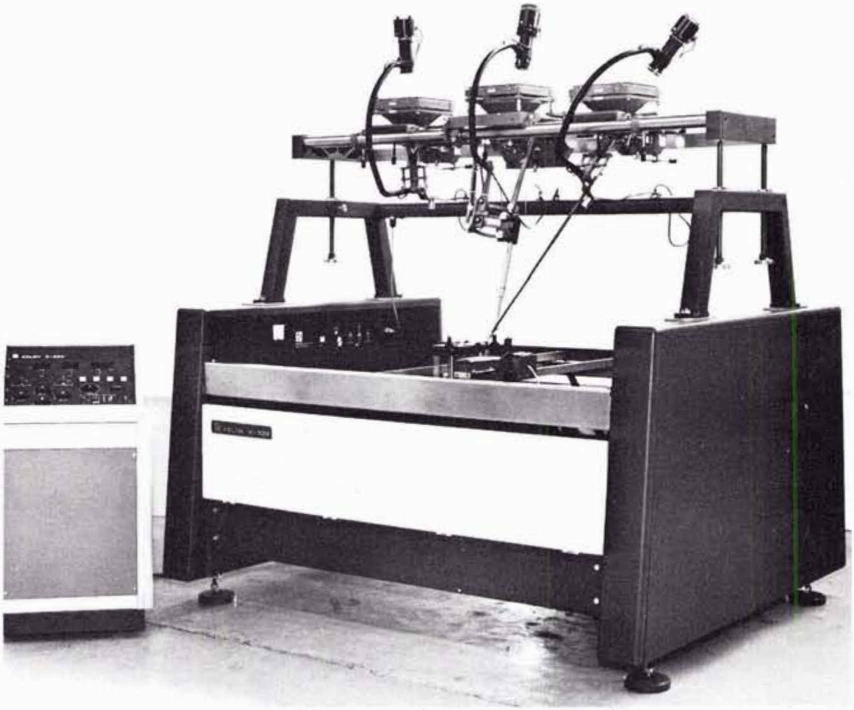

FIG. 1. The K-320 ORTHOSCAN is an orthophoto instrument without a granite reference surface.

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Quick Orientation of the K-320 ORTHOSCAN

Helpful features and a logical technique facilitates the absolute orientation of this orthophoto device and stereoplotters.

(Abstract on next page)

THE NEED FOR A NEW SYSTEM

IT HAS OFTEN been said that necessity is the mother of invention. This is certainly the case with the absolute orientation method that is about to be described. The Kelsh K-320 ORTHOSCAN is an orthophoto instrument that does not have a granite reference surface. Indeed, the design of the instrument provides no flat surface under the projectors to support a manuscript with plotted control points.[1] See Figure 1.

Manuscripts have been used, heretofore, for absolute orientation scaling on projection-type stereoplotters. Such manuscripts are usually of mylar, with grid lines at standard spacings. Control points are plotted with an engineering or cartographer's scale from the convenient grid lines.

After the relative orientation, or *clearing* has been performed on the stereo model, the manuscript comes into play. It is first placed on the granite reference surface so that one plotted control point is directly under that same point in the stereo model. A weight is sometimes placed on the manuscript at this point. One projector is then moved in X to scale the stereo model to the manuscript points. The manuscript can be worked around on the granite until two plotted control points match the scale of the same two points in the stereo model. The model is then fine leveled and fine scaled until the operator is satisfied that the projected model will meet National Map Accuracy Standards.

In the course of this absolute orientation positioning, the Kelsh operator uses *rule of thumb* or trial and error methods for the movement of the projectors and the X bar to bring the stereo model into scale. Many compilers have worked out their own systems for these methods.

