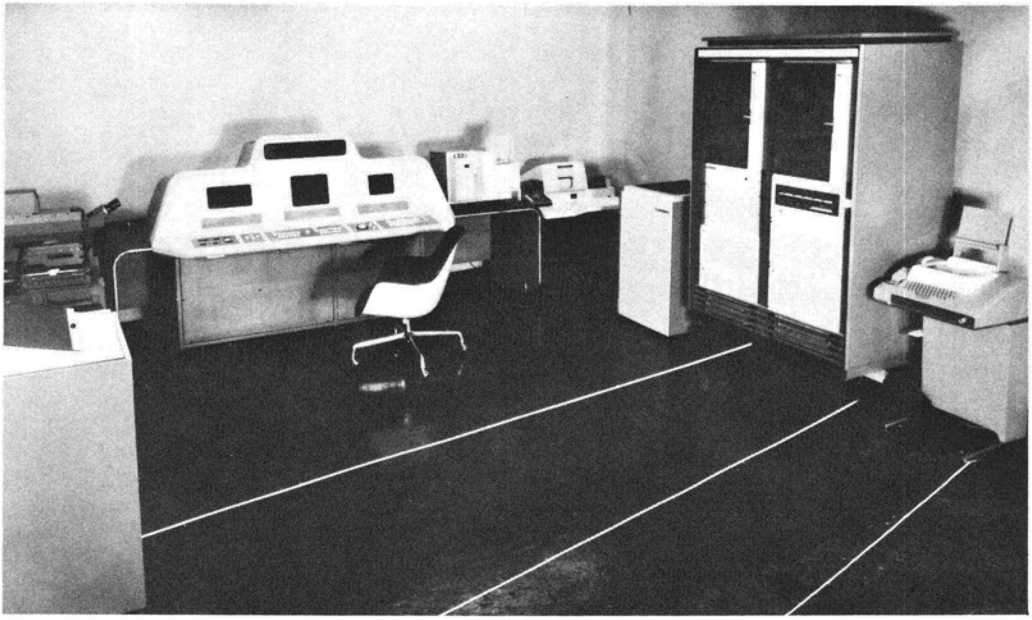

FRONTISPIECE. Automatic Reseau Measuring Equipment.

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The Automatic Reseau Measuring Equipment (ARME)*

A computer-controlled monocomparator capable of centering on reseaus, stars, and marked points on photographs.

(Abstract on next page)

INTRODUCTION

THE ARME was developed by the U. S. Army Engineer Topographic Laboratories (USAETL) under contract to DBA Systems, Incorporated, and was delivered to the Defense Mapping Agency Topographic Center (DMATC) in August 1974, where it is at present undergoing engineer design and service testing. Attempts have been made in the past to automate the measuring process of image points symmetrical or near-symmetrical in shape, with limited success. This is the first attempt to use computer programming techniques to center on these image points. The success of centering is determined by the quality of the image point, and the methods used to extract the point from the surrounding background.

DESCRIPTION

The basic function of the ARME when centering on selected points is to digitize in matrix form the area which encompasses the point to be measured, and extract by computer programming techniques the location of the point within this matrix. Thus the main components of the equipment are a numerically controlled monocomparator with a scanner-digitizer and minicomputer with attendant peripheral equipment. The

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ABSTRACT: *The Automatic Reseau Measuring Equipment (ARME) is an instrument which rapidly and accurately centers on* reseaus, *stars, and marked points on photographs with either homogeneous or heterogeneous background and measures their coordinates. The equipment consists of a precise computer-controlled monocomparator with a TV camera, an operator console, a point locator, and a computer system with card and magnetic tape inputs and card, magnetic tape, and hard copy outputs.*

This paper presents a description of this equipment and method of operation, and a discussion of test results. Primary emphasis in description of operation and discussion of results will be placed on the automatic centering system.

monocomparator provides the basis for accurate measurement of points after automatic centering; and the computer controls the table's movements, collects and processes the digitized data, and outputs the resultant required information on magnetic tape.

