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Aided-Track Cursor for Improved Digitizing Accuracy

A dedicated minicomputer is used to combine the digitizing encoder outputs with the array correctional counts to derive accurate coordinate values, even in the presence of tracking errors up to 1/16th inch.

Coordinate Digitizing Tables

Digitizing tables are a common means for converting graphic material into digitized *x-y* coordinate data points which can be stored, edited, and used for recreating the original or modified functions. Specific applications are found in cartography, meteorology, pattern tracing, contouring, architectural drawings, and in the preparation of numerical control tapes. A present major field of application is in the generation of artwork for producing large scale integrated electronic circuits.

A coordinate digitizing table generally consists of a movable, hand-held cursor containing a fiducial mark, such as a crosshair, used for tracing desired graphic material placed on an encoding table. The table provides a means for sensing the coordinate position of the cursor with respect to a table coordinate axis as the cursor moves on the table top. Both opaque and backlighted tables are available for use, and can range in size from 12 by 12 inch tablets for computer graphics to 72 by 72 inch platforms for high precision digitizing of artwork.

Numerous techniques have been developed for sensing the position of the cursor (magnetostrictive and acoustic ranging, for example). Of these, coded grid lines in the table sensed by a transducer in the cursor, and either remotely coupled or directly coupled incremental encoders responding to cursor motion, are superior in accuracy and resolution to most other methods. A profile survey[1] of graphic digitizers treats the manner in which graphic materials may be digitized and the relative accuracies obtain-

Abstract: *A developmental model of an aided-track digitizing cursor used in conjunction with a digitizing table is described. Use of this cursor significantly increases the efficiency of digitizing graphic materials. The cursor incorporates a rotatable linear photodiode array onto which the feature being digitized is imaged. Processing of the array output produces a count indication of the deviation of the feature from the table encoder fiducial marking. A dedicated minicomputer is used to combine the digitizing encoder outputs with the array correctional counts to derive accurate coordinate values, even in the presence of tracking errors up to 1/16th inch. Rotational commands are generated by the computer to orient the array perpendicular to the traced feature for maintaining accuracy in cases where curvatures exist in the traced function. Rotation through ±360 degrees permits closed contours to be traced with no sacrifice in encoding accuracy.*

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able from presently marketed digitizing tables.

The aided-track cursor to be described was developed for use on a backlighted table such as the one manufactured by Instronics Ltd. of Ontario and known by the trade name Gradicon. In this table, cursor position sensing is remotely achieved by having an x-y motor-driven carriage servo slaved to cursor motion by magnetic position sensing. Coordinate data is generated by incremental optical encoders coupled to the carriage guide system, which is capable of motion over a 42 by 60 inch area. The carriage also contains a light source for backlighting the graphic manuscript; this source follows the cursor as the carriage motion tracks cursor position. Motion of the cursor is measured in counts per inch, which can range from 100 to 1000, depending on desired resolution. It should be pointed out that use of the aided-track cursor is not necessarily restricted to this table, but is applicable to any backlighted system.

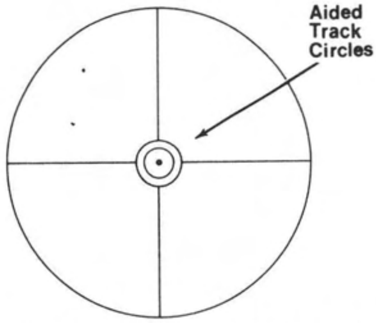

FIG. 1. Cursor reticle fiducial markings showing selectable aided-track circles. Feature being tracked must be maintained within aided-track circle to generate correction factors. Table encoders provide the coordinate position of the center point shown.

AIDED-TRACK TABLE DIGITIZING

Following feasibility studies,[2] the aided-track cursor was developed to provide a significant increase in tracing speeds while relieving the operator fatigue common to manual tracking. Development was sponsored by the Experimental Cartographic Facility at the Rome Air Development Center,* and was conducted by the RCA Advanced Technology Laboratories. (As a design goal, the cursor will tolerate tracing errors of 1/32 to 1/16 inch, depending on operator selection, correcting the error to within ±4 mils of the true coordinate value.) The cursor reticle with a selectable fine or coarse mode tracing circle is shown in Figure 1. Coordinate values given by the encoder of the digitizing table define the position of the center fiducial dot shown within the aided-track circles at discrete grid points of the table. This dot represents the extrapolated intersection of the cross-hairs of the reticle. Any feature within the aided-track circles will generate the necessary correctional factors with respect to the encoder values. Selection of the circle used is based on the density of the feature area on the manuscript. A provision is made for reverting to normal tracing operations when use of the aided-track feature is not practical.

