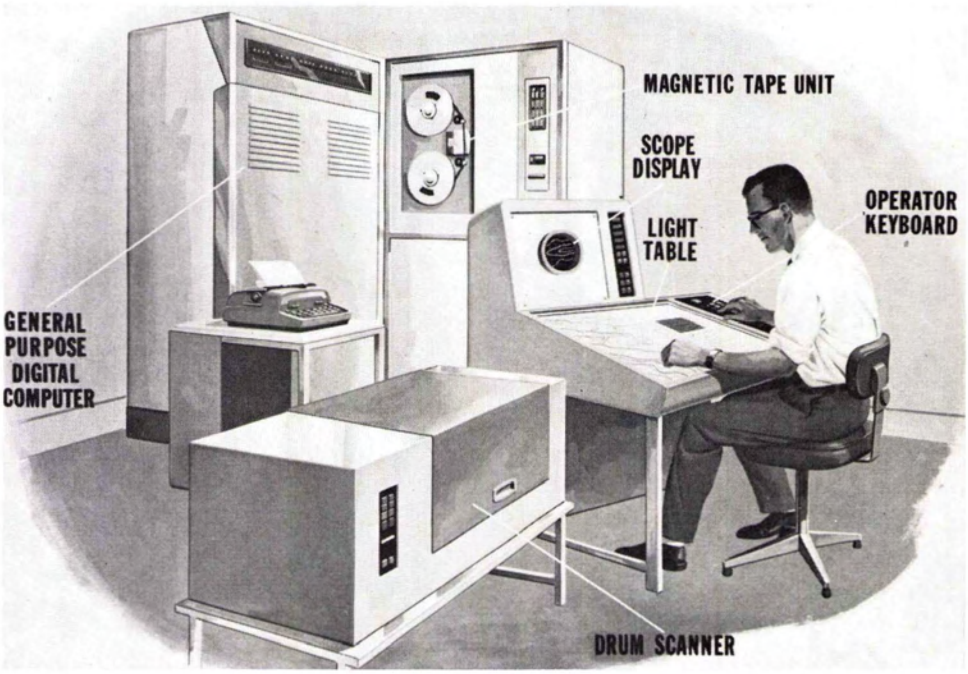

FRONTISPIECE. Sketch of Automatic Contour Digitizer being developed for ETL by Concord Control, Inc.

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Automatic Contour Digitizer

Routine, repetitive tasks are performed by the computer whereas decision making is left to the human operator.

(Abstract on next page)

INTRODUCTION

MY PRIMARY OBJECTIVE is to describe to you the Automatic Contour Digitizer being developed by GIMRADA† for producing digitized terrain data. This will include the equipment configuration, the operation, and the use of the system. Prior to this description, however, I'll very briefly go into the background that led to its development.

To begin with, just what is digitized terrain data (DTD)? You might say that its a representation of terrain in computer language. More specifically, let's say that it's the elevation or Z-data for every XY-position of the terrain in digital computer code. This form is desired only to enable processing of the terrain data by digital computers. Some examples of the type of things that may be done by the computer are earthwork computations in the design of roads, airports, etc., line of sight and communication network design problems, and many others. However, the many conceivable applications of the digital data will not be further discussed here.

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† Recently renamed ETL: Engineer Topographic Laboratories.

The main objective here is to discuss from where, and then how, DTD is produced.

There are many conceivable sources, but for this discussion we shall limit the input source to the contour color separation of existing topographic line maps (Figure 1). This separation contains only the contour lines, the elevation numbers, and spot elevation symbols.

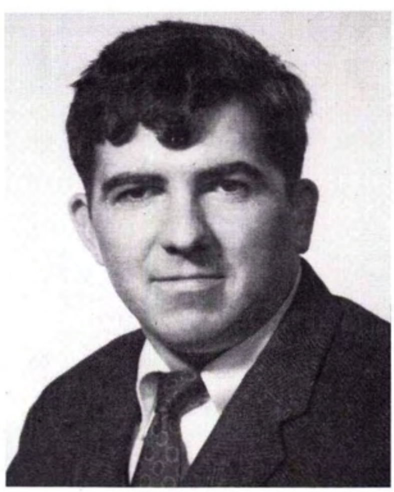
ABSTRACT: *The Automatic Contour Digitizer is a second-generation graphic data-processing system designed especially for converting graphic map elevation data, both contour lines and spot elevations, to digital form on magnetic tape. Essentially, the system consists of an electro-optical drum scanner: an electrostore and CRT monitor with an editing, joystick controlled, light spot; a reference light table; and a medium size, high-speed computer. Using the CRT and joystick-controlled light spot, an I/O typewriter, and the reference map sheet, the operator directs the system operation, edits the data, and assigns elevations to the untagged lines and points. Under the direction of the operator and executive software, the system automatically scans each map section, 1×1 inch, 2×2 inch, or 4×4 inch, automatically tracks each line, formats the output data, keeps track of what has been done, and tests the output for errors. Throughout the process the requirements for accuracy, reliability, and usability of the output data are maintained. The efficient combination of the operator's decision-making capability with the computer's high speed cability enables the system to digitize a 24×30-inch sheet containing about 15,000 linear inches of contour lines in about eight hours.*