- The K-320 has digital readouts in X, Y and Z. X and Y may be read to the nearest 0.1 mm and Z may be read to the nearest 0.01 mm with a plus or minus sign from the zero point.
- The operator has the ability to zero each of the above readouts at any time by depressing reset buttons.
- The exact planimetric positions are known for the three X bar elevating screws.
- The Kelsh *PPV*® (polarized viewing system)[2] is used with the K-320 for off-line scanning. The *PPV* platen-light dot provides a convenient reference mark to place on control points in the stereo model.
- Graduated handwheels (Figure 2) were added to the X-bar elevating screws. The K-320 and Kelsh stereoplotters use elevating screws with a ⅛-inch thread. This means that the pitch of each thread is .125 inch, which is the distance the screw will advance in one revolution. The handwheel was produced with 25 graduations on it, so that each graduation represents .005 inch.

ABSTRACT: *Three dimensional digitizers for projection stereoplotters have become increasingly popular in recent years. The Kelsh K-320 ORTHOSCAN is an orthophoto instrument which also has a three-dimensional digitized readout. A fast method for absolute orientation has been developed for the K-320 which could also apply to digitizers on stereoplotters. The method permits the operator to scale the model without the use of plotted control points on a manuscript, which heretofore has been the usual practice. Also, this system provides a basis for recapturing the projected model to the same control points that were originally digitized, if that should be required at a future date. The principles described can also be helpful for Kelsh plotters without digitizers. The only auxiliary equipment that would be required would be a small electronic desk-type calculator of the kind that is becoming increasingly popular on the market today.*

The K-320 ORTHOSCAN has been designed to project 9 × 9-in (23×23-cm) diapositives at a magnification range of 3.8× to 5.8×. It was important to be able to level and scale the model directly on the K-320 so that the orthonegative that was produced would be to the final map scale required, if possible. In this way, the maximum amount of resolution could be captured on the orthophoto. Every time an orthonegative has to go through a copy camera for an enlargement, between 10 and 15 percent of the resolution is lost, even in the best of cameras. Therefore, scaling the model directly on the K-320 was a most important consideration.

PARAMETERS AVAILABLE

To develop a new system, we first made a list of the features that were available on the K-320 ORTHOSCAN that could be used for absolute orientation scaling. This information may be listed as follows:

FIG. 2. Graduated handwheels have been added to the elevating screws.

FIG. 3. With the graduated handwheel and a square, the elevating screw becomes a micrometer.

- Fixed base pads were added under each elevating screw so that a 12-inch mechanic's square with ⅛-inch (.125-inch) graduations could be positioned against the circumference of the handwheel, as shown in figure 3. The scribe line on the circumference of the small handwheel provided the reference position in elevation against the blade of the square. In this way, each elevating screw became a *micrometer* and the operator could position or reposition each screw to within .001 inch quite easily.

During the last few years, a number of electronic desk-type calculators have come on the market at reasonable prices. We found that a calculator with both a memory and a square-root function could be most useful for our new system. Several such calculators were found to be available, one being somewhat better than the others for our purposes.

THE BASIC SCALING CHART

Except for the elevating screws, the K-320 ORTHOSCAN is a metric instrument, and all readouts are in millimeters. We found that the operator could prepare a simple chart from four control points to guide him in scaling the model. The chart would look something like the one shown in Figure 4.

A, *B*, *C* and *D* are either analytical or ground control points, somewhere in the neat-model corner areas of the stereo model. For all of these points, the absolute ground positions have been calculated or are known. The distance between each of the points has been computed and converted to millimeters based on a scale of 25.4 mm per inch. The well-known Pythagorean theorem has been

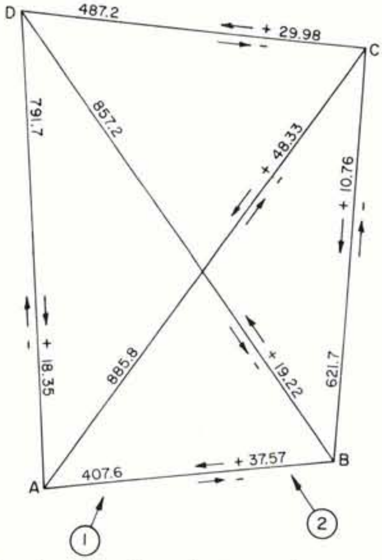

FIG. 4. A scaling chart may be prepared by the operator from the available control.