While specifically aimed at improving the efficiency of cartographic processes, the aided-track concept has direct application to general digitizing table operations of mask and artwork production, function digitizing, and similar uses.

PHOTODIODE ARRAY INCORPORATED INTO CURSOR

The key feature of the new aided-track cursor is the incorporation of a linear photosensitive array consisting of 64 photodiodes spaced at a 2-mil pitch distance. The array is self-scanned repetitively at 25 kilosamples per second, with an output rate of 362 scans per second. While the operator views the function he desires to digitize, which can range in line width from 4 to 20 mils, it is simultaneously imaged onto the array by means of a beamsplitter and a 0.75 inch (19 mm) focal length lens working at 1:1 magnification.

While this concept employing photosensitive arrays is especially attractive for use on backlighted tables such as shown in Figure 2 where the optical configuration for the cursor system is given, its application can be extended to opaque-top digitizers, being used in a reflective mode as well as the transmissive mode described here. The

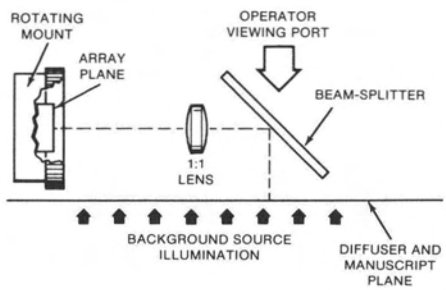

FIG. 2. Optical configuration of a backlighted scanning array cursor.

* Air Force Contract No. F30602-76-C-0443 (a feasibility model was developed under Contract No. F30602-74-C-0318).

positional variation of the feature with respect to an initial reference element is detected, converted to a digital count, and scaled to array pitch distance. The distance then serves as a correctional term for the x-y coordinate values obtained from the table encoders. As indicated in Figure 2, the array is mounted on a rotatable platform for accuracy in tracking feature curvatures.

Array Rotation Maintains Accuracy in Contour Tracing

For achieving accuracy in the presence of line curvature, a computer used in conjunction with the cursor calculates a rotational signal from prior coordinate values to maintain the array perpendicular to the curve being traced. Rotation of the array mounting platform is servo-controlled by means of a miniature motor-potentiometer assembly housed within the cursor.

Because of the small dimensions involved, small angular inaccuracies (on the order to 5 to 10 degrees) can be tolerated, and will have only second-order effects on the overall encoding accuracy. By allowing rotation through angles greater than ±360 degrees, closed contours can be uniquely traced without degradation in accuracy. Figure 3 illustrates the concept of array rotation in following curvatures to preserve the machine accuracy. Distances shown in the illustration for the various sample points are exaggerated for clarity. In actual operation, the array is sequentially scanned at a high rate, so that only small angular changes are required from point to point.

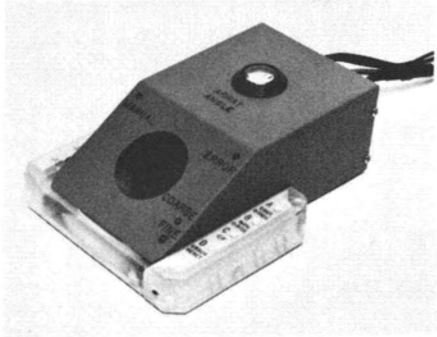

Fig. 4. Photograph of the advanced developmental model aided-track cursor.