How is digitized terrain data extracted from the contour color separations? This is the digitizing process and will be discussed in some detail since that is what the ACD is all about.

There are four basic tasks involved in digitizing a contour color separation: (1) interpreting, (2) tracking, (3) digitizing, and (4) formatting and recording. Interpreting is assigning elevations to the lines. Tracking is establishing *XY*-coordinate points along the line to describe the line accurately. Digitizing is converting the tracked data from analog to digital form. Formatting and recording, as implied, is outputting the data in a meaningful form for use in ADP equipment.

The first-generation digitizer, the Digital Graphics Recorder (DGR) now being used at AMS, automatically performs only the last two of the above four tasks (Figure 2). The operator is required to track the lines and to enter the elevations; the device automatically converts the tracked data to digital form, and formats and records the output data.

An average (if there is such a thing) 24×30-inch contour sheet contains about 15,000 linear inches of contour lines. This average sheet requires from 40 to 80 hours to be digitized on the DGR. This is about 3½ to 7 inches of line per minute. (An equal amount of time is required to prepare the sheet prior to the digitizing process.) This is really not too objectionable, considering the task involved. However, if you consider the number of *existing* AMS maps to be digitized, you can see why we need a faster digitizing system. In early 1965, GIMRADA began development of a system to automate the terrain digitizing process. A contract was negotiated with Concord Control Inc. (CCI), for the ACD system. Charles W. Adams Associates was selected by CCI as the subcontractor responsible for the computer programs.



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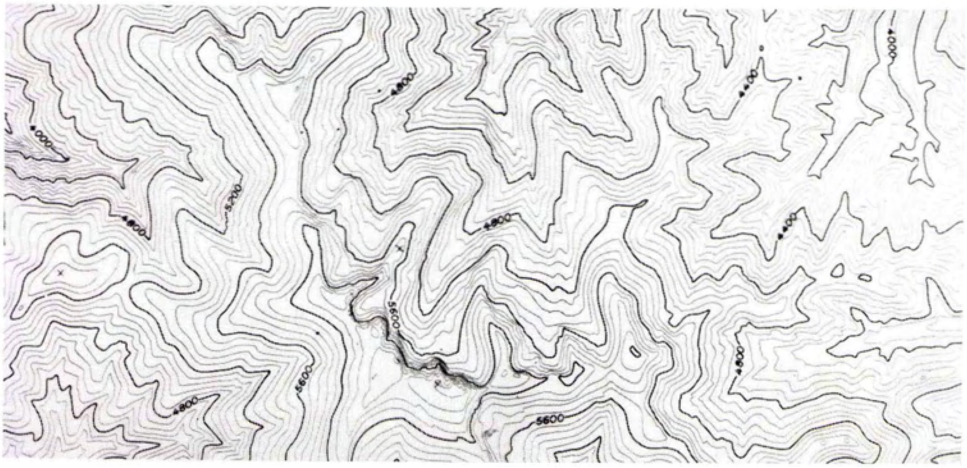

FIG. 1. Contour color-separation overlay used in map reproduction constitutes the source for the digitizer.

The ACD system concept was to automate as much of the digitizing process as was practical. With respect to the four basic tasks outlined above, the system was designed to perform automatic line tracking, digitizing (i.e., A/D conversion), and formatting and recording. Again, as in the 1st generation system, the most difficult and perhaps the most important task, interpreting, was left with the operator. The major advantages of the system will be automatic line tracking and bookkeeping and other operator aids that help the operator perform his tasks. (Here, bookkeeping means keeping track of what has been done.) In view of this design performance, the ACD system will consist of (1) a drum scanner for extracting image data from the input sheet, (2) an operator console for interpretation, editing, and system operation control and (3) a digital computer for system operation control. The Frontispiece is an artist's concept of the ACD system. In the lower left is the drum scanner, in the right is the operator console, and in the background is the digital com-

