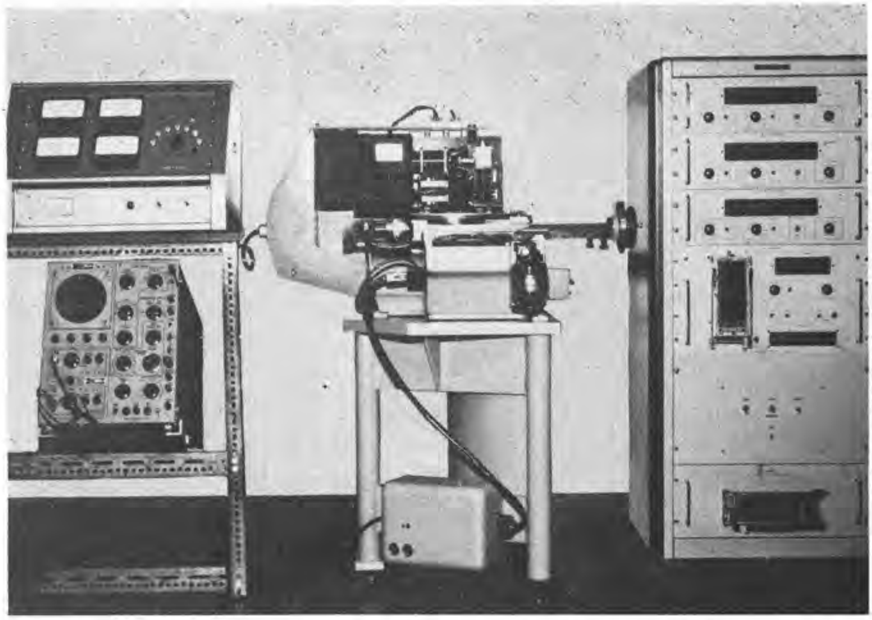

FIG. 1. BAI correlator adapted to readout-equipped comparator for scanning and measuring of aerial photographs.

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Washington, D. C. 20006

The BAI Image Correlator

As the study on this area scanning device shows an ability to match photo images, it may apply to nearly all stereo jobs.

INTRODUCTION

IN THE SPRING OF 1967, research engineers of the U. S. Geological Survey were made aware of the capabilities of an electro-optical area (image) correlator developed by BAI Corporation† of Glenbrook, Connecticut. The correlator had been used with outstanding success aboard the five Lunar Orbiter spacecraft to provide image-motion compensation, intervalometer control, and crab-altitude alinement for the spacecraft cameras.

The BAI instrument can scan areal images, either in the "real world" or on photographs, store bi-level analogs of the scanned images on a magnetic drum or other memory, and compare and correlate the stored image analogs with others scanned later in real time. These demonstrated capabilities suggested the possibility of applying the BAI correlator to several photogrammetric tasks, specifically those that would benefit from a more positive identification and a more precise correlation of corresponding images on overlapping aerial photographs.

Therefore, specifications were prepared and a contract let for the purchase of a BAI correlator equipped with an external optical system and mounted on an available, USGS-owned comparator. This adaptation was intended to provide a research instrument for

* Publication authorized by the Director, U. S. Geological Survey. Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1968. Updated to April 1969 by M. J. Stephens. (See also following article "An Area Correlator and a Photosensitive Crystal".—*Editor.*)

† Formerly Bolsey Associates, Inc.

evaluating the photogrammetric capabilities of the correlator in scanning and analyzing vertical aerial photographs. The instrument was delivered in December 1967, and has been in nearly continuous use for research since that time.

Components and Functions of Correlator

As adapted for USGS photogrammetric research, the present correlator consists of two major components (Figure 1). The scanner and associated electronic gear are mounted on an encoded 9- by 9-inch Mann comparator which provides a holder for the photographs to be scanned and a means for measuring x and y displacements to one μm.* The other major component is a console containing the controls and four display meters.

The microscope assembly, diagramed in Figure 2, provides for simultaneous viewing of a photoimage area by the operator and scanning by the optical system of the instrument. The operator looks through a microscope containing an etched cross reticle which indicates the geometrical center of the scanned area. The microscope also contains a beamsplitter to reflect the same scene to the scanner through an auxiliary turret lens system. Interchangeable objective lenses in the auxiliary system provide total magnifications of 25×, 48×, and 58×, so that the scanner operates on areas having outside diameters of approximately 1.50, 0.80, and 0.65 mm on the photograph.

