Image displacements shown are a function of relief only.

model of the proposed instrument had been completed. Using this equipment with double-projection stereoplotting instruments making use of anaglyphs, it was possible to eliminate scale inconsistencies caused by relief and tilt displacements in perspective photographs, and thus produce uniform-scale orthophotographs (See Figure 3). Because of the mock-up nature of this model, the orthophotographs could not be executed with the desired precision, but it was definitely demonstrated that the method was feasible.

Engineering plans for a precise Orthophotoscope were begun in January, 1954. Concurrently with the planning, the fabrication of a prototype model based on the new plans, was begun by the Geological Survey. Completion of the first production model by the middle of 1955 is expected.

OPERATION OF THE ORTHOPHOTOSCOPE

The Orthophotoscope operates in the following manner (See Figure 4):

A conventional double-projection stereoscopic plotter (Multiplex, Kelsh, or ER-55) employing the analyphic principle is used to project two conventional overlapping aerial photographs to the screen. One of the photographs is projected through a blue-green filter and the other through a red filter. The projectors are properly oriented to form a correct stereoscopic model exactly as in map-plotting procedures. The screen is opaque except that it has one small opening called the "scanning slit." The screen is in direct contact with a sheet of photographic film bearing an emulsion which is sensitive to the blue-green light but not to the red light. The sheet of film rests, in turn, on a flat platen which is parallel to the datum. By a mechanical arrangment, as indicated in Figure 5, the screen can be moved in a horizontal plane parallel to the film, either in the x- or y-direction. The film, however, remains in a fixed relation to the two projectors except in the z-direction (up and down). The movement of the screen is controlled so that the scanning slit can be passed over the film in any desired direction, causing a piecemeal exposure of the film to the projected images through the slit. The platen bearing the film and screen can be raised or lowered in a manner similar to the raising or lowering of a Multiplex tracing table, so that the scanning slit always appears to be "on the ground" in the stereoscopic model. The screen and the film remain essentially in contact at all times as the screen slides horizontally over the film. The motion of the screen in the direction of scanning can be regulated for automatic operation at a fixed speed. When a given strip has been scanned, an automatic step-over of the screen or slit, in a direction perpendicular to the direction of scanning, is accomplished by an escapement device; the amount of this step-over is governed by the chosen width of the slit.

In operating the Orthophotoscope, the operator first completes the orientation of the stereoscopic plotting instrument so that the stereoscopic model is properly related to horizontal and vertical control points plotted on a base sheet at a particular scale or makes use of a "set-up" which is the result of regular mapping. The Orthophotoscope is then placed on the table top of the stereoscopic plotting instrument and adjusted so that the platen of the Orthophotoscope is parallel to the table top and remains parallel as the platen is raised or lowered. The operator adjusts the position of the screen so that the scanning slit (temporarily covered) is at the point where the scanning is to begin, usually a corner of the neat model. The regulating mechanism is set for the desired speed of scanning (usually in the y-direction). The room lights are then turned off, the projector lights are turned on, and the scanning begins. A strip is scanned in the selected direction, the operator manipulating the height regulator so that the slit is always in contact with the apparent ground surface in the optical model. This results in the exposure of a strip of film to a width equal to the width of the scanning slit and to a length equal to the length of the model in the selected direction, or to such other length as the operator may select. The platen is maintained at the correct elevation so that relief displacement of images is eliminated. Only the images projected through the blue-green filter affect the emulsion on the film, as the red light has no actinic value. After the first strip has been scanned, the screen is automatically positioned for scanning of the next strip. A driving mechanism moves the screen so that the slit motion is parallel to the path of the first strip, and displaced from it by an amount equal to the slit width. A device is provided for the constant orientation of the slit so that it is maintained at the average strike of the terrain. The second strip is then scanned in the same manner as the first strip. This operation is repeated until the whole model has been scanned. The film is then removed and developed by conventional photographic techniques to give a negative covering the model area, with tilt and relief displacements removed. Positive prints can then be made from the negative.