The Frontispiece is a picture of the Automatic Reseau Measuring Equipment. It consists of, from left to right: a point locator, a modified H. Dell Foster monocomparator, an operator console with a card reader located next to it, a card punch, a printer plotter, a cabinet containing two magnetic tape units and the computer, and a teletype. In order to simplify the description of the equipment, it is convenient to divide it into three main groups based upon their supplier; specifically that part of the ARME provided by H. Dell Foster Company, Varian Data Machines, and DBA Systems, Inc.

The equipment supplied by H. Dell Foster consists of an RSS-600 Monocomparator, as seen in Figure 1, modified by adding a drive system and the Digital Control System from the RSS-700 Digital Automatic Drafting System. The overhead arm containing the optics are redesigned as were the optics, and an MTI, VC-22 729-line TV camera was added. Newly designed reticles were also added to the eight-position reticle wheel. The table is air floated and guided with servo-driven lead screws and has a 10 by 19-inch measuring area. Linear encoders provide a mensuration resolution of 1 micrometer. A rotary encoder attached to the servo motors monitors table motion. Two plate holders are provided, one for glass plates and one for film.

A Digital Control System provides for computer control of the table. It instructs the table to perform a move of any magnitude up to 2-inches-per-second in any direction, and the table moves from point to point in a straight line. Both the rotary and linear encoders are used to provide information to make this a true closed-loop system. This system also controls the reticle light on/off position, the image light intensity, the image shutter, and the limit switches.

The viewing system as seen in the optical schematic, Figure 2, consists of (1) a binocular microscope with a variable magnification from 20× to 80×, (2) K-mirror to rotate image and reticle, (3) beam splitter, (4) reticle lens, (5) K-mirror to rotate the reticle, (6) turret containing 8 reticles, (7) incandescent light source, (8) image objective lens movable to adjust focus, (9) shutter used during window centering, (10) image plane, (11) 45 degree front surface mirror, (12) microscope objective lens, and (13) vidicon camera. The image objective lens has a magnification of 2× and the microscope lens has a magnification of 7.5×, providing a total magnification of 15× of the image on the vidicon tube. The vidicon views an area of 600 by 800 micrometers at the image plane and displays it on the monitor on the operator console at a magnification of a little over 400×.

The second group of equipment is provided by Varian Data Machines. It consists of the 620f-100 computer system. It has a central processing unit with a 32K core memory, a 491K fixed-head disc memory, an automatic boot-strap loader, two priority interrupt modules, five buffer interlace controllers, two buffered input/output controllers, two 9-track 800 BPI magnetic tapes, one alphanumerical CRT monitor and keyboard, an ASR 33 teletypewriter, a UNIVAC card punch, a Bridge card reader, and a Statos 31 electrostatic printer and plotter. Also, a Vortex operating system software package is provided.

The third group which was provided by DBA Systems,, Inc. consists of the point locator, the operator console, interface electronic packages, and all the software preparation, operation, and post-processing.

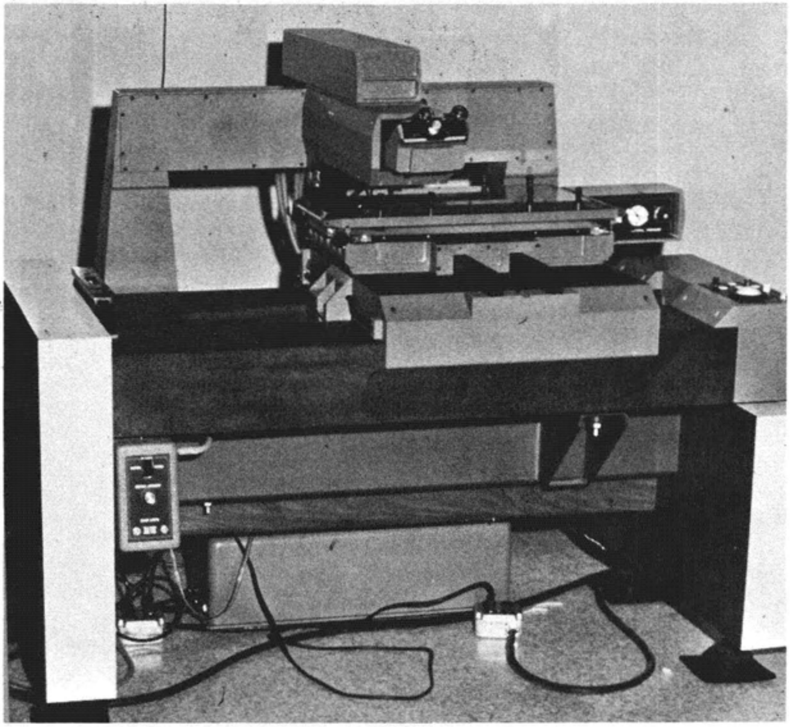

FIG. 1. Monocomparator.