The external optical system projects a real image onto the circular scanner face for examination by a rotating sensor (the end of a fiber-optics light-pipe) which appears in the flat face of a rotating cylinder as a narrow radial slitlike aperture (Figure 3). Due to the length and position of the aperture in the rotating head, the area scanned has an annular shape. The fiber-optics light-pipe, rotating at 3,600 rpm, transmits variations in image brightness through the hollow shaft of the drive motor to a photomultiplier, which senses the changing light intensity and produces a video-rate electrical analog signal.

The video-signal processor (Figure 4) receives from the photomultiplier the raw analog signal and quantizes it into a two-level modulated pulse train. The pulse train consists of 10 to 30 pulses and contains the scene information in the form of pulse spacing and duration, a form ideally suited for storing in a memory a scene signature uniquely defining the area scanned.

The memory of the present system (Figure 3) consists of a revolving drum with eight

ABSTRACT: *The U. S. Geological Survey is testing and evaluating a BAI image correlator for possible application to various phases of topographic mapping. The correlator, an invention of BAI Corporation, was used in the Lunar Orbiter to provide image-motion compensation. It is composed of two parts, an optical scanner and a correlator. Operationally, the device scans an area of a real object or a photograph and develops an electrical signal, called a signature, which uniquely defines the scanned area. In the unit being tested, as many as eight signatures can be stored in memory. The signature of a corresponding area subsequently scanned can be compared with a stored signature for correlation. When two signatures do not correlate perfectly because of displacement, the correlator produces outputs proportional to the displacement, resolved into* x, y, *and* κ *components.*

JAMES S. CRABTREE

* Micrometer, successor to the micron.—*Editor.*

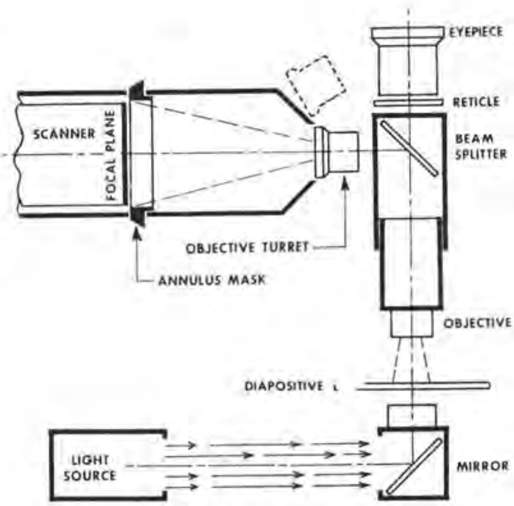


FIG. 2. Microscope assembly.

magnetic tracks. On command, each track can receive and hold a complete scene signature from the video processor. Each track has a separate read-record head so that the tracks can be loaded or read in any desired order. As the recording system is magnetic, no information is lost when the system is switched off and allowed to remain idle for extended periods.

A ninth magnetic track carries a prerecorded synchronizing signal. This track is read by two heads 90 degrees apart, representing the electrical x and y axes of the system, which are alined with the comparator axes. The outputs of these two heads are used in the electrical resolver, which converts the

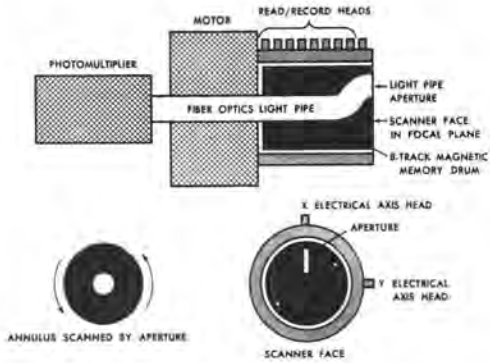


FIG. 3. Scanner and memory system.

correlation displacement signal into x, y, and κ components.

There is inherently perfect synchronism between the magnetic memory tracks and the optical scanner, for both are integral parts of the same rotating cylinder and therefore cannot get out of phase.