used to compute distances *AB* and the other legs in a similar manner as shown below:

$$AB = \left[(An - Bn)^2 + (Ae - Be)^2\right]^{1/2} \times Scaling\ Factor_{xy}$$

where *An* is the northing of point *A*, *Bn* is the northing of point *B*, *Ae* is the easting of point *A*, *Be* is the easting of point *B*, and Scaling $Factor_{xy}$ is 25.4/(map scale in ft per in).

This is where the modern desk type calculator can be very helpful. If the calculator has both a square root function and a memory, as shown in Figure 5, the above computation can usually be made in *one operation.* The distance *AB* can then be written on the scaling chart by the operator to the nearest 0.1 mm, as indicated in the first feature shown on the scaling chart.

The difference in elevation between point *A* and point *B* has also been determined in millimeters and recorded on the scaling chart, as indicated in the second feature. If the principal distance setting of the projector lens is equal to the focal length of the taking camera lens, the Z differential between *A* and *B* may be calculated as follows:

$$Z_{AB} = (Ah - Bh) \times Scaling\ Factor_z$$

where *Ah* is the elevation of point *A*, *Bh* is the elevation of point *B*, and Scaling $Factor_Z$ = same as computed above for *X* and *Y*.

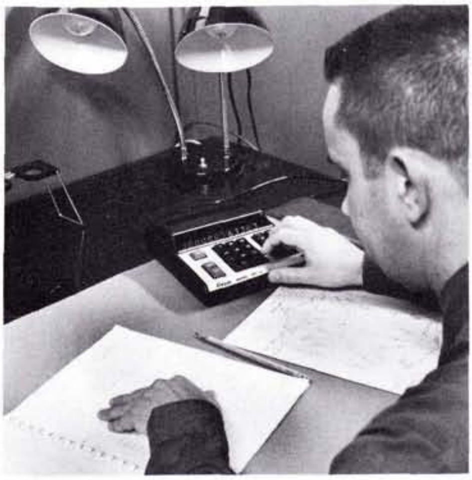

FIG. 5. A modern desk-type calculator can be used to compute the scaling and leveling data.

If the principal distance *(P.D.)* of the projector lens and the focal length *(F.L.)* of the taking camera lens are *not* the same, but the photography is reasonably level, an affine solution may be computed by using the following scaling factor for Z:

$$\text{Scaling Factor}_Z = (\text{Scaling Factor}_{xy}) \times (P.D./F.L.).$$

The difference in elevation is recorded on the chart to the nearest 0.01 mm. The arrows indicate that if going from point *B* to point *A*, the elevation would increase and therefore would carry a plus sign; but in going from *A* to *B*, the elevation would drop, indicating a minus sign. Each of the six lines on the scaling chart has been computed in the same manner, and the distances and the plus and minus elevation differentials recorded on the chart. These calculations could be made by the operator, or a software program could prepare them in advance.

Of course, it is only necessary to have *one* scaling distance computed on the above chart, but is convenient to have four points in elevation for leveling. A software program