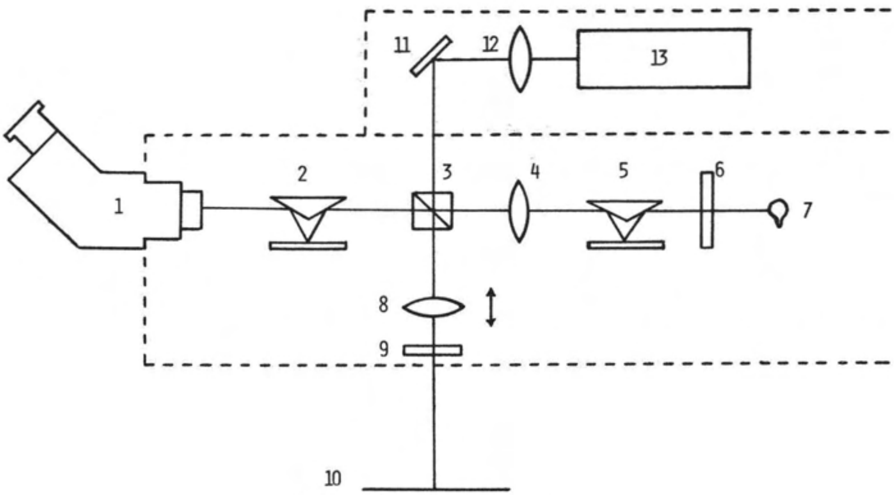

FIG. 2. Optical schematic.

The point locator consists of the same closed-loop TV system that the table uses with a monitor on the operator console. A print of the input material is placed on top of the unit upside down underneath a rubber cover, and the camera views the entire 9 by 18-inch format.

The operator console contains all the controls necessary to operate the system after loading the input material and the magnetic tapes. It contains a digital display on top with two sets of x, y coordinates, a quality control number for both x and y coordinates, an identification number, and a clock showing hours, minutes, and seconds. One set of coordinates indicates present table coordinates, and the second the table coordinates of the previous point. There are three monitor screens. The left one is for the point locator. A TV picture of the print of the input material is displayed on it, plus a small white cross which, under computer control, moves across the screen to indicate the position of the scanned image with respect to the whole photograph. The center monitor is for the image. It displays the scanned image plus a white-bordered square in the center which is referred to as the window. This window is used in the automatic measuring process and will be discussed later in this paper.

The right monitor is an alphanumerical CRT and displays all messages that are either put on it by the keyboard or by the computer. This is a fast and easy method for the operator to communicate with the computer for such tasks as calling up programs, determining status, and maintenance. In the preparation or setup mode, the monitor is extensively used to display messages to aid the operator in the proper execution of all steps of setup. All the controls are located below the monitors. They consist of: four pushbuttons to move the cross on the point locator monitor for orientation purposes; a series of pushbuttons to enter parameters into the computer such as type of point to be measured, type of measuring to be done, whether the point is a black or white image, the intensity of table illumination, etc.; a ball-and-disc integrator for fine table motion, and switches for fast motion and to correct table fault status; and lastly the CRT keyboard. A duplicate set of table controls is on the table so that the table can be moved by either set of controls in the manual mode.

Operation

Equipment operation consists of the preparation or setup mode, the measuring mode, and the post-processing mode. In the setup mode, a series of instructions must be given to the computer and operational steps followed to set the correct parameters for measuring that particular photo, check the origin of the table's coordinate system, calibrate the window, calibrate the reticle, and find three or more points on the photo to relate the photo to be measured to the data on the magnetic tape for pre-positioning. A tape containing pre-positioning data, which may also be calibrated positions for that photo, is loaded onto one of the two magnetic tape units by the operator. A computer program transforms all the points on the pre-positioning tape to the table's coordinate system and stores them in the computer.