During correlation (Figure 5), the electronic correlator receives and compares two quantized signals (signatures), one from the memory, the other (in real time) directly from the optical scanner through the video processor. The output of the electronic correlator consists of two electrical signals. One is displayed on a voltmeter as an indication of the instantaneous level and quality of correlation. The other signal contains the unresolved displacement-error information and is sent to the electrical resolver, a synchronous detector, which converts the correlation error signal into x, y, and κ components. These

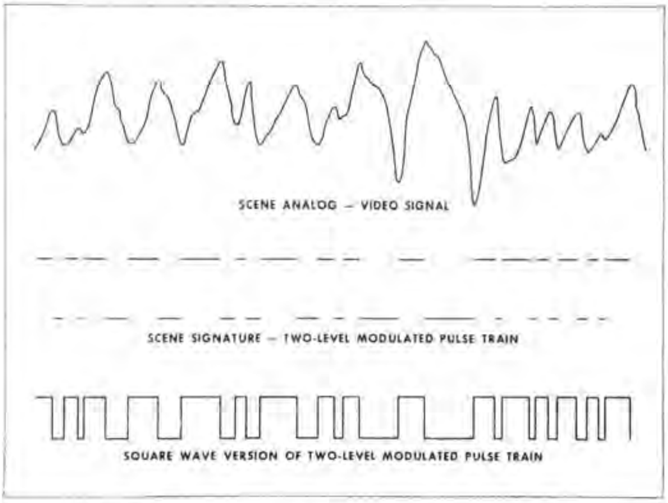


FIG. 4. Conversion of video signal for recording.

three components of the correlation error are presented to the operator in the form of negative or positive voltmeter readings. These resolved outputs could also be used to control servo loops and cause the system to home in on the area corresponding to that which was memorized; however, the present system was built primarily to investigate the practicality of future applications, and therefore all adjustments are made manually.

One of the principal features of the BAI correlator is that it works with areas rather than discrete points or images. There are many possible advantages in this feature, and we therefore specified flexibility in the selection of the inner and outer diameters of the scanned areas. If pass points can be defined by the larger features which surround them rather than by a discrete, individual point, many of the problems of precisely locating the corresponding images on overlapping plates can be eliminated. This problem is well known to those engaged in aerotriangulation and is evidenced by the increasing use of artificially marked pass points.

The flexibility available in selecting the inner and outer diameters of the scanned areas is indicated in Figure 6. The outer diameters are controlled by the magnification selected. The inner diameters are controlled by placing circular masks of varying sizes in front of the scanner face. These masks block out the central portion of the scene being scanned. The resulting widths of scan range from 0.1 to 1.3 mm. It should be noted that the slit aperture does not reach the center of the rotating scanner face and therefore a circular area at the center of the scene is never scanned. This is an advantage in that small circular holes or indentations in the emulsion, such as are used to mark points, lie completely inside the scanned annulus and thus do not affect the correlation.

THE TESTING PROGRAM

The tests that can be carried out with the present instrumentation are limited and simple, but their results will be significant in justifying and guiding future development. From our investigation we are obtaining answers to such questions as: How well can an electrical signal define a photographic scene? How well can the system correlate corresponding images from overlapping aerial photographs? Can the annular area scanned on a photograph be reduced geometrically to a single point in space? How stable is the system, both physically and electronically? What effects do relief and tilt have on ability

