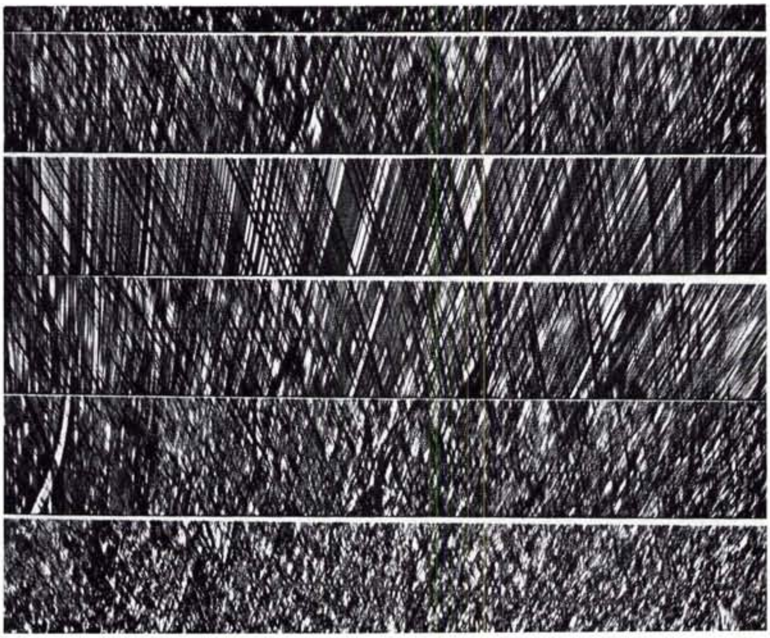

FRONTISPIECE. Sample profiles by ray-intersection technique.

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USGS Automatic Orthophoto System

A photographic technique for recording multiple terrain profiles in a stereoscopic model is under development.

(*Abstract on next page*)

INTRODUCTION

INSTRUMENTATION FOR producing orthophotographs has undergone considerable change since the conception and fabrication of the pump-handled, plywood breadboard model of 1954 that was the first practical Orthophotoscope. That breakthrough was the springboard from which orthophotography was propelled through an important and productive evolutionary period. The U. S. Geological Survey (USGS) progressively improved the design of the Orthophotoscope and produced three operational models in the past 17 years. The breadboard model was followed by the engineered prototype, and then the U-60 drum-type Orthophotoscope.

Since 1964, the T-64 Orthophotoscope has been the workhorse model of the USGS. Its output was used throughout the early development of orthophotomapping. In the nearly two decades that orthophotography has been achieving an accepted position in mapping, other innovators have contributed handsomely to the field. Progressive strides have been made with electronic image correlation applied in the dynamic mode to orthophoto-producing instruments; electronic imaging has been used and improved con-

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siderably. Automation in orthophotograph production has been moving over the horizon for some time. The current USGS instrumentation development effort in orthophotography is aimed squarely at automating the process.

The Automatic Orthophoto System is similar to the Orthophotoscope in several basic respects. Both require relative and absolute orientation of a stereoscopic model; both require profile scanning along parallel paths; and both require incremental yet continuous exposure of film to a properly oriented bundle of rays so that exposure is made with the film always at ground-image level. Instrumentally and operationally the two systems diverge considerably. With the Orthophotoscope, the profiling and incremental film exposure are accomplished in a single operation. With the new Orthophoto System, the profiles are generated on a separate instrument, then another instrument is used to follow the profiles automatically while simultaneously providing profile-data input to the orthophoto-producing instrument. The Automatic Orthophoto System components are as follows:

1. a. Analog Profiler (produces analog profiles by manual operation), or
   b. Auto Stereo Profiler (produces analog profiles automatically through photographic recording of corresponding ray intersections), or
   c. Scanner-Digitizer (produces digital profiles automatically from a contour plot)
2. Autoline (follows analog profiles automatically)
3. Orthophotomat (prepares the orthophotograph automatically)

Prototype production instruments are completely fabricated and in use for all but the Auto Stereo Profiler and the Scanner-Digitizer, which are in the design stage.