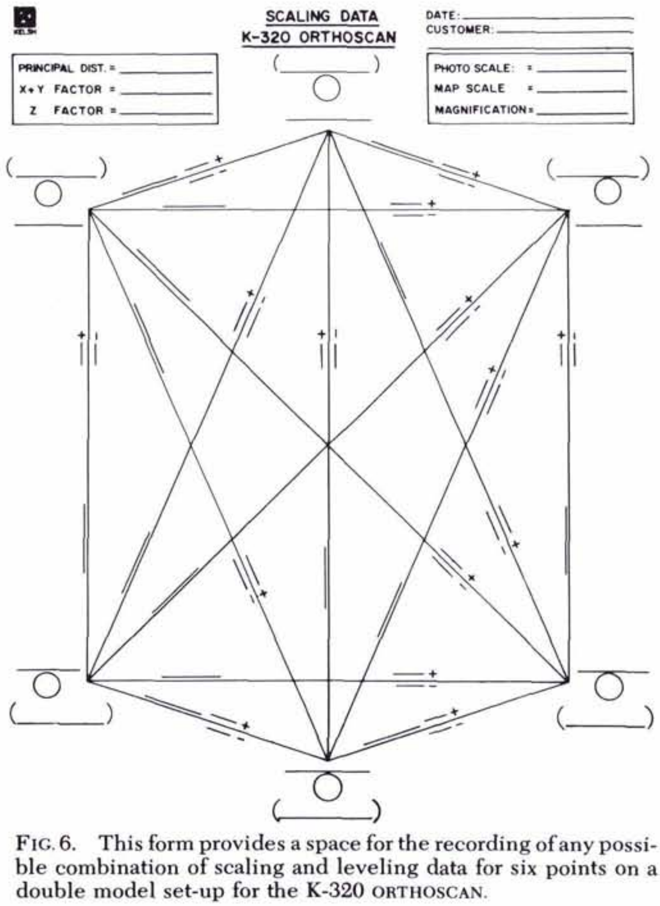

FIG. 6. This form provides a space for the recording of any possible combination of scaling and leveling data for six points on a double model set-up for the K-320 ORTHOSCAN.

can generate the information for *all* of the legs rather quickly, and the operator may select only the data that he needs. For descriptive purposes, we have shown all of the leg distances on the scaling chart.

For a double model, a similar chart must be prepared for the second model, and one leg of the new chart would include either leg *AD* or *BC* from the original one. Figure 6 shows a form which we use with the ORTHOSCAN for the full double model that is projected. The arrows are complete, except for the arrowheads which may be added by the operator, along with the other necessary information that he may require.

Scaling and Leveling Geometry

SCALING GEOMETRY

The common *X* and *Bx* motions of the projectors are used to scale a model on the K-320 ORTHOSCAN as well as on a Kelsh plotter. As shown in Figure 7, the scale of the stereo model is determined by the base distance between the two projectors.If projector *L* is moved to the right by distance *X*, the stereo model will be reduced to the size as shown by the broken line.

Let us assume that an initial scale measurement is made from *B* to *A*, and distance *B'A'* is the final scale required. Then, projector *L* is moved in *X* so that point *A* moves approximately the *full* difference in *X* between *BA* and *B'A'*. Point *B* will stay essentially in the *X* position, but will move to *B'*. Point A will move to point A'.

The scaling may also be done in the *Y* direction. Let us assume that an initial scale measurement is made from *B* to *C* and distance *B'C'* is the final scale required. Then projector *L* is moved in *X* so that point *C* moves by approximately *half* the difference in *Y* between *BC* and *B'C'*. Point *B* will move near *B'*. Point *C* will move near *C'*.

If point *C* is somewhat closer to projector *R* than point *B*, the operator will realize that the *Y* correction for *CC'* would be somewhat less than half the difference noted.

Control points are almost never in true *X* and *Y* direction in respect to each other. In moving from one point to the other there will be a movement in both *X* and *Y*. However, if only the *X readout* is used for correcting the scale in the *X* direction, and only the *Y readout* is used for correcting the scale in the *Y* direction, the above approximation will be quite close.

LEVELING GEOMETRY IN Y

On the K-320, as well as on modern Kelsh plotters, the distance between the two right-hand leveling screws is 15.625 inches, as shown in Figure 8. These two screws support the right-hand side of the X bar. One of the support points is a cone, and one is a flat surface.