Key Factor is Cursor Packaging

Primary importance placed on construction of a cursor package emphasized size and weight considerations, which play an important role in operator acceptance of the device. Form factors which could hinder normal cursor operations must be judiciously avoided. A photograph of the development cursor constructed is shown in Figure 4; normal station control function switches are on the left side, while the right side contains the aided-track control functions. The aided-track mode allows selection of the aided-track circle (coarse or fine) and momentary or continuous over-ride of the aided-track function. Appropriate indicators on the cursor housing indicate the operational status of the cursor. A cutaway drawing of the cursor (showing the internal configuration of the array on its rotational platform, the platform motor drive servo, and the associated optics) is shown in Figure 5;

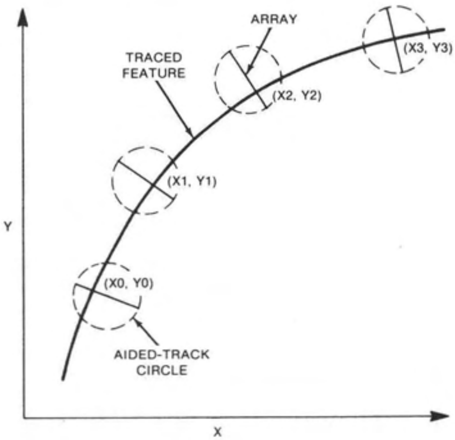

Fig. 3. Rotation of the array to remain orthogonal to the traced feature allows an accurate estimate of line position. The estimate is unaffected by feature curvature.

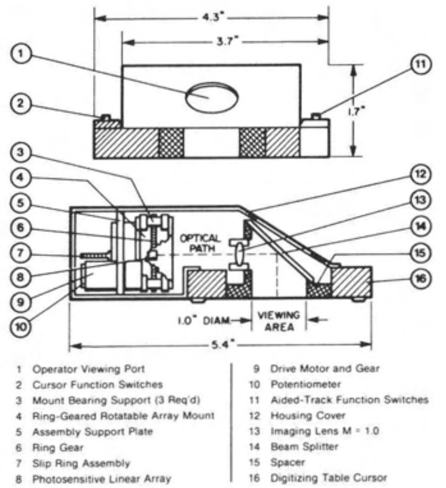

Fig. 5. Mechanical configuration of aided-track cursor.

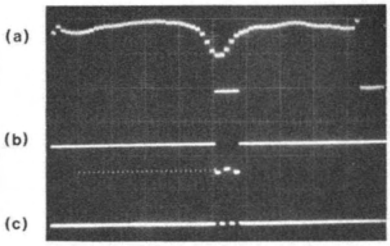

FIG. 6. Shown is one array scan output for a 20 kHz clock rate to illustrate typical waveforms of the video processor. The detected feature is a 9-mil line.

(a) Array output

(b) Count control gate to divide clock by 2 to estimate count to line center

(c) Output count to computer. Each count represents a distance of 2 mils along the array.

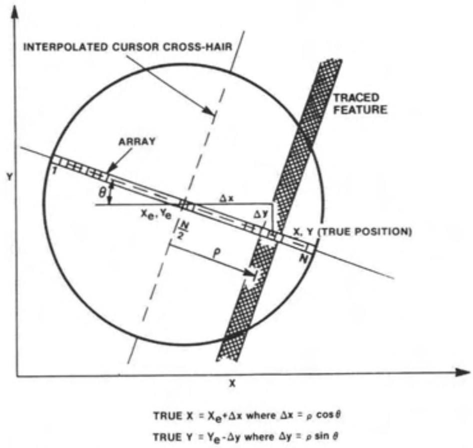

FIG. 7. Geometry of aided-track correction generation concept.

the legend identifies the major components of the cursor. Design of the cursor package allows it to be installed on existing table cursors for conversion to an aided-track mode of operation.

Electronic Circuit Utilizes both Analog and Digital Processing

Processing of the detected array signal combines both analog and digital circuitry. The analog processing produces, as an end result, a gate proportional to the number of elements intercepted on the array. The array scan clock is counted to determine the start of the detected line with respect to a reference element. The gate produced by the analog processing controls the clock count within the detection interval to produce a final output count which is related to the position of the center of the detected feature. The logic employed to determine the center position thus allows a fairly wide tolerance in modulation depth changes of the traced feature. Typical waveforms for generating the output count are shown in Figure 6 for a 9-mil feature detection.

Included in the signal processing is a threshold adjustment for compensating for illumination shading variations or when the cursor is used interchangeably between tables where light levels may vary.