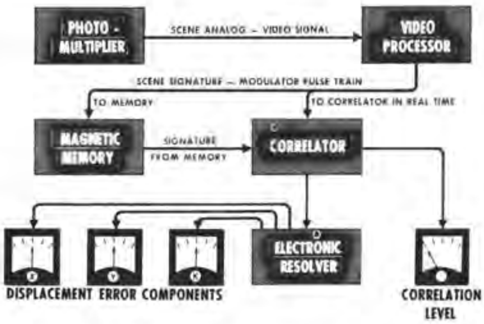
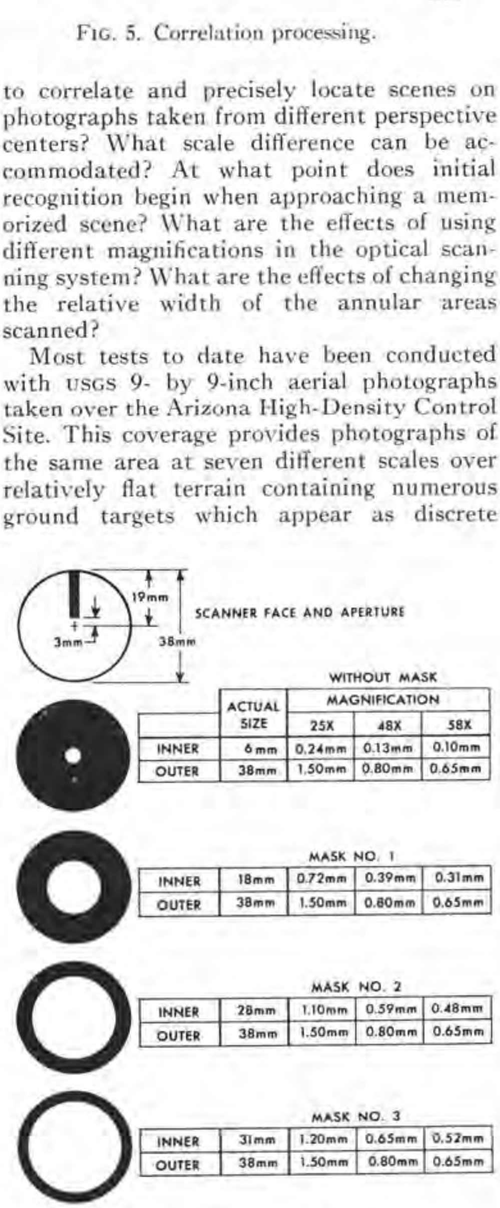


FIG. 5. Correlation processing.

to correlate and precisely locate scenes on photographs taken from different perspective centers? What scale difference can be accommodated? At what point does initial recognition begin when approaching a memorized scene? What are the effects of using different magnifications in the optical scanning system? What are the effects of changing the relative width of the annular areas scanned?

Most tests to date have been conducted with USGS 9- by 9-inch aerial photographs taken over the Arizona High-Density Control Site. This coverage provides photographs of the same area at seven different scales over relatively flat terrain containing numerous ground targets which appear as discrete



WITHOUT MASK

	ACTUAL SIZE	MAGNIFICATION 25X	48X	58X
INNER	6 mm	0.24mm	0.13mm	0.10mm
OUTER	38mm	1.50mm	0.80mm	0.65mm

MASK NO. 1

INNER	18mm	0.72mm	0.39mm	0.31mm
OUTER	38mm	1.50mm	0.80mm	0.65mm

MASK NO. 2

INNER	28mm	1.10mm	0.59mm	0.48mm
OUTER	38mm	1.50mm	0.80mm	0.65mm

MASK NO. 3

INNER	31mm	1.20mm	0.65mm	0.52mm
OUTER	38mm	1.50mm	0.80mm	0.65mm

FIG. 6. Dimensions of annuli.

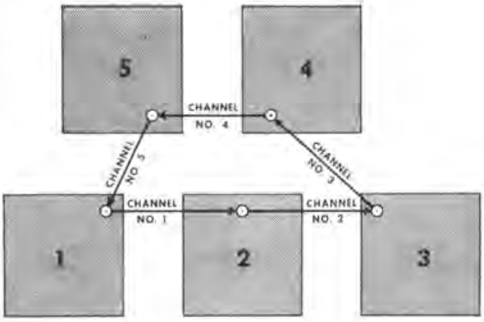


FIG. 7. Photo-traverse.

images on the photographs and therefore provide excellent reference marks for measurement.

AUTOCORRELATION TESTS

The most obvious and spectacular experiment is to test the BAI correlator's ability to recover, by autocorrelation, the exact position of a scene which has just been stored in the memory. This is done by recording a scene from a photograph, introducing a random displacement of the photograph with the x and y motions of the comparator, and then recovering the position of the scene by observing the error-displacement dials of the correlator and bringing them to null with the x, y motions of the comparator. The comparator coordinates for the initial and recovered position will invariably agree to a micrometer, which is the resolution of the comparator being used. There is reason to believe that the resolution of the correlator is even finer than this.