Once a stereo model has been cleared by relative orientation, it is effectively *locked* to the *X* bar as if it is a rigid structure. Therefore, a change in level of the *X* bar causes a proportional change in the level of the stereo model. This change in positioning, however, is not precisely proportional. There are errors introduced by the radial movement of the model about the cone point, but the proportion is close enough to develop an empirical formula. For leveling in *Y*, the distance *h* that

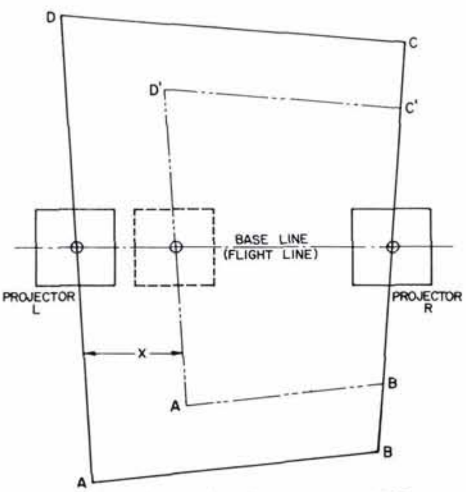

FIG. 7. The scale of a stereo model is determined by the base distance between two projectors.

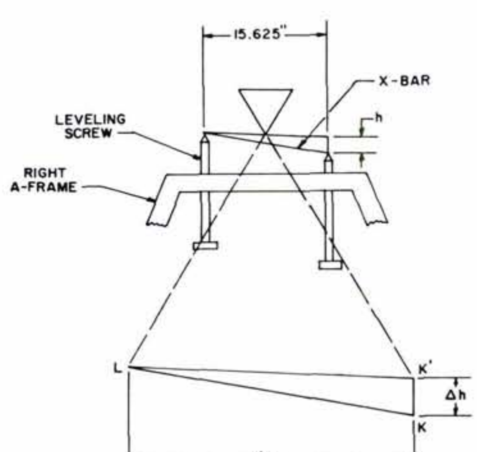

FIG. 8. An empirical proportion may be developed for the leveling in *Y*.

one right-hand leveling screw must be moved in respect to the other would be developed as follows: from Figure 8,

$$\frac{h}{15.625} = \frac{\Delta h}{dy}$$

$$h = (\Delta h/dy) \times 15.625$$

where h is the movement for *one* right-hand elevating screw in the plus or minus direction, as required, to the nearest .001 inch, Δh is the variance *(KK')* of the Z-elevation differential between L and K as it was first measured, and what it *should be*, (i.e., L to K'), dy is the Y *coordinate* measured upon moving in X and Y from L to K (or the Y readout).

But because the h movement is empirical anyway, we have rounded off the 15.625 dimension to an even 16. Thus, the formula for leveling in Y becomes $h = (\Delta h/dy) \times 16$. The operator may split the amount of relative change in the Y leveling screws *(h)* between the two right-hand screws, moving one up and one down, if desired.

LEVELING GEOMETRY IN X

The distance between the elevating screws in the X direction on the K-320 is 76 inches. Just one elevating screw on the left-hand frame supports the X bar, along with the two screws on the right-hand frame. The X bar rides on the left-hand screw in a V slot which has been oriented in the X direction. By moving the one left-hand elevating screw up or down, the stereo model may be leveled in X accordingly.

The same geometry applies in X as it does in Y, as shown in Figure 9. The stereo model is still *locked* onto the X bar by the two projectors L and R. The distance H that the left-hand elevating screw must be moved may be computed as follows: from Figure 9,

$$\frac{h}{76} = \frac{\Delta h}{dx}$$

$$h = (\Delta h/dx) \times 76$$

where h is the movement for the one left-hand elevating screw in the plus or minus direction, as required, to the nearest .001 inch, Δh is the variance *(TT')* of the Z elevation differential between S and T as it was first measured, and what it *should be*, (i.e., S to T'), dx is the X *coordinate* measured in moving in X and Y from S to T (or the X readout).