Geometry of Aided-Track Concept

In the simplest case, where the center of rotation of the array corresponds to the encoder reference point, the geometry of Figure 7 is applicable. (In practical cases, any off-sets between the center of rotation and the imaged fiducial point can be accommodated within the computer algorithm used for coordinate correction.) The encoder outputs, which occur at discrete spatial intervals, are modified by the next succeeding count from the high scan rate array for generating corrected coordinated values.

In order to provide the necessary corrections to determine the true x-y position, the following equations are solved by the computer:

True $X = X_e + \rho \cos \theta$

True $Y = Y_e - \rho \sin \theta$

The angle, θ, is computed from

$$\theta = \tan^{-1}\frac{Y_{-2} - Y_{-1}}{X_{-2} - X_{-1}} - \frac{\pi}{2}$$

where subscripts indicate the prior pairs of samples; X_e, Y_e are table encoder coordinate counts converted to distance; and ρ is the distance generated to the line intercept from the array center determined from the array pitch distance and the cursor output count.

The initial orientation of the array is achieved by an accurate track of the first two points of the function being digitized.

Overall System Operation in the Aided-Track Mode

An overall block diagram of a typical graphic digitizing table system using an aided-track cursor is shown in Figure 8. The system consists of the following elements:

(1) The digitizing table, containing a means for encoding the cursor position in its normal operating manner. Associated with the table are pulse counting, formatting, and control logic for transfer of data to the minicomputer shown, or to display and/ or recording devices.

(2) An intermediate minicomputer which

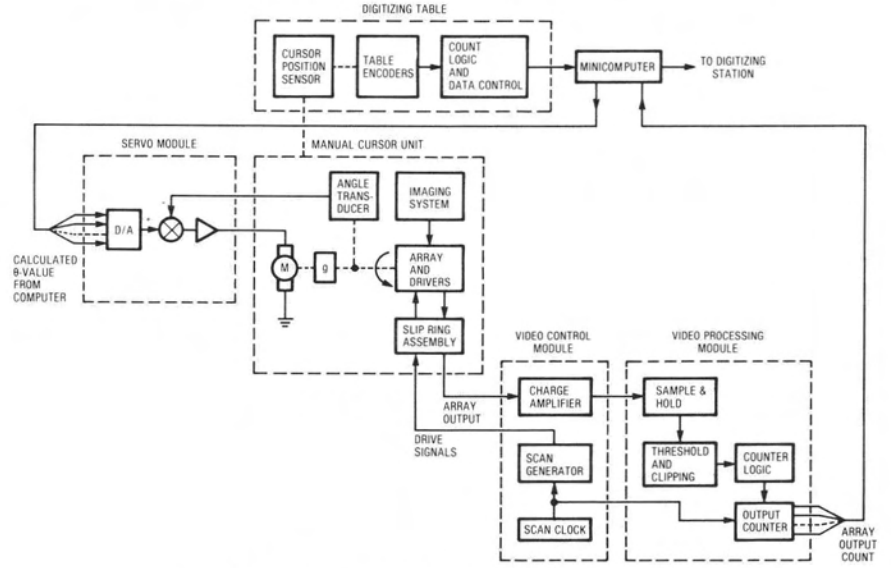

FIG. 8. Block diagram of aided-track cursor system.

interfaces with the digitizing table data console, the aided-track cursor, and the station processor. Correctional algorithms use the inputs from the console and cursor to produce corrected coordinate values in the presence of tracing inaccuracies. In addition, computations are performed to output an angular command signal for the rotatable array mount to account for curvatures in the digitized function. This unique feature has been described to demonstrate the principle of maximizing accuracy of correctional factors by maintaining the array perpendicular to the function.

(3) A manual aided-track cursor as previously described produces a high rate repetitive scan of the photodiode array. Within the cursor housing a servoed motor drive system rotates the array to orient it perpendicularly to the traced curve by computer command. A typical digitizing cursor used has pushbutton controls for mode selection (continuous or point-by-point manual digitizing), editing functions, and transfer commands. The aided-track cursor is provided with an over-ride control in areas where intersections of graphic features occur or in other circumstances where the operator must resort to normal operations, carefully tracing the feature through these areas.

(4) The video processing electronic circuitry accepts the array output and produces an output count representing the deviation of the function being digitized with respect to the table encoder fiducial mark. Included in the electronics are analog threshold and gain adjustments to accommodate variations in table illumination characteristics such as shading and intensity. The digital counter logic employed is designed to produce a count representing the best estimate to the center of the intercepted function, which may cover several array elements. The output of the video processing chain is continuously transferred to the computer for correcting the table encoder values as they are entered at discrete motion intervals.