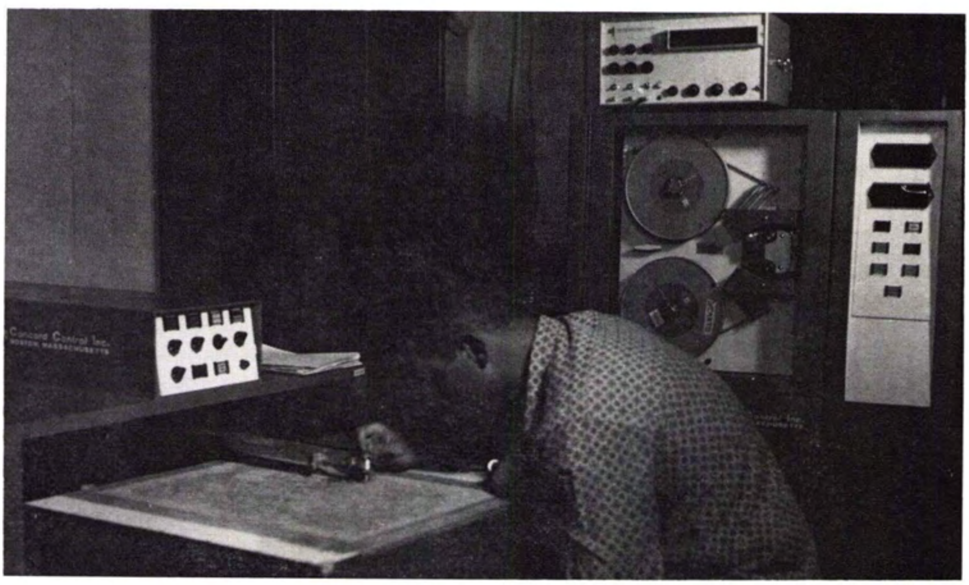

FIG. 2. The manually operated Digital Graphics Recorder is a first-generation digitizer which has been in use at the Army Map Service.

puter. I'll discuss each of these main components in turn, beginning with the drum scanner.

Drum Scanner

As the name implies the drum scanner has a drum transport mechanism on which the contour sheet is fastened, an optical-electrical scanning device, and appropriate encoders for measuring the exact position being examined at any given time. The scanning device is simply a light source to illuminate the map surface, a microscope to focus on the appropriate spot, and a photomultiplier tube to sense the amount of reflected energy. This arrangement is mounted on a precision, step-motor-driven, ball screw and moves in an X-direction parallel to the axis of the drum. The drum rotates the map sheet in the Y-direction at a rate of 1,200 rpm. The drum is equipped with optical encoders for measuring the exact Y-position (Figure 1).

This is the type of input to the system. It is a high-contrast positive (black lines on an opaque white background). The logic in the scanning process is straight-forward. Through the scanner encoders the computer knows at all times the XY-position being looked at on the contour sheet. When the photomultiplier signals that it is looking at a portion of a black line, the computer simply records a hit at that XY-position.

Because of the very large quantity of data involved, the system operates only on a small section of the map at a time. Each section may be 4×4 inches, 2×2 inches, or 1×1 inch. The scan is always 400 spots/inch in both X and Y. For the 1×1-inch areas, all 160,000 scanned points (each 0.0025 inch ×0.0025 inch) are stored in the computer core memory as either a part of a line, a binary 1, or not a part of a line, a binary 0. For a 2×2-inch section, four of the spots are "or'ed" together so that again the section occupies the 160,000 bit section of core. Similarly, for a 4×4-inch section, 16 of the spots are combined to maintain the same size core image. (Even a 4×4-inch section is stored and processed at 100 spots/inch, which is equal to the maximum resolution of the 1st generation DGR.) The smaller sections are used for very dense sections of the input sheet. During the input sheet scanning, only the selection of the section size is under operator control. All other scanning operations are automatic.