It should be noted that the orthophotograph covers the overlap area of two adjacent photographs rather than the entire area of either one. The orthophotographs may be made with the green-blue filter in either of the two projectors involved. The scale of the orthophotograph negative is the same as the stereoscopic model scale; enlargements or reductions can, of course, be made from this negative in any quantity and at any reasonable enlargement or reduction of scale. In choosing the stereoplotting instrument, the quality of the projected images will generally be a more important factor than the scale of the negative.

It should also be noted that the Orthophotoscope works with either vertical, horizontal, or low oblique photographs.

In the Gallus-Ferber photorestitution machine, the operation was quite different. The first step in the Gallus-Ferber procedure was to draw a profile for each scanning strip (an operation not required in the Orthophotoscope, although it can be done readily if profiles are desired). One of the two projector lights was then turned off, so that a single projector could be used for exposing the sensitized paper. The profile of each scanning strip was used in connection with an electric motor to raise and lower the projector to agree with the profile as the strip was traversed, the height of the screen remaining fixed. In the Orthophotoscope, on the other hand, any standard double-projection apparatus can be used to project the images, and the projectors remain stationary in their rela-

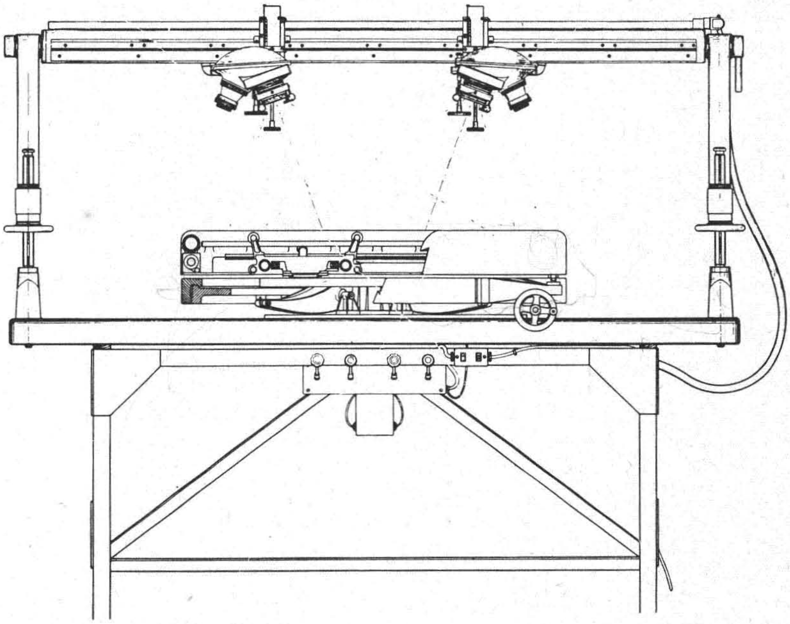

FIG. 4. Front view, partially cut away, of production model of Orthophotoscope, as used with the ER-55 plotter.

tive orientation as they do in conventional mapping; the plane of the screen is raised and lowered by direct stereoscopic observation of the model and the exposure is made without requiring previously-drawn profiles. A primary objective of the Orthophotoscope has been to eliminate excessive cost and tedium. Although the Gallus-Ferber apparatus was ingenious in conception, it appears that it had only a limited amount of successful use in actual practice.

DESIGN FEATURES

The engineering design of the Orthophotoscope for precise operation involves two major features, the height-control system, and the scanning system.

The height-control system (Figure 4) for keeping the platen at ground elevation as the model is scanned, consists of 4 jackscrews and levers designed to maintain the platen parallel to the table-top datum at all times. The jackscrews and levers are actuated through gears by a hand-wheel controlled by the operator.

