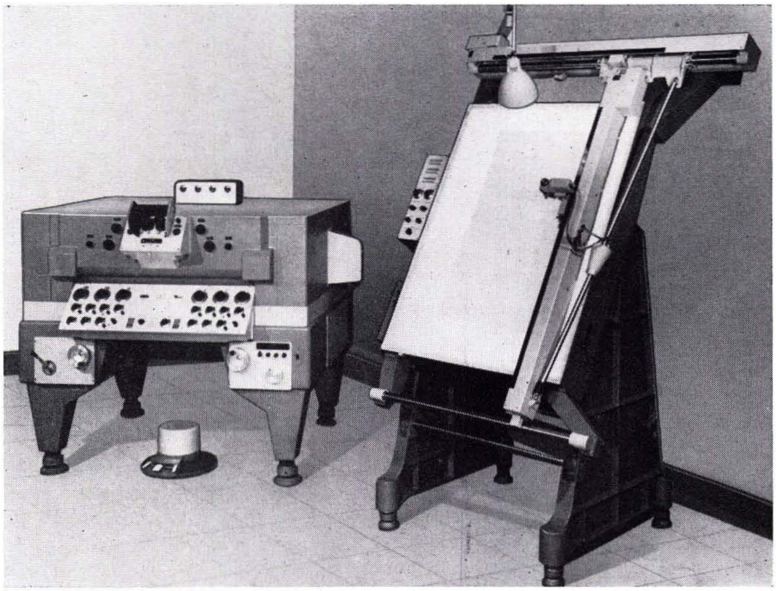

FIG. 1. Chart Analysis Device

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The Chart Analysis Device —A New Analytical Plotter

This second-order stereoplotter applies analog electronics.

INTRODUCTION

THIS PAPER DESCRIBES the Chart Analysis Device—a new compact mapping instrument based on the analytical stereoplotter principle. The instrument was developed by Bendix Research Laboratories and Ottico Meccanica Italiana (OMI) for the Rome Air Development Center (RADC), Air Force Systems Command. A second instrument is currently in operation at the Topographic Systems Division, U.S. Army Engineering Topographic Laboratory, Fort Belvoir, Virginia.

Compared to previous analytical stereoplotters, the Chart Analysis Device offers the advantages of greater compactness and lower cost. Earlier analytical stereoplotters produced by Bendix and OMI consisted of three separate units—a stereoscopic viewer, a digital control computer, and a coordinatograph for producing the output charts; the Chart Analysis Device, however, has only two separate units. The stereoscopic viewer

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington D. C., March 1967.

and analog control computer are integrated into a single, compact unit. In addition, the coordinatograph, which has a relatively large plotting surface, is positioned vertically. As shown in Figure 1, this arrangement contributes to system compactness, and it also permits the operator to easily view output maps as they are plotted. The use of analog techniques results in lower accuracy than in digitally controlled systems, but the accuracy is quite adequate for many mapping situations. A major benefit of using analog techniques is the reduced equipment costs due to simpler component and structural requirements.

the calculated photo coordinates are directly under two measuring marks in the optical train. Thus, the operator sees a stereo image with a single floating mark in the center, just as he would with one of the classical plotters. When the operator turns a handwheel or footwheel to change the floating mark position in the stereo model, the computer calculates the new photo coordinates for the changed model position, and moves the photo stages so that the new photo coordinates are under the measuring marks. This sequence is performed so rapidly that the operator sees no delay between his handwheel or footwheel command

ABSTRACT: *The Chart Analysis Device is a second-order stereoplotter designed to compile or revise cartographic charts. Both frame and panoramic photographs with wide ranges of tilts and focal lengths can be accommodated in the instrument. The Chart Analysis Device implements the well-known analytical plotter principle by means of analog electronics. The result is a compact instrument with operating procedures quite similar to those of the conventional mechanical-analog plotters.*

ANALYTICAL PLOTTER PRINCIPLES

Although the principles of U. V. Helava's analytical plotter are well known, a summary of the analytical plotter concept may be helpful. In general, photogrammetric stereoplotters relate the image spaces of two photos to an object space. In classical stereo instruments, this is done by optical or mechanical projection methods. In the analytical plotter, the projection is done mathematically, by solving the projective equations with a high-speed computer. In classical instruments, the plotter recreates in miniature the positions, attitudes, and internal geometry of the aerial cameras at the time of exposure. With an analytical plotter, the computer program models the geometry mathematically, so that the mechanical construction is much simpler—essentially a precision stereocomparator.