In the measuring mode a program drives the table to the first point, performs automatic centering, applies corrections for table errors, and stores the measured point on a magnetic tape located in the second magnetic tape unit. The table is then driven to the second point and this procedure is repeated. In this manner, all points on the pre-positioning tape are automatically measured. Several check routines are incorporated to optimize measuring accuracy. Periodically the window is recalibrated and the first point on the photo is remeasured to check for any count skip errors of the linear encoders. In addition, there is a program which can be called to measure a symmetric pattern of *reseaus* or grid line intersections periodically when measuring a large number of points under unstable temperature and humidity conditions. Another program then corrects the measured data for any shifts in the position of this pattern of points.

In the post-processing mode, if needed, the data are massaged to correct for all known distortions, and the corrected data are then output on cards, magnetic tapes, or hard copy.

Automatic Centering

The Automatic Centering Program is the most interesting feature of this equipment. The center area of the vidicon, previously mentioned as the window, contains 255 video lines. A video processor divides each line into 255 bits of data. Since the window is approximately 200 micrometers in size, each bit is equal to 0.8 micrometer. A threshold routine sets the density threshold at a certain level so that all video information above this threshold becomes "one" bits and all video information below this threshold becomes "zero" bits. A horizontal accumulator adds the number of "one" bits of each horizontal line and stores it in the computer in a row matrix. A vertical accumulator adds the number of "one" bits of each of the 255 columns and stores it in a column matrix. The largest number of bits that can be stored is thus 255^2 or 65,025. The characteristic of summing data is that undesirable "bogies" which may also be in the window do not bias the centering measurement, especially for cross-type targets.

The threshold setting combined with the intensity of illumination setting determines the amount of data in relation to noise in the window for a particular type of imagery. Because of the noise with film and the different shapes of the points measured, one routine is used for determining threshold for *reseaus* and grids and another routine for stars and the reticle. *Reseaus* and grids have much more information summed in the window than stars and the reticle. For instance, a 20-micrometer-wide grid line intersection will have a theoretical sum of each matrix of a little over 12K. A 40-micrometer-diameter star will have a sum of only approximately 2K.

The threshold routine for grids and *reseaus* sets the threshold so that data accumulation falls within the range 16-28K. This range takes into account all the noise that is added with the target. The threshold routine for stars and reticle first finds a threshold level where all points are above the threshold, then the level where all points are below the threshold. The threshold is then set to a percentage of the range between the two determined levels. A choice of two settings is available at present, 25 and 40 per cent, and is entered into the centering program during the setup mode.

In order to determine the center of the image, a computer routine next performs the following steps on each data matrix:

1. Smooths the data with a five-point averaging filter.
2. Finds the maximum positive slope and its location within the smoothed data.
3. Finds the maximum negative slope and its location within the smoothed data.
4. Computes the size of the target as the distance between these two locations and sets the halfway point as the center of the target.
5. Performs a left to right correlation using a sliding window technique with the window set to the size of the target just computed, to search for the location which has the greatest density of data within the matrix. This is the second center of the target.
6. The average of the two centers is then selected as the center of the target.

Many edit routines are used throughout the centering program to eliminate undesirable targets or bad measurements. A quality control number from 0 through 9 is attached to each instrument with 9 being the most desirable measurement. If the centering program cannot find the target by the above listed technique, special programs are called. For *reseaus* and stars, the window is moved to the four cardinal directions and positioned adjacent to its original position. Three times as much data for each axis is gathered, divided by 3, and the above-listed centering program repeated. If the center is found, the measurement is recorded with the quality number reduced by 1. If the target is again not found, a new program is called which performs a weighted accumulation. Ten samples are taken; for each sample the threshold is reduced by a fixed amount and the weight increased by 1. The 10 samples are then added and normalized. The centering routine is again called. If it is not found, a quality control number of "0" is assigned to the measurement, and the point is placed in the error file in the computer. The weighted accumulation program is applied to stars and the reticle only if the target is not found the first time through.