POINT TRANSFER TESTS

Studies have been made to evaluate the system's accuracy and limitations in correlating imagery for point transfers in aerotriangulation. Initially, two techniques were used to test the ability of the correlator to transfer a point, as represented by a scan area, from one photograph to other overlapping photographs. In both tests, the same aerial photographs were used (6-inch, 1:24,000-scale, Arizona test site), consisting of five exposures, three consecutive exposures from one flight and two consecutive exposures from an overlapping adjacent flight.

In the first test, the procedure diagramed in Figure 7 and simulating a closed traverse was used repetitively to test the correlator's ability to transfer points. With the same five photographs as in the previous test, a scene from photo 1 was recorded in memory channel 1. The corresponding scene on photo 2 was then correlated with respect to memory channel 1 and recorded in channel 2. The scene on photo 3 was correlated with respect to memory channel 2 and recorded in channel 3. The sequence was continued until the scene on photo 5 was recorded in channel 5. Photo 1 was then correlated with channel 5 and comparator readings were taken. Finally, photo 1 was correlated again with its original recording in channel 1 and comparator readings were taken. The discrepancy in comparator readings between the last two steps indicates the closure or cumulative error of the several transfers. Photo-traverses of this sort have been carried out with optical magnifications of 66×, 17×, and 10×, with resultant closures between 4 and 8 μm. Since there were 5 transfers, the error per transfer was less than 2 μm.

In another series of tests, designed to evaluate the application of the correlation system to an aerotriangulation problem, plate coordinates measured on Arizona test site glass-plate negatives of three flight heights—12,000, 18,000, and 24,000 feet (1:24,000-, 1:36,000-, and 1:48,000-scale)—were used for fully analytical aerotriangulation. The solutions were analyzed in terms of the residual parallaxes and the position closures on the available ground-survey control.

The 1:24,000- and 1:36,000-scale photocoverage included only single strips of five models and four models respectively, whereas the 1:48,000-scale photocoverage included a 14-model, two-strip block. The latter configuration provided the opportunity to evaluate the capability of the instrument to correlate images appearing on adjacent strips (i.e., to transfer strip tie points). During measurement, a high degree of repeatability was evident among the four readings made on each point—43 percent had no variation, 55 percent had only a 1-μm variation, and only 2 percent had a 2-μm variation in the photocoordinate readings. This suggests that the multiple observations essential in visual correlation are not necessary when the correlator is used.

A preliminary test aerotringulation of one of the two strips revealed that the "want of intersection" of corresponding projective rays, after relative orientation, averaged less than 1 μm at photo scale. The root-mean-square errors at targeted test points, after adjusting the strip to five targeted horizontal and vertical control points, were 2.0 feet (horizontal) and 2.3 feet (vertical).

When the two 7-model strips were computed in the block configuration with 11 hor-

TABLE 1. ROOT-MEAN-SQUARE ERRORS OBTAINED IN BLOCK ADJUSTMENT

Strip	*Number of held control points*	*Number of test points*	*Type of point*	*RMSE horizontal (ground ft.)*	*RMSE vertical (ground ft.)*
I	6 H&V		Targeted control pts.	1.59	0.65
		15	Targeted test pts.	2.04	2.06
			Targeted control pts. and test pts.	1.91	1.81
II	5 H&V		Targeted control pts.	0.92	1.03
		20	Targeted test pts.	2.01	2.32
			Targeted control pts. and test pts.	1.86	2.14
				Half-discrepancies	
I and II			Strip tie pts. (4 H&V)	1.45	0.57

izontal and vertical control points and 4 strip tie points, the RMSE values shown in Table 1 were obtained.

Realizing that terrain slope presents a problem for precise correlation, we have purposely attempted to avoid this problem in our initial testing. However, tests with artificial targets of known slope have indicated that ground areas which have a slope greater than 15° to 20° should not be used as pass points.

OTHER TESTS

The correlator does not require complicated imagery to be effective. Tests show that it works equally well with the simple cross design used for many camera fiducial marks. This finding is important for any future application of the correlator to analytical aerotriangulation.

This ability to precisely discriminate and correlate a simple geometric pattern provides a simple means of calibrating the offset caused by changing objectives to alter the area scanned. A symmetrical pie-segment black-and-white target (Figure 8) is scanned and the signature recorded through one objective. Then the objective is changed and the target is correlated with its stored signature. The distance the comparator handwheels are moved to null the error-displacement dials indicates the displacement caused by the change in objective lenses.