The computer continuously solves the equations that relate stereo model coordinates X_m, Y_m, and Z_m to the conjugate photo images at x_1, y_1, x_2, and y_2 in the two photo coordinate systems. This geometry is illustrated in Figure 2 for frame photography. (An earth curvature correction which changes terrain elevation, E_m, to the Cartesian Z_m is included but is not shown in the figure.) When the computer calculates a set of photo coordinates, it commands servo motors to move both photo stages in x and y directions until

and the corresponding movement of the floating mark in the stereo model. The sensation is exactly the same as that experienced when operating a plotter with a mechanical linkage between model coordinates and mark movement.

The analytical plotter concept offers several advantages over mechanical or optical projection techniques. The single most important advantage, possibly, is the ability to perform stereomapping from any kind of image

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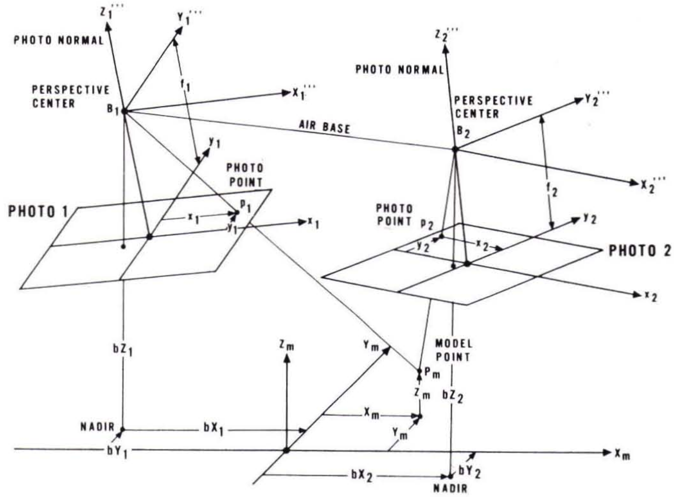

FIG. 2. Geometry and principal coordinate systems involved in processing frame photography.

record with a describable geometry. Previous analytical plotters, such as the AS-11A or the AP-C use stored program digital computers; they can be reprogrammed for any image geometry. For example, to plot from a stereo pair composed of an oblique 35-millimeter slide from an amateur camera and an infrared line-scan record, it would be possible to write a computer program for the analytical plotter that would allow plotting from this combination. The accuracy of a manuscript produced in this way would be limited primarily by how well the geometry of these records could be programmed, and by how well the operator could maintain stereovision of the model.

Such an unlimited capability in image record acceptance is a necessity for some organizations, but it is certainly not required by others. And that brings us to the Chart Analysis Device.

General Description of the Chart Analysis Device

The Chart Analysis Device is a second-order analytical stereoplotter with intentionally limited capability. Instead of a stored-program digital computer, an electronic analog computer is used. Therefore, the Chart Analysis Device cannot be "reprogrammed" in the usual sense to accommodate unusual photo geometry. However, the analog control computer could be wired differently to handle such geometry.

Although the capability of the Chart Analysis Device is less than universal, it is still quite impressive. Frame or panoramic stereo pairs of from 3- to 100-inch focal length can be plotted. Camera tilts up to 45 degrees and panoramic sweep angles up to 60 degrees are provided. Greater tilts and sweep angles can be handled, although with reduced accuracy.

In general then, although the Chart Analysis Device is less than a completely universal analytical plotter, it has much more capability than one of the classical optical-mechanical plotters.