A routine can be called to plot on the printer-plotter a graphical representation of the information stored in the row and column matrices in the computer. Figure 3 is a plot of a grid line intersection, Figure 4 a *reseau*, Figure 5 a *reseau* after being processed by the weighted accumulation program, Figure 6 a star with a 25 per cent threshold, and Figure 7 the same star with a 40 per cent threshold.

During automatic mode of operation, the reticle is not used and is not illuminated. It is, however, measured periodically during this mode to insure that it remains in the center of the window and thus establishes the window center as table reference. This measurement is done by closing the image shutter and turn-

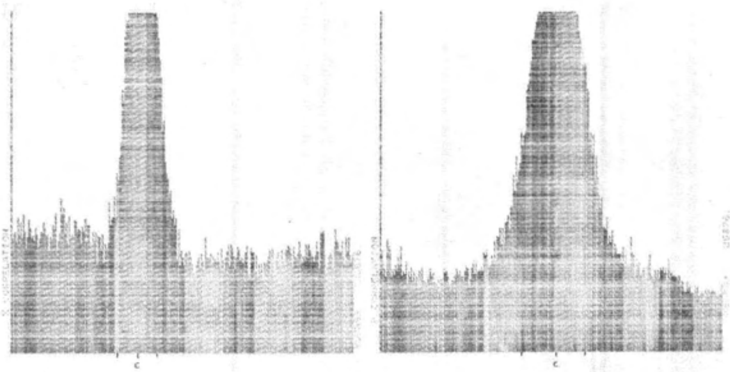

FIG. 3. Grid line.

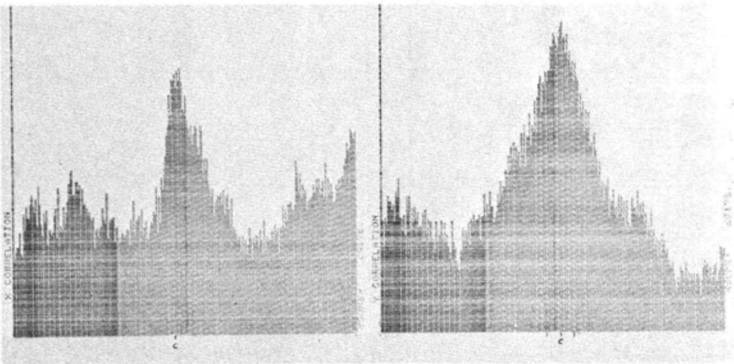

FIG. 4. Reseau.

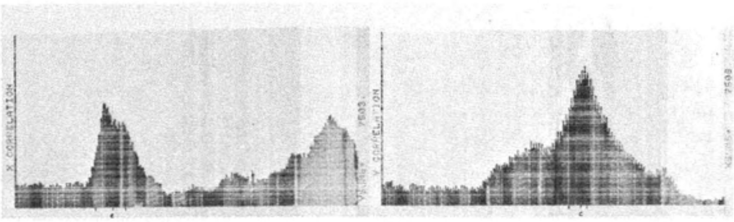

FIG. 5. Reseau.

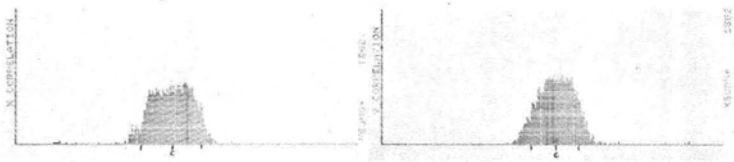

FIG. 6. Star, 25 per cent threshold.

FIG. 7. Star, 40 per cent threshold.

ing on the reticle light so that the vidicon sees only the reticle, measures the reticle, and adjusts the window if necessary. Then the shutter is opened, the reticle light turned off, and the measuring of points is continued. The speed of operation in the measuring mode is between 4 and 5 seconds per point including table movement as an average, depending upon the quality of the point and any difficulty encountered in measuring.

RESULTS

Tests made on the equipment to date consist of an extensive amount of grid, star, and *reseau* measurements. A large amount of accuracy data is available on the grid measurements, and a small amount on stars and *reseaus* to date.