Absolute Orientation Procedure

With the above three principles and formulas in mind, the operator may begin to level and scale the model. He has on hand the completed scaling chart as shown in Figure 4. As we explained for Figure 7, the scaling may take place in the X direction or the Y direction. For our example below, we have used the Y direction. However, the reader will understand that a scaling in the X direction could be substituted for this part of the following procedure.

Referring to Figure 7, the operator first places his PPV dot on point B in the stereo model. (Figure 10 shows the operator positioning the PPV on the ORTHOSCAN). He then zeroes X, Y and Z on the digital readout. Next, the operator moves the reference dot to point C on the model. He will now have a reading on his display for X and Y as well as for Z. With his desk type calculator, the operator may quickly find the distance between B and C as follows:

$$BC = \sqrt{(X^2 + Y^2)}.$$

This may be performed in a single opera-

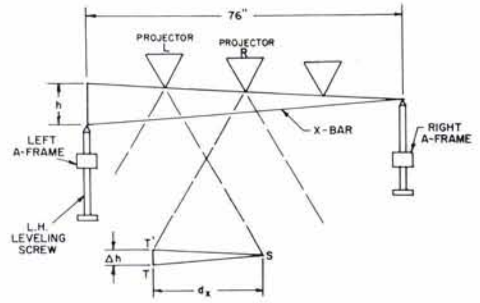

FIG. 9. The single left hand elevating screw is used for leveling in X.

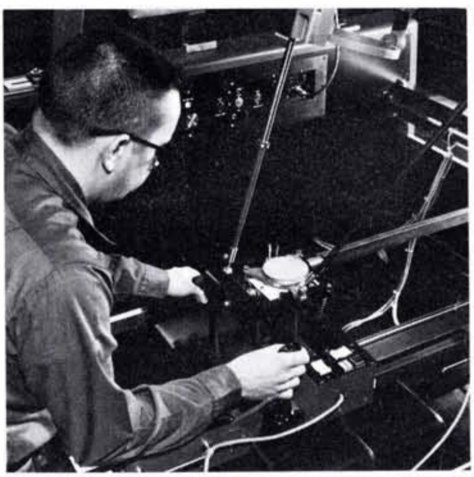

FIG. 10. On the K-320, the operator may position the PPV reference dot directly on a control point in the model.

tion on the calculator. The measurement *BC* will be greater or smaller than the distance required for this line by the scaling chart. While he is at point *C*, the operator should zero the display again in *X*, *Y* and *Z*. He should now move the reference dot in *Y only*, toward *C'*, by half the difference between the original *BC* reading and the required reading *B'C'*. At this time, the operator should move projector *L* in the *X* direction until control point *C lines up in Y* with the PPV dot near *C'*. Then he must reposition his reference dot directly on point *C'*. Next, he zeroes the *X*, *Y* and *Z* readouts *again* and moves in *Y* (and in *X*) to point *B'*. He should now be roughly scaled closely enough to allow him to go to the next step without repositioning projector *L*.

At point *B'*, besides the reading in *X* and *Y*, the operator has a plus or minus reading in *Z*. By looking at his scaling chart, he can see that his *Z* reading is more or less than that required for the elevation differential between *B* and *C*. This variation is called Δh. He then goes to his desk calculator and works out the equation for *Y*-leveling: $h = (\Delta h/dy) \times 16$ where dy is the value shown on the *Y* readout upon moving from *C'* to *B'* on the roughly scaled model.

With his 12-inch square and the calibrated handwheel, the operator can move one of the right-hand screws accordingly to within .001 inch. The model should now be roughly leveled in *Y*.

The leveling in *X* is now undertaken. The operator repositions the reference dot on the ground at *B'* and zeroes the *X*, *Y* and *Z* readouts. He then moves in *X* (and in *Y*) to point *A'*. The readouts show a plus or minus value for *Z* as well as values in *X* and *Y*. As compared to his scaling chart, the operator can see how much variance there is in the *Z* level position of line *A'B'*. This variance is again called Δh and the equation for leveling in *X* is used: $h = (\Delta h/dx) \times 76$. After the left-hand elevation screw has been moved accordingly, the model should be roughly scaled and roughly leveled in both the *X* and *Y* direction.