For camera focal lengths up to 40 inches, a Chart Analysis Device standard error of 50 microns is specified for the X and Y stereo model coordinates, when model scale is equal to photo scale. A standard error of 100 microns is permitted for focal lengths over 40 inches. Tests with typical materials have given better accuracy than specified: standard errors of 18 microns and 23 microns in X and Y for 6-inch frame photos, and standard errors of 14, 36, and 21 microns in X, Y, and Z for 12-inch convergent panoramic photos.

Detailed Description of the Chart Analysis Device

The Chart Analysis Device is composed of two separate units, the viewer and the coordinatograph. The analog computer is built into several compartments of the viewer units, as shown in Figure 3.

Most of the operator controls are located on the front of the viewer unit (Figure 4). The operator can turn knobs to change orientation elements, just as on a mechanical analog plotter, by turning the B_x, B_y, B_z, ϕ, ω, and κ control panel dials for each photo. A closeup

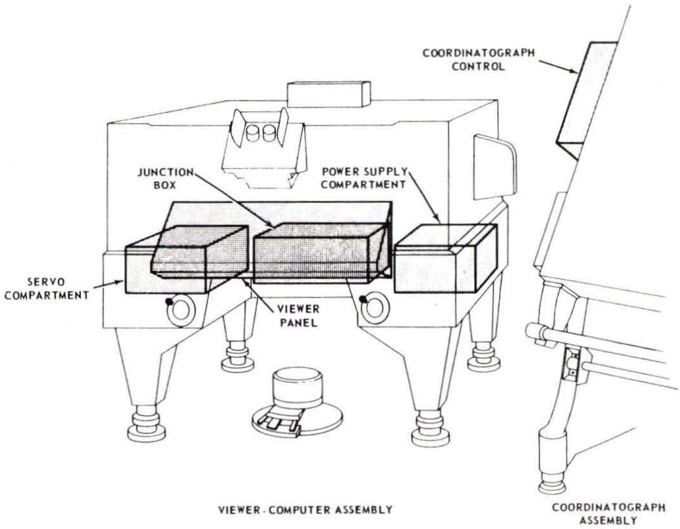

FIG. 3. Locations of electronic components.

of the control panel is shown in Figure 5. The focal length of each camera is entered in the same way, by turning dials.

Handwheels control the X and Y stereo model movement and a footwheel is used for changing the floating mark height in the model—again, just as in most mechanical analog plotters. These are some of the controls one would expect to find on any stereoplotter. The Chart Analysis Device has a few other controls which are a little more unusual.

Besides the normal dove prism controls that rotate the images, the Chart Analysis Device has a separate zoom magnification control for each eyepiece. Depending on the objective used, this allows either a 4× to 8× or an 8× to 16× magnification range. During plotting, the computer automatically controls the image rotation and magnification to help the operator maintain his stereo perception with a minimum of discomfort. This computer-controlled adjustment of image rotation and magnification is quite useful in working with panoramic or convergent frame photographs.

X and Y movements of the floating mark in the stereo model can be directed with the Veltropolo. The Veltropolo is a slewing con-

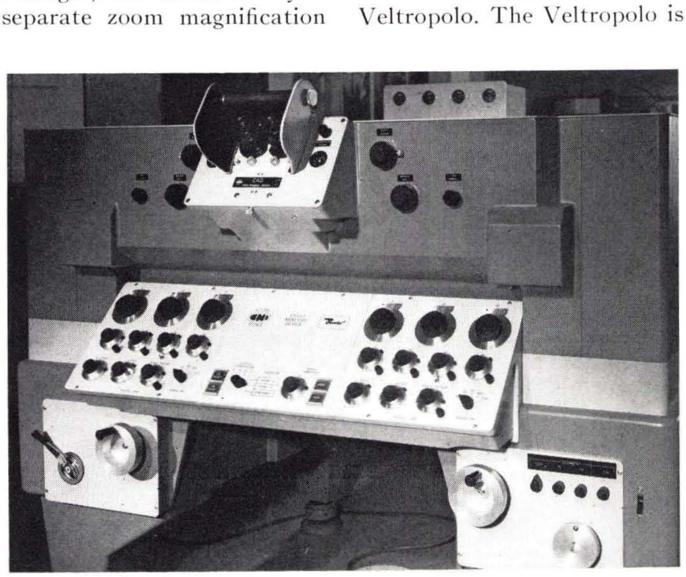

FIG. 4. Viewer Controls.