The grid measurements were made using a 9 by 18-inch grid plate with 20mm separation between 20-micrometer-wide grid lines with calibration data known to one-half micrometer. The 312 grid line intersections were measured by using the automatic centering system and the measurements fitted to the calibration data using a full surface fit (20 coefficients). Results show a standard deviation of below 1 micrometer for both x and y.

In order to determine table stability, a Quality Control program is called after a grid is measured using the correction coefficients. This program compares the measurements with the calibrated positions using a three-parameter fit (translation and rotation). The standard deviation of the residuals is computed and is the measure of table stability. For many months in the past this stability test was performed once a day and at present it is performed twice a week.

Results from September 1974 to date show that a standard deviation of slightly below 1 micrometer in x and slightly above 1 micrometer in y has been maintained for a period of at least 1 week and of up to 1 month. Changes in the standard deviation have been limited to 0.2 micrometers or less between each set of grid measurements from day to day. If the accuracy becomes too low, a new calibration can be performed and a new set of coefficients entered into the computer.

The accuracy of star measurements to date has been determined by a comparison between manual vs automatic measurements. Results with one star plate containing 700 measurements show a standard deviation of 3 micrometers in x and y when compared to a mean of manual measurements performed on another comparator, with only 2 per cent of the points placed in the error file. In addition, manual and automatic measurements plus repeated automatic measurements on stars, *reseaus*, and marked points have been performed on this instrument and the results listed in Table 1. The data show that automatic centering on targets with high signal-to-noise ratio such as grids have a repeatability equal to the resolution of the scanning system, and that for image points on photographic background, the accuracy varies as a function of the quality of the target and the S/N ratio of the surrounding background. The accuracy results are impressive in these preliminary tests.

TABLE 1. TEST RESULTS.

Type	Repeatability			Accuracy (Manual-Automatic)	
	Sx	Sy	n	x	y
Grid	0.9	0.5	23	——	——
Grid	0.6	0.6	20	——	——
Reseau (a)	1.0	0.8	6	−1.3	−0.8
Reseau (a)	2.8	2.4	20	2.0	2.3
Reseau (a)	1.7	5.1	4	−2.5	6.5
Reseau (b)	1.1	0.9	12	−1.2	0.6
Reseau (b)	2.7	2.7	8	−3.9	−3.9
Reseau (b)	1.1	1.6	10	−2.5	2.2
Star	1.0	1.4	12	0.1	0.7
Star	1.8	2.6	25	−2.8	−0.4
Star	1.3	2.0	12	−5.7	2.7
Marked Point	1.6	1.3	18	1.8	−0.1
Marked Point	1.0	0.6	19	−0.5	−1.9

Manual is a mean of five observations with repeatability of between 0.5–0.9 micrometer Sx, Sy.

Accuracy is the difference between the mean of manual and the mean of automatic observations.

No observation eliminated in any of above data.

The Service Test Data obtained to date also have been quite satisfactory and have been equal to or have surpassed the expected accuracies. It is expected that the operation tests at the Topographic Center will continue to demonstrate the accuracy and versatility of this new and unique instrument.

INTERNATIONAL SYMPOSIUM ON COMPUTER ASSISTED CARTOGRAPHY

An International Symposium on Computer Assisted Cartography will be held in Washington, D. C. from September 21 through 25, 1975. The conference is sponsored by the American Congress on Surveying and Mapping, in cooperation with the U. S. Bureau of the Census.

The purpose of the meeting is to promote an international exchange of information about methodology application problems and software and hardware in the field of computerized cartography.

Computer mapping is playing an increasingly important role in planning and data analysis. Computer maps are especially effective for administrative and public information purposes since the visual impact and clarity of maps can make trends immediately apparent.

Workshops and panels will deal with the use of statistical mapping and cover such topics as map reading and perception, interactive map editing, and urban information systems. The registration fee for the conference is $60. Exhibit space will be available for commercial and non-commercial presentations. Special tours for interested participants will be provided by the U. S. Bureau of the Census and the U. S. Geological Survey.

For further information contact: Dorothy Bomberger, Symposium Secretariat, U. S. Bureau of the Census, Washington, D. C. 20233, Tel: (301) 763-7094.