ABSTRACT: *An advanced system for producing orthophotographs has been designed and fabricated by the U. S. Geological Survey. The system consists of instrumentation for deriving profiles in a stereoscopic model by manual or automatic means, following these profiles automatically, and transmitting scanning motions to an off-line Orthophotoscope. The Analog Profiler has been designed and fabricated for manual scanning and recording terrain profiles in a stereoscopic model formed by a direct-projection stereoplotter. An automatic photographic technique for recording multiple terrain profiles from a stereoscopic model is under development. The Autoline (automatic line follower) uses analog profiles, derived either manually or automatically, as a means of controlling the scanning motions of the Orthophotomat. The Autoline follows profiles by means of two cadmium sulfide photocells mounted side-by-side to straddle the profile. The Orthophotomat is a single-projector instrument for off-line automatic production of orthophotographs.*

Analog Profiler

The Analog Profiler is an instrument designed for manual scanning and graphic recording of terrain profiles from a stereoscopic model formed by a direct-projection stereoplotter (Figure 1). Profiles derived with this instrument are used as input to the Autoline, which in turn provides input for automatic operation of the Orthophotomat.

As depicted in the more detailed view in Figure 2, the profiler consists of a tracing table platen assembly mounted on the carriage and x-arm of a coordinatograph. The elevation screw of the platen assembly has a pitch of 4 inches so that the platen can be moved rapidly up or down with the elevation lever to keep the floating mark in contact with the apparent surface of the terrain model. A small *d.c.* motor moves the platen assembly and x-arm along the y-arm of the coordinatograph. Scanning speed is controlled by rotating the elevation lever about its longitudinal axis. At the end of each scan, the scanning carriage is stopped by a microswitch, and the stepover to the next scan is accomplished manually. An automatic vertical locking mechanism maintains the correct datum in the stepover. The stepover distance is controlled by detents in the scan-spacing wheel, which can be changed to permit variability in the stepover distance. The horizontal distance between profiles in the model must agree precisely with both the scan width of the exposing slot and the stepover distance of the Orthophotomat. By means of a cable linkage, a profile derived in the yz-plane is recorded in the xy-plane on paper or plastic sheet. Profiles may be scribed or inked on the recording sheet. A set of profiles is shown in position in Figure 2.

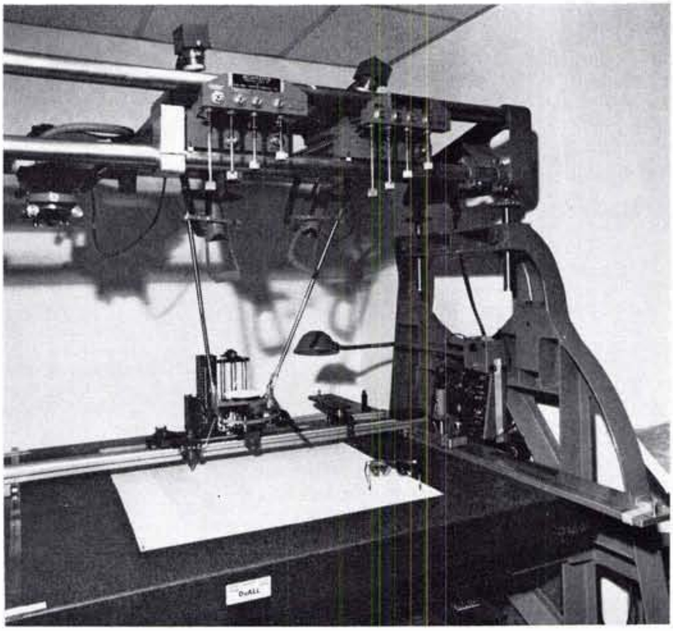

FIG. 1. Analog Profiler, mounted on anaglyphic plotter.

The profiles from the Analog Profiler are at model scale and normally require a photographic scale change to bring them to the exposing scale of the Orthophotomat. The final profile plot most easily followed by the Autoline consists of black lines on white background. Profile plots derived from the Analog Profiler have been used successfully to operate the Orthophotomat.

AUTO STEREO PROFILER

(Stereoscopic Profiling by Intersection of Ray Traces)

The automatic photographic technique for deriving analog profiles is conceptually straightforward, technologically promising, and extremely attractive from the viewpoint of efficiency potential. In a paper given at the 1970 ACSM-ASP Fall Technical Conference in Denver, James G. Lewis of the USGS introduced the subject of ray-intersection profiling to the photogrammetric community. Since then, further improvements in the reliability of the technique have been made, a related innovation has been conceived, and prototype production instrument design has started. These matters are related in this section of the paper, following a brief review of the concept involved.