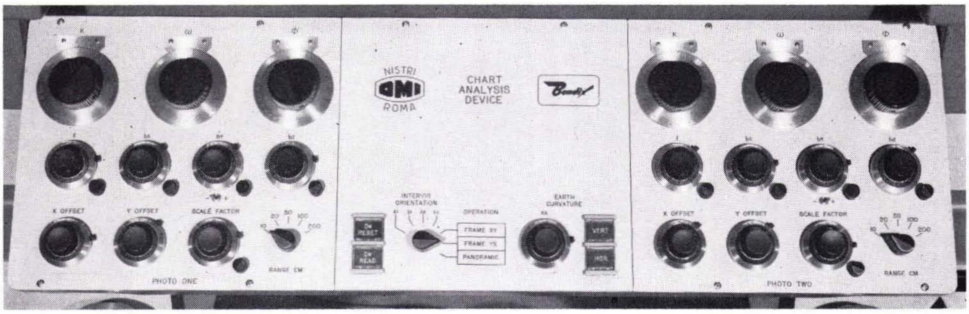

FIG. 5. Viewer control panel.

trol with two components, analogous to a steering wheel and an accelerator. The Veltropolo rate switch (the accelerator) is located to the left of the X handwheel, while the direction control (the steering wheel) is to the right of the Y handwheel. When using the Veltropolo or the handwheels, the operator can slew the floating mark in the stereo model at speeds up to 30 millimeters per second.

The effect of the photo coordinate rotation knobs is to rotate the photo coordinates to be parallel to the stage coordinates. These controls are essentially κ or swing motions in the plane of the photo. This alignment need not be used for frame photos, but it is essential for panoramic photographs.

The Chart Analysis Device photo stages are each 9 inches by 18 inches, instead of the usual 9 inches square. The principal point can be offset as much as 9 inches in Y from the center of the stage, so that it is possible to plot from segmented photographs as far as 18 inches from the principal point in the Y direction. This feature is intended primarily for use with panoramic photography.

The Chart Analysis Device includes controls which automatically remove the effects of earth curvature from both the elevation coordinates and the X, Y model coordinates. To set up this computation, the operator sets a dial to the reciprocal of the radius of the earth in meters at model scale.

Systematic film shrinkage effects can be removed with a small differential photo-scale adjustment knob on the control panel.

On the top of the viewer unit are the numerical read-out dials for the X, Y, and elevation values at model scale. The fourth dial, D_m, continually indicates model X, Y distance from a zero reference point. The operator can set the reference to be anywhere in the model by pressing a button on the control panel. Each of the four read-out dials has a least-direct-reading of 10 microns.

The Chart Analysis Device coordinatograph is controlled by the computer through connecting cables. The coordinatograph standard positional plotting error is less than 0.1 mm. The near-vertical attitude of the plotting surface (Figure 1) is intended to save floor space, and to help the operator check the manuscript as he plots. The plotting scale is determined by control box switches at the left side of the coordinatograph. X and Y plotting scales can be entered independently, anywhere from one-half to 6 times the scale of the stereo model.

Operation of the Chart Analysis Device is quite similar to the operation of any mechanical analog plotter that has numerical entry of orientation elements; very little preliminary instruction is required. The Chart Analysis Device operator performs relative and absolute orientation with the same methods used with any first-order mechanical analog plotter.