Console

The operator's console (Frontispiece) as shown on the right is made up of a reference light table, a TV monitor with a joystick-controlled light spot, and all the necessary control buttons. The reference light table schematically shown in Figure 3 consists of 720 separately lightable sections—one for each 1×1-inch section for a 24×30-inch

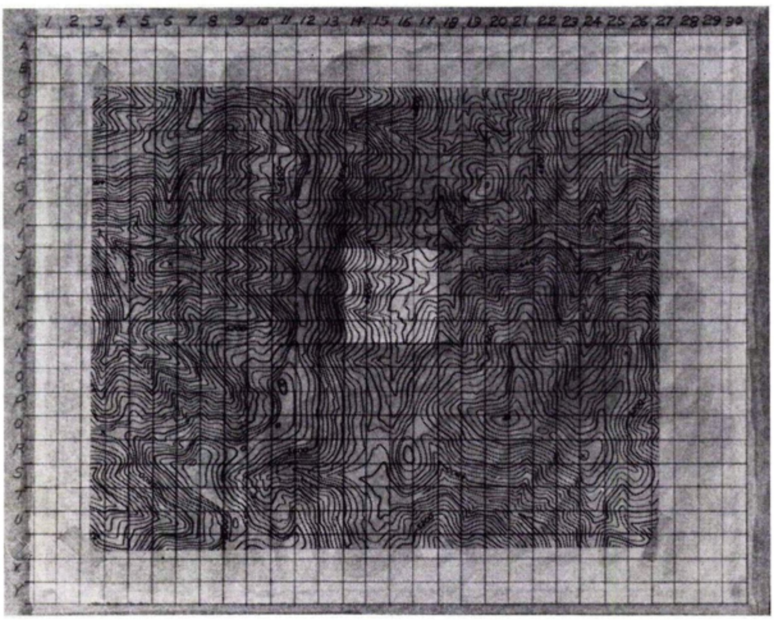

FIG. 3. The reference light table shows the illuminated area being digitized.

FIG. 4. Conception of the TV monitor in which the editing light spot is shown as a black dot.

map. The computer automatically lights that section of the light table (reference map) that is being scanned and processed. Here the lighted section is depicted as the white section of the table. The alpha-numeric coding along the edges of the sheet is for specifying or identifying each section of the sheet. The TV monitor screen on the operator's console displays, at an enlarged scale, the section that has been scanned and is being processed.

In addition to the scanned image, the TV monitor also shows a joystick controlled light spot for editing and identifying lines and points. Figure 4 shows conceptionally the TV monitor. The editing light spot is depicted here as the black dot. This spot is maneuvered by the operator with the joystick mounted on the console. The light spot is used to associate an elevation with each line and to make any required corrections to the graphic data. It should be pointed out that the light spot and its position are generated by the computer. Thus whatever editing that is performed is not done with *light pen* techniques on the surface of the tube, but is done in the computer core memory. The distortions inherent in the TV display thus do not matter.

The image data are not written directly from core memory onto the TV monitor, but are written first on the grid or mask of a dual-gun storage tube. The hardware associated with the storage tube provides a raster scan of the grid to form the TV monitor display. With this technique, the computer need not update the storage tube as often as would be required to update the TV monitor for a flicker-free display; this saves a lot of computer time. The light spot position, however, is updated at a rate of about 60 times per second by the computer.

COMPUTER

The remaining major component of the system is the computer (Frontispiece). It is an SDS-930 with 32K of 24-bit words of core storage. The I/O peripherals required are paper tape, typewriter, and magnetic tape. The scanner and the CCI control logic are interfaced to the computer somewhat like a magnetic tape transport and controller.

As mentioned previously, the purpose of the computer is to control the digitizing operations by coordinating the various inputs from the scanner and the operator console. In addition it performs a task that is the basis of the system—automatically tracking or establishing lines from the binary image matrix. The technique involves associating adjacent points and testing them against a set of rules. The software routines are quite detailed and will not be further discussed here. You might say that by not discussing in detail the system software that I'm leaving out discussions of about 75 percent of what makes the system work. However, I shall point out some of the software effort as we go along.

OPERATION CYCLE

Having briefly gone over the various components of the ACD system, I'll now describe a cycle of operation. First the input contour sheet shown in Figure 1 is mounted onto the drum. The drum is equipped with a set of

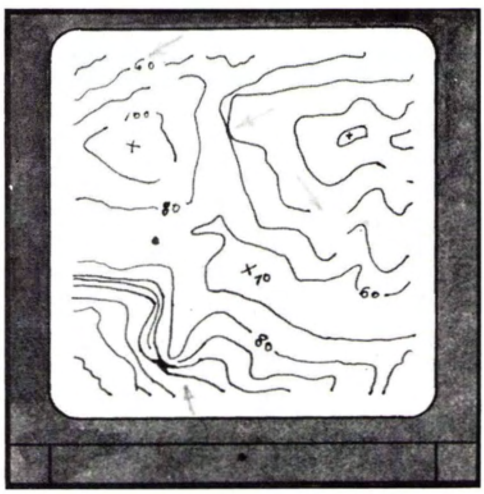

FIG. 5. An unedited scan product will conceivably include discrepancies such as those pointed out by the gray arrows.