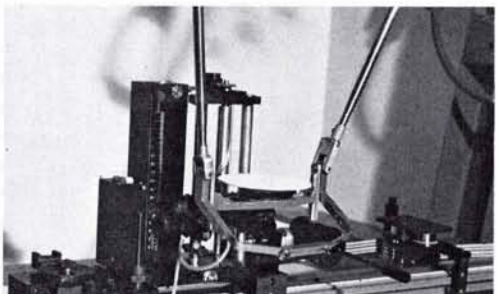

FIG. 2. Tracing table platen assembly of Analog Profiler.

Stereoscopic profiling by intersection of ray traces was conceived on the basis of the following optical principles:

- In a steroscopic terrain model formed by direct projection of one positive and one negative photographic image, the intersections of all corresponding rays are characterized by a nearly constant intensity of illumination, or a nearly constant density in a photographic record of the rays.
- The model surface (or ground surface) has continuity throughout the model (although this is a truism, it is an essential element of the concept).
- Corresponding rays (one positive and the other negative) intersect and form a continuous neutral-density line on a plane wherever the plane cuts the surface of the model.

With exceedingly simple experimental instrumentation, it has been proved that

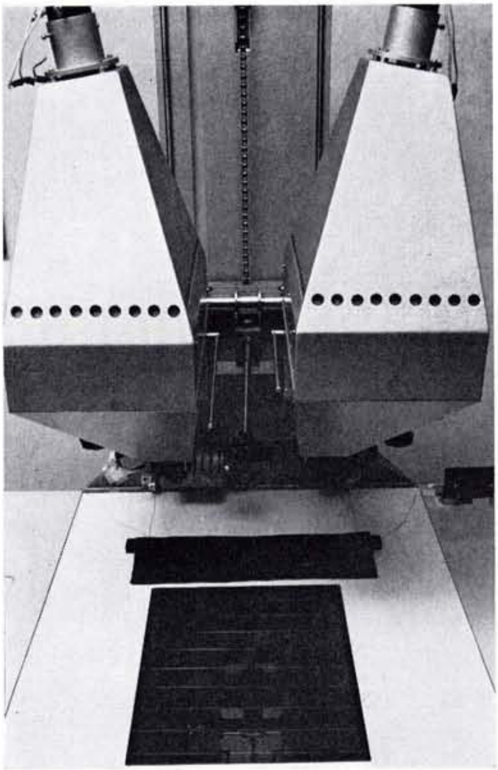

FIG. 3. Instrumentation for experimental ray-trace profiling.

profiles can be recorded photographically by applying these principles. Experimentation has progressed to the point that, with only very slight modification of the original equipment, seven profiles extending across the model in the x-direction have been obtained simultaneously in a single 10- to 15-second scanning-exposing operation. The equipment setup is shown in Figure 3. In this experiment, a glass-plate mask with seven slots was used rather than the single-slot mask used in earlier research. A profile is produced for each slot, and the number of profiles that can be recorded in a single exposure, therefore, is limited only by the ability to translate unexposed film beneath the closely spaced slots. Sample profiles are shown in the frontispiece.

Scanning tests have been made with input transparencies processed in several different ways. The results have indicated that (1) photographs with numerous small and contrasty image elements produce well-defined profiles and (2) edge-enhanced transparencies, as compared with continuous tone, produce narrower ray traces and consequently thinner, more pronounced profiles.

Profiling by this technique is not without problems. Manifestation of profiles in the form shown in the frontispiece presents an obstacle to complete automation of the process. The signals which form the profiles are intersecting ray traces. To put the profiles to work in the Orthophoto System, they must be extracted from the background of ray traces above and below the profile.

Manual extraction of the profiles is possible, but if the profiles could be extracted automatically, the technique would have much greater production potential. Optical means such as Kineform filters are now being investigated for filtering the wheat from the chaff.

Recently an instrument modification was conceived which would permit two adjacent models, the equivalent of one full photograph, to be profiled in the same operation. This modification is shown in Figure 4, in a schematic diagram of the proposed production profiling instrument. A thin, flat, dull-black