CHART ANALYSIS DEVICE ANALOG COMPUTER

In digitally controlled systems, computations are performed serially, with potentially unlimited accuracy. In an analytical plotter, such serial computations must be carried out quite rapidly so that the operator sees no noticeable lag between his model coordinate commands and the resulting movement of the floating mark in the stereo model. Thus, time is an important factor in performing the calculations digitally, but computational accuracies of a micron are easy to maintain over a photograph 23 cm square.

In an analog computer, all computations are being performed simultaneously because the entire computer is a single electrical circuit. Thus, the time of response of the system is limited only by the characteristics of the servos used to move the photos in the X and Y axes.

However, accuracy is a different matter. Analog measurements are limited in accuracy

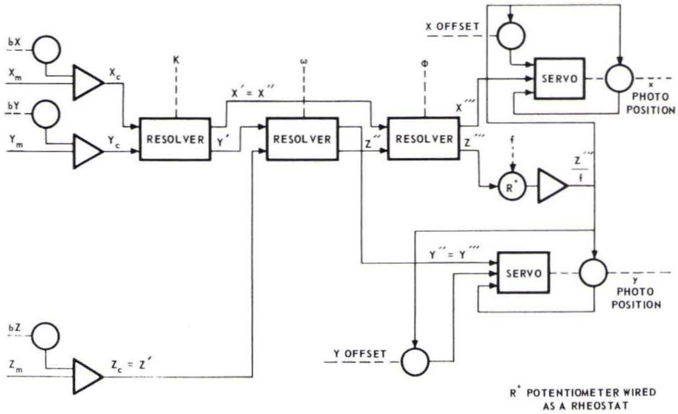

FIG. 6. Photo-position computation, frame photography.

to a few hundredths of one percent. This limitation is one of technology and cannot be improved upon without basic improvements in electronic component design. True, by clever computer design, the effects of the component errors can be lessened, but these errors still present a real limit to the accuracy that can be achieved at practical cost.

In the analog computer that controls the Chart Analysis Device, physical quantities are represented by electrical signal, voltages, or shaft angles, which are proportional to the sizes of the physical quantities. Three principal kinds of computing elements are used: AC potentiometers, operational amplifiers, and resolvers. These elements can be connected to perform multiplication, addition, and subtraction. The potentiometers can be used for squaring or multiplying quantities, or as storage elements. For example, on the Chart Analysis Device the values of B_x, B_y, and B_z are entered by the operator on potentiometers and stored there.

The operational amplifier serves as a constant or coefficient multiplier, or as a sum-and-difference device. The resolver is an electromagnetic device which, in effect, rotates a vector through the angle set into the resolver. In the Chart Analysis Device, the operator sets resolver angles when he adjusts the ϕ, ω, and κ control knobs.

The connections between components can be illustrated by the model-to-photo coordinate computing sequence for frame photography shown in Figure 6. The signals representing X_m, Y_m, and E_m are adjusted by the B_x, B_y, and B_z quantities for each photo so that they represent the X, Y, Z components of a vector from each exposure station. This vector is then rotated through the three angular orientation elements in the order κ, then ω, then ϕ. For each photo, this rotates the vector into an X''', Y''', Z''' coordinate system parallel to the photo coordinate system. The X''' and Y''' values are fed into the photo stage servos. Z'''/f is used to normalize these values to the photo coordinates x, y and the motors drive the x, y lead screws until these coordinates are obtained.

At the same time the above operations are performed, the computer calculates the magnification and rotation required for each image. Servo motors on the zoom optics and dove prisms perform these adjustments.

Concurrently, the computer also updates the model distance value from the distance reference point and displays it on the read-out dials. In addition, the X_m and Y_m model coordinate signals are scaled by the X and Y scale potentiometers on the coordinatograph and the resulting signals drive the coordinatograph X and Y lead screws to perform the manuscript plotting.

SUMMARY

The Chart Analysis Device is intended to provide a stereoplotter of intermediate capability, one that comes between the classical mechanical analog plotters and the higher accuracy, nearly universal, digitally controlled analytical plotters. The system requirements have been achieved, and it is hoped that this new analytical plotter will find a useful place in map and chart compilation and revision.