(5) The video control unit contains the necessary circuitry for generating timing signals and phase clocks for the self-scanned array. The electronic circuitry provides for adjustments in scan rate and in scan period, allowing control of the array integration time for developing adequate signal modulation levels to ensure positive detections.

(6) The servo module shown contains a digital-to-analog converter to generate the motor drive signal, and the necessary compensation and drive amplifiers for the servo position loop to respond to the angular digital commands calculated by the computer.

EVALUATION TESTING TO DETERMINE OPERATIONAL PERFORMANCE

The aided-track cursor is presently under evaluation. An initial result, demonstrating its ability to provide correction for contour features is shown in the digitizing station output plots of Figure 9. Test circles A and B were traced in a normal unaided mode; circle C is a resultant aided-track output circle which was traced allowing the feature

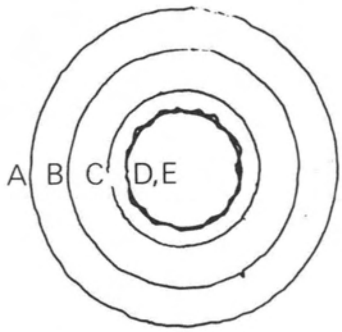

FIG. 9. Initial test results of the aided-track cursor demonstrating its ability to provide correction around closed contours.

to wander within the extremes of the coarse aided-track circle of the tracing reticle. Circle D is an uncorrected output plot to indicate the error execursions introduced in the tracing operation; superimposed on this is circle E, traced in the aided-track mode. Peak tracing errors of D are in the order of ±30 mils.

A trace of a typical cartographic feature is shown in Figure 10; in this photograph the unaided and aided-track outputs are given for comparison. Initial trials show an average 3:1 improvement in tracing time using the aided-track cursor on manuscript material.

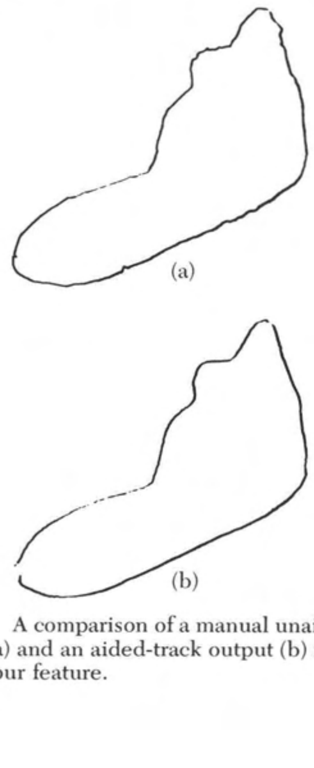

FIG. 10. A comparison of a manual unaided trace output (a) and an aided-track output (b) for a typical contour feature.

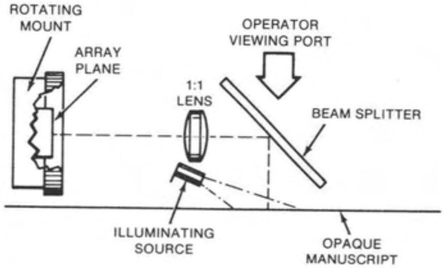

FIG. 11. Configuration of scanning array cursor for use on opaque tables.

EXTENSION TO OPAQUE DIGITIZER TABLES

As an extension of the usefulness of the aided-track cursor concept, testing is being performed to adapt it for use on opaque digitizing tables. A possible implementation of a cursor that can be used for opaque table digitizing is shown in Figure 11.

An internal light source is included within the cursor to illuminate the function to be traced, and detection is based on the reflection changes caused by the imaged function. With this extension, the cursor can become a versatile instrument, unrestricted by table construction considerations.

If the aided-track cursor presently under evaluation results in improved operator efficiency in producing precise digitized data, a significant aid will have been added to the overall cartographic digitizing process.

REFERENCES

1. Graphic Digitizers, *Modern Data*, August 1971, pp. 38-44.
2. *Scanning Cursor Techniques*, RADC-TR-76-363, Final Contract Report, prepared by RCA, December 1976.

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