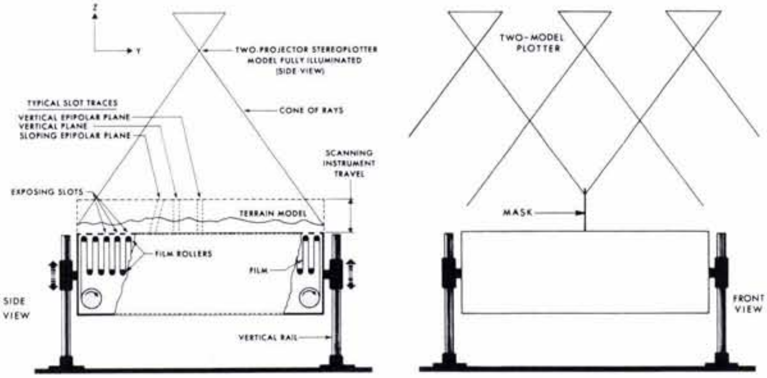

FIG. 4. Schematic of proposed production-model Auto Stereo Profiler (left); Profiler modified for two-model operation (right).

mask is to be placed in a yz-plane containing the perspective center of the middle projector. The bottom edge of the mask should be in the plane of the slots. The y-dimension of the mask should equal the y-dimension of the model. The mask should be about 4 inches high to prevent rays projected by the outboard projectors from exposing film on the opposite sides of the mask. It should be made of extremely thin material because its presence would block all rays in the yz-plane from the middle projector. The film, therefore, would not be exposed along a narrow line under the mask, and the net result would be an interruption in every profile along the common edge of the two models. If the mask is extremely thin, say 0.005 inch, the void in each profile should roughly equal that amount, which is really insignificant because it represents only several feet on the ground. With this modification, the output format of the Auto Stereo Profiler should be entirely compatible with that of the Autoline-Orthophotomat combination.

USGS Scanner-Digitizer

The USGS Scanner-Digitizer, which is in an early stage of development, is a device which converts data in graphic form to computer-readable form. The conversion is accomplished by raster scanning of the graphic image by a vidicon-optical system which records data in raster address format on magnetic tape. A series of computer programs then converts these data to a compressed digital line or outline form. The complete hardware/software system is designed to provide extreme flexibility in support of automatic cartographic techniques in which analog-to-digital binary data conversion is required. In the case of the Automatic Orthophoto System, the Scanner-Digitizer would be used to digitize terrain data from existing topographic maps. The data would then be converted to either analog or numerical profiles (on tape) and used as input to the Orthophotomat.

Technical information on the Scanner-Digitizer was presented by Dean T. Edson on an ACSM Panel on the Status of Automation in Cartography at the 1971 ASP-ACSM Convention.

Autoline

The Autoline, shown in Figure 5, is an automatic electronic single-axis line follower designed and built by the USGS. Its function in the Automatic Orthophoto System is to follow previously obtained analog profiles and simultaneously emit signals that control the z scanning motion of the Orthophotomat.

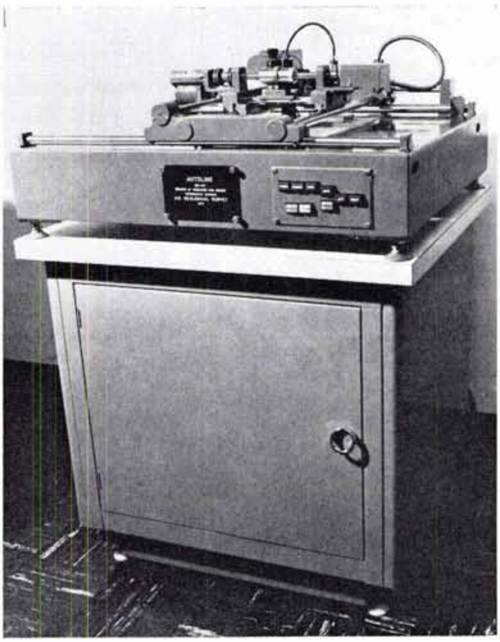

FIG. 5. Autoline prototype.

The Autoline has an optical-electronic sensor and mechanical components mounted on top of a metal cabinet containing the electronic components. The principal components are: photocell unit; ball-bearing screws for the x, y, and z axes; stage plate; *d.c.* servomotor; synchro transmitter and receiver; tach generator; and other electronic equipment to activate the photocell unit and power the motors. A closeup view of the Autoline is shown in Figure 6.

The Autoline follows profiles by means of two cadmium sulfide photoconductive cells mounted side-by-side to straddle the profile line. The photocell unit, which is attached to a 6-inch z-axis ballscrew, receives the reflected light from the profile plot in the form of an optically enlarged field containing the image of the line. If the amount of reflected light received by the two photocells is equal, the photocell unit is centered over the line. Inequality of light sensed by the two photocells immediately activates the servomotor, which centers the photocell unit over the line. The geometric sensitivity of the photocell unit is about 5 micrometers.