At this point, the model is usually rechecked for *Y* parallax. Then, by going through the above cycle just *one more time*, with perhaps one final adjustment for the scale, the absolute orientation should be complete and accurate. And the movement of the reference dot has been kept to a minimum during this procedure. The distance legs and elevation measurements to point *D* may be used to double check the final orientation of the model.

In a three-projector set-up, such as is used on the K-320, it is best to level and scale one model, and then to bridge the other one to it.

Conclusion

The above method will work quite effectively on projection plotters with *X*, *Y* and *Z* digitizers as well as on the K-320. It is convenient if the four points that are used are somewhat in the shape of a rectangle, approximating the neat model, but this is not essential. Only the dy or dx movements as shown on the digital readouts enter into the calculations, in respect to scaling corrections and the movement of the elevating screws.

The micrometer knobs and base blocks for the 12-inch square have now been added to all standard Kelsh plotters. The *Y* leveling formula for a Kelsh plotter would be the same as described above; that is: $h = (\Delta h/dy) \times 16$. But because the length of the *X* bar on a standard Kelsh plotter is 61 inches, the leveling formula in the *X* direction would be: $h = (\Delta h/dx) \times 61$. It is obvious that a formula could be developed for the spacing of the elevating screws for any projection plotter.

Also, Δh, dx and dy may be in *any* unit of measure as well as millimeters. These scale units will cancel out upon computing the results for h in inches for the elevating screw adjustments.

If the digital readouts are in inches, the scaling factor for *X* and *Y* may be calculated as follows for preparing the scaling chart in inches:

$$\text{Scaling Factor}_{xy} = 1/(\text{map scale in ft per inch}).$$

If the Northings and Eastings (or other terrestrial coordinates) are in meters, the scaling factor (xy) for converting the legs of the scaling chart to millimeters are as follows:

$$\text{Scaling Factor}_{xy} = 1000 \times \text{metric map scale}$$

where the metric map scale is a fraction, such as 1/2500.

There are many advantages to the above system if used for scaling orthophotos on the K-320 ORTHOSCAN as well as scaling models on a stereoplotter:

- ★ The operator measures his control point positions digitally, directly on the stereo model, avoiding the chance of a plotting error on the manuscript.
- ★ If a grid-line manuscript must be used, the scaled stereo model provides a good check on the plotted position of the control points.
- ★ The scaling and leveling system is fast, eliminating guess work. Using the empiri-

cal formulas, only two cycles of the procedure are usually required for fine-leveling and scaling.

- ★ The system has been developed for the K-320 ORTHOSCAN, but can be used effectively on any projection plotter equipped with an XYZ digitizer, or even an XY digitizer.
- ★ The method can also be helpful if using projection plotters without digitizers, as long as the three elevating screws are equipped with micrometer handwheels.
- ★ The empirical formulas could be developed for any projection plotter from the X-bar screw locations.
- ★ The system provides a basis for the recording of absolute orientation information, which would allow the same stereo model to be set up more quickly at a later date.

This method of absolute orientation has been tested in the field on the ORTHOSCAN by a number of experienced Kelsh compilers, and they seem quite enthusiastic about it. We thought that a published explanation might be helpful to the many people who are now using Kelsh plotters. It also gives us an opportunity to explain how we can quickly and accurately establish the final scale for an orthonegative on the K-320 ORTHOSCAN.

REFERENCES

1. Danko, Joseph O., Jr. "A New Concept in Orthophotography", *Photogrammetric Engineering*. 39(11):1161-1170, 1973.
2. Danko, Joseph O., Jr., "Color, the Kelsh and the PPV", *Photogrammetric Engineering. 38(1):83-88, 1972.*

PI Manual Wanted

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