The scanning system (Figure 5) consists of a fibre (or other material) viewing screen having a rectangular or parallelogram-shaped aperture (of a chosen size for the particular relief or terrain to be scanned); the screen and all other moving parts are actuated by a small motor mounted on top of the rear casting. The screen is connected to a continuous driving chain passing over two sprockets, one mounted at the front of the apparatus and the other geared to the driving motor at the back. Y-motion of the screen, at the desired speed, is imparted by the motor-and-chain system. Two adjustable dogs are mounted on the chain in such a way as to trip an escapement when the desired length of strip has been scanned. When the escapement is tripped, the screen moves automatically in the x-direction a distance equal to the strip width (much in the manner of a typewriter carriage moving one space), the motion of the slit reverses, and scanning of the next strip in the opposite direction begins. All the operator has to do is keep the slit continually on the ground by operating the hand wheel as though he were plotting a profile (or following a road). The terms "x-direction" and "y-direction" are used in the relative sense only, for the whole apparatus can be swung 360 degrees in its mount so that scanning can be accomplished in any desired direction. This freedom to choose the scanning direction permits the operator to scan in the optimum direction with respect to the orientation of terrain features,

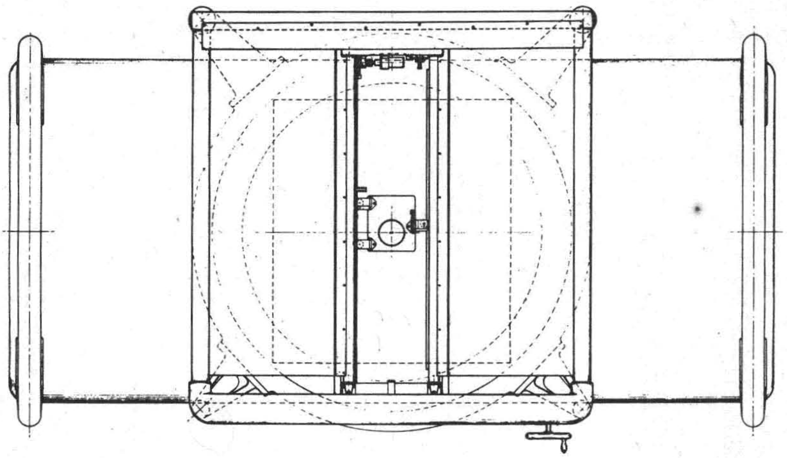

FIG. 5. Plan view of production model of Orthophotoscope.

thus keeping to a minimum sharp changes in relief that might adversely affect the accuracy of the procedure.

As the film is registered on pins, it will also be possible to expose one film as outlined, and then, by registering a second film in the position of the first, expose this in several smaller sections, each of which is scanned in the most favorable direction. The two can then be registered on pins, and cuts made through both films. The most favorable sections can then be fitted together for the final negative from which reproductions are made.

Some consideration has been given to the possibility of operating the instrument by electronic means. So far no one has been able to solve the problem of successfully matching unlike images of the same object by electronic devices. There is a wide-open field for research in this direction.

LIMITATIONS OF THE INSTRUMENT

Like most new devices, the Orthophotoscope is bound to have its limitations. It is not yet possible to predict to what degree the scale of the orthophotographs will be completely uniform. Although there is no need to have misgivings concerning the ability of the operator to keep the slit "on the ground," there is an undeniable source of error, in that the width of the slit may cover an extreme elevation in abrupt country. A solution in such instances is to use a very small slit in country of this type; a smaller slit requires that more strips be scanned and hence increases the cost of the orthophotographs. Also, it is possible to orient the slit to the strike of the country.

There is also a limitation in the accuracy of orthophotographs in skyscraper areas, inasmuch as a true map shows the intersection of objects with the ground surface. Presumably, the operator of the Orthophotoscope will keep the slit on the ground rather than attempt to climb up and down the sides of the buildings. If he does stay on the ground, the images of the tops of buildings, etc., may be shown out of position. This limitation must be recognized, and after all, what proportion of the country is covered by skyscrapers?

CONCLUSION

The Orthophotoscope is one of those instruments that invariably raises the hackles on any photogrammetrist to whom it is first mentioned, for he is likely to believe that this is something that cannot be done, or at least not done easily. One can hardly blame the man who has his doubts. Nevertheless, another barrier seems to have been penetrated. We can look forward to orthophotographs, produced efficiently and economically, and being applied to an ever-expanding field of activities.