Signals generated by the rotation of the z-ballscrew (profile data) are transmitted to the z-axis of the Orthophotomat by a small synchro transmitter attached to the end of

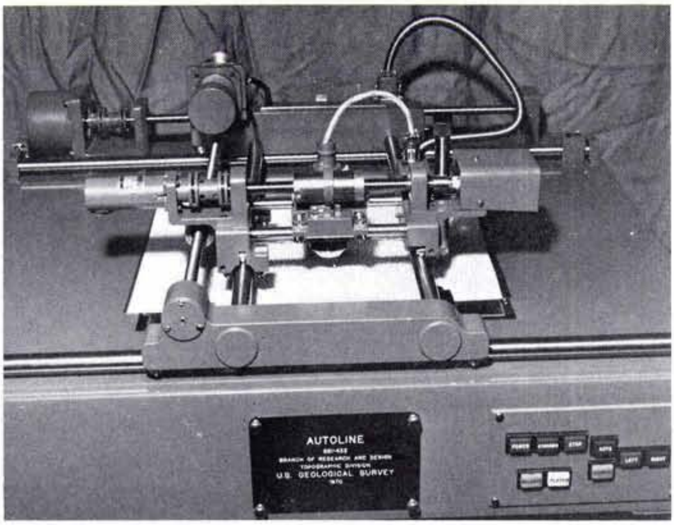

FIG. 6. Autoline, closeup view.

the z-screw. These signals are received by a synchro control transformer mounted in line with the servomotor on the end of the Orthophotomat z ballscrew. The data are demodulated and amplified before the power is transmitted to the servomotor.

Motions of the x and y axes of both the Autoline and Orthophotomat are carefully registered and synchronized:

- The x axes are powered by a preset indexer through identical stepping motors with a least-count movement of 0.001 inch.
- The y-axis of the Orthophotomat is powered by a synchronous motor mounted directly on the Orthophotomat y-ballscrew. The shaft-rotation data of the synchronous motor are transmitted to the y-ballscrew of the Autoline by means of a synchro transmitter to a synchro receiver mounted on the Autoline y-ball screw.

The procedures to be used in the combined Autoline-Orthophotomat operation are covered after the description of the latter instrument.

ORTHOPHOTOMAT

The final element of the Automatic Orthophoto System is the Orthophotomat. It is a single-projector differential rectification instrument for off-line, automatic production of orthophotographs. The prototype, just completed, is shown in Figure 7. As stated before, scanning motions with this instrument are controlled by analog profiles.

The Orthophotomat consists of the main support structure, film platen, scanning assembly, and the projector assembly. The projector assembly contains a 9×9-inch format projector with a 115-mm focal-length hypergon lens, which magnifies the imagery about 2.8 times at an optimum projection distance of 430 mm. The projector is provided with controls for x-tilt, y-tilt, swing, and z-motion to permit proper orientation. The light-source assembly is mechanically independent of the projector.

The 27×27-inch film platen contains a vacuum surface plate that is flat within 0.001 inch. The plate contains 729 drilled holes 0.028 inch in diameter to insure that the film is held firm and flat throughout the format.

The film platen is guided in its vertical motion by ball bushings which roll on four guide rods attached to the main support structure. On each guide rod there are two ball bushings 10 inches apart. The platen is driven in z through a range of 150 mm by a centrally located ballscrew. The x and y axes can be disengaged for orientation and, when re-engaged, can be adjusted for indexing. The z-motion on the Orthophotomat has a separate motor that can be activated for manual operation during orientation.

The Orthophotomat was designed for darkroom operation without a curtain directly over the film platen. Light baffles are provided to prevent exposure of the film by any light except the intended imaging rays. Interchangeable exposing slots of different widths are available for different terrain conditions. The slot is mounted in a ring that is adjustable in height to account for films of different thicknesses. The slot can be replaced with a crosshair reticle for use in scaling the projected imagery before scanning.