Tests show that the correlator can, under certain conditions, accommodate scale changes up to 40 percent with no zoom.* This makes the correlator potentially useful for the transfer of horizontal control points to compilation photographs from small-scale identification photographs.

* Electronic zoom capability is provided in the new BAI system delivered to USGS in October 1969.

POTENTIAL APPLICATIONS OF CORRELATOR

Although the investigation of the BAI system in its present form has not been completed, plans are being prepared to mount a newer version, having an electronic scanner and an expanded memory capacity, on an encoded Nistri monocomparator as the next step toward developing a correlating system which will improve present techniques and instrumentation for the collection of photocoordinate data for analytical aerotriangulation. Present manual methods of obtaining the data are very time-consuming and vulnerable to errors. We hope that the proposed correlator-controlled system will improve the quality of data and reduce the cost of obtaining them.

At least 50 memory channels are needed for efficient use of the correlator in block

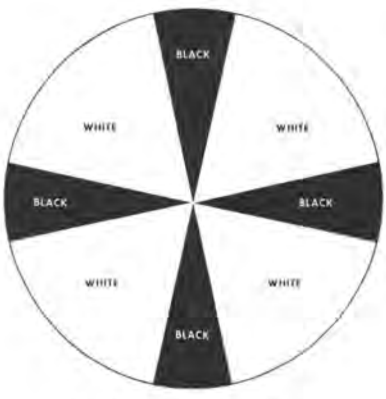


FIG. 8. Calibration target.

aerotriangulation. The punched-card memory used in the new system will provide unlimited capacity and completely solve the data storage problem.

In the proposed mode of operation, the correlator system will aid in the transfer of pass points from one plate to another by carrying pass-point identification information forward in memory. The ability of the correlator to recognize corresponding scenes, to match them with the memorized scenes, and to produce error signals will aid in pointing precisely to pass points so that their photocoordinates can be measured. The ability of the system to memorize, recognize, and correlate a four-legged target will be used for centering on and determining the coordinates of the fiducial marks on each plate. Also, the ability of the system to accommodate a scale change will be used in transferring ground-control identification and pass points between photographs of different scales. This proposed adaptation of the correlator does not include the use of any servo loops; however, if automation seems to be desirable later, the hardware is available, having been developed and used in image-motion compensation for the cameras of the Lunar Orbiters.

As the BAI correlator has demonstrated an ability to correlate corresponding photo-images, it apparently has potential application in virtually all stereophotogrammetric operations. Data gathering for analytical aerotriangulation requires greater accuracy than most other types of photogrammetric measurements. A less demanding application of the correlator, which we plan to investigate, will be an adaptation for measuring x-parallax along cross-sections through a stereomodel to develop terrain profiles. The profiles can be used as z-motion control for Orthophotoscope scanning. It will take some time to explore these and other possible applications of the correlator.

FORUM

Dear Editor:

In the July and August issues of PHOTOGRAMMETRIC ENGINEERING a K&E advertisement stated that the Zeiss Planimat was the only full-sized stereoplotter that could handle focal lengths from 85 mm. to 310 mm.

It has been brought to our attention that the Analytical Stereoplotter, Model AP/C, manufactured by Ottico Meccanica Italiana of Rome, Italy, can readily handle the aforementioned focal lengths.

It would be appreciated if you would publish this letter in a forthcoming issue of the magazine.

Keuffel & Esser Company
Photogrammetric Systems Division

RESEARCH PROPOSALS SOLICITED

The Army Research Office-Durham has available limited funds for the support of unsolicited research proposals that are clearly of a basic nature in the field of Cartography in the widest sense of the word.

Proposals for such research may be submitted by universities, colleges, non-profit research organizations and other suitable organizations. Research projects may be supported by grants or contracts. The grants program is limited to non-profit organizations. Proposals may be for one, two or three years.

In its broadest sense the interest is concerned with the acquisition of terrain data, their accuracy, their extraction, processing, storage, retrieval and subsequent display in various manners.

Inquiries should be directed to Dr. William Van Royen, Director, Division of Environmental Sciences, U. S. Army Research Office-Durham, Box CM, Duke Station, Durham, N. C. 27706.