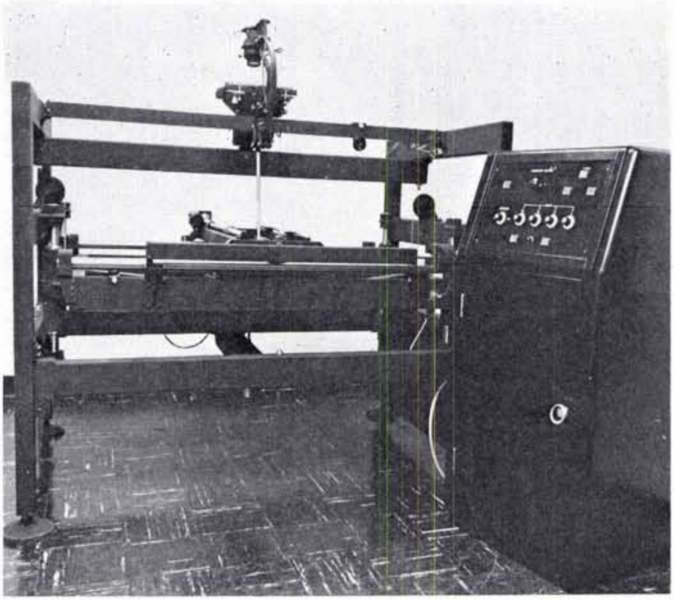

FIG. 7. Orthophotomat prototype.

Operating procedures for the Orthophotomat require the use of preselected image points as a basis for orienting the single projector of the Orthophotomat. If the stereoscopic model is oriented for manual or automatic profiling, the selected scaling points, as seen on the monoscopic projection, are plotted on a horizontal plane at optimum projection distance. The same points are then used to orient the Orthophotomat projector.

SCANNING-EXPOSING OPERATION

The actual sequence of Autoline-Orthophotomat operation is as follows:

1. The profile plot is reproduced on a copy camera at a scale compatible with the optimum projection distance of the Orthophotomat (430 mm). Another copy for the Autoline to follow is made at exactly one-half the Orthophotomat image scale. This 1:2 ratio permits an Autoline scanning speed of 4 to 8 mm a second and an Orthophotomat scanning speed of 8 to 16 mm a second.
2. The respective profile plots are positioned on the Autoline and the Orthophotomat. The Orthophotomat projector is oriented so that the preselected image points coincide with the corresponding points marked on the profile plot.
3. The photocell unit of the Autoline and the exposing slot of the Orthophotomat are positioned at corresponding starting points and locked together electronically.
4. The profile plot on the Orthophotomat is replaced with unexposed film under darkroom conditions.
5. The scanning motions (y-travel) of both instruments are started simultaneously.
6. The Autoline photocell unit, which follows the profile lines, transmits the identical profile data to the z axis of the Orthophotomat. Thus the projected imagery is recorded on the film in orthographic position.
7. At the end of the scan, cutoff switches stop both y-carriages, stepover of both units proceeds synchronously, and scanning of the next profile line commences.
8. Scanning and exposure of the entire model area proceeds automatically.
9. The stepover from the last profile line actuates the *end-of-model* switch.

CONCLUSION

Several justifications support using the partially off-line approach described above. Rather broad experience with manually operated Orthophotoscopes has indicated the need to automate for several reasons. First, in manual Orthophotoscope operation, the vertical accuracy of profiling, though adequate, is somewhat impaired because the floating mark is the rectangular exposing aperture or slot. The discrete, illuminated floating mark in the Analog Profiler promotes higher vertical scanning accuracy.

Second, manual scanning of a model in an Orthophotoscope is a tedious task which takes more than two hours and should be done in one sitting without a stop. Operator boredom and then fatigue set in. If the operator of the Analog Profiler needs a break, he can stop any time without affecting the profile plot.

Third, the operator of the Orthophotoscope who makes a major vertical scanning error knows that the orthonegative irrevocably contains the horizontal effects of his blunder, and he must later re-scan part of the model and mosaick it with the original orthophoto. This step reduces efficiency and may result in a substandard product. A similar vertical error made in the Analog Profiler can be corrected immediately by rerunning the suspected profiles. Additionally, the analog profiles can be spot-checked for accuracy before being removed from the plotter table.

Fourth, the Automatic Orthophoto System is expected to be more efficient because of the scanning-speed control in the Analog Profiler. Now, Orthophotoscope scanning progresses at a constant speed of about 10 mm a second—a requirement for uniform film exposure. The Analog Profiler's control for scanning speed will enable the operator to select maximum speed for different terrain types. Smooth terrain with few slope changes should allow higher scanning speeds, and rough terrain, slower speeds. So the new system should provide some advantages and flexibilities not found in the earlier system.

At the outset of this paper, the reference to several different models of Orthophotoscopes indicates the evolutionary nature of instruments for orthophotography. The Automatic Orthophoto System is looked upon as another step in the mapping technology parade. Complete automation of this system may be the next step.