dowel pins and thumb screws for stretching the Mylar base input sheet around the drum. In addition a transparent positive copy of the input sheet is placed on the reference light table. Next the typewriter is used to enter the pertinent variables concerning that particular contour sheet. These are: the lowest elevation on the sheet, the contour interval, and the desired output resolution. After selecting the section size of the first area the computer is signaled to scan. The computer takes control, positions the scanner, and scans the data. The binary image is simultaneously written into core memory and onto the storage tube mask. The storage tube data is raster scanned onto the TV monitor. This operation takes from 20–80 seconds depending on the section size.

Figure 5 depicts what is shown on the TV monitor as a section of the map that has been scanned. The arrows indicate those places where some editing is required either before or during the digitizing process. The light spot, shown in black, is used under joystick control to make corrections to the image. Broken lines may be corrected by drawing in the sections in a *follow me* mode, or by straight-line connection of two or more points indicated by the positions of the light spot. Erroneous data may be deleted from the image in a similar manner, using both the indicator light spot and the function keys. Figure 6 shows that same area after it is cleaned up and corrected. The map section is now ready to be processed. Again, I want to point out that practically all the clean-up work could have been done on-line during the digitizing process. We will determine by operating the system which method is the most economical.

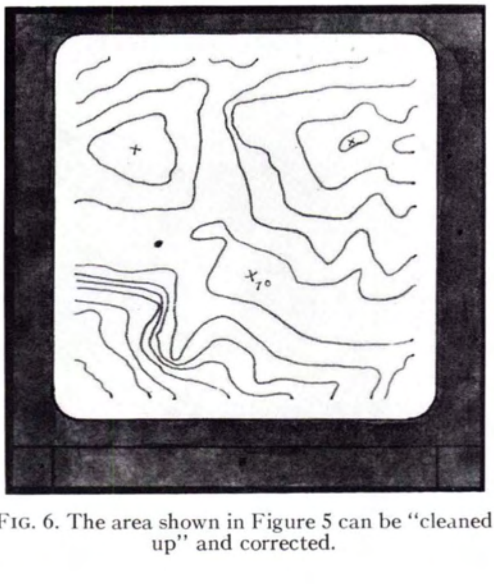

FIG. 6. The area shown in Figure 5 can be "cleaned up" and corrected.

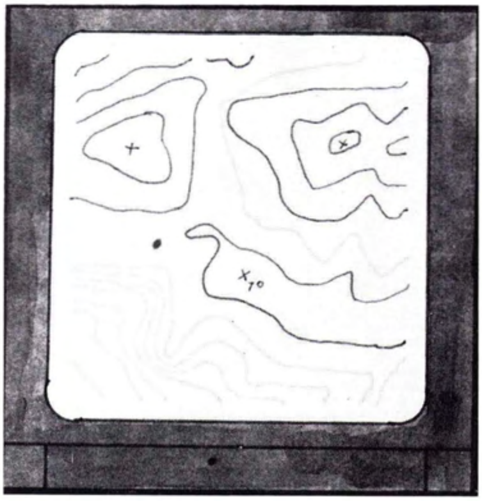

FIG. 7. Lines in Figures 5 and 6 can be deleted and re-scanned as shown by the gray lines.

Now, using the light spot, a line to be tracked is selected and the appropriate elevation is entered via the keyboard on the console. The initial approximate direction of the line is indicated by pushing one of the eight direction push-buttons. Finally, the track button is pushed, and the computer automatically follows along the entire line. The light spot tracks along the line to show what the computer is doing. When the line has been completely tracked (to the edge of the section, or until it closes on itself) it is dimmed. This shows what has been processed in the section, or conversely and perhaps most importantly, it shows what has not been processed. (This approach leaves the image less and less cluttered as work progresses; hence it is easier to keep track of what remains to be done.) The above process is repeated for each line in the section.

Figure 7 shows a section in which several of the lines have been dimmed—shown here as the gray lines. When a section has been completed, the computer formats the data and records that section on magnetic tape as a data record. It should be noted that if too many mistakes are made, or it is desired for some other reason to delete the section, it may be rescanned and reprocessed.

This procedure is repeated for each section except with one very important difference. That is, the computer will automatically assign the elevations to and track all those lines that are continued from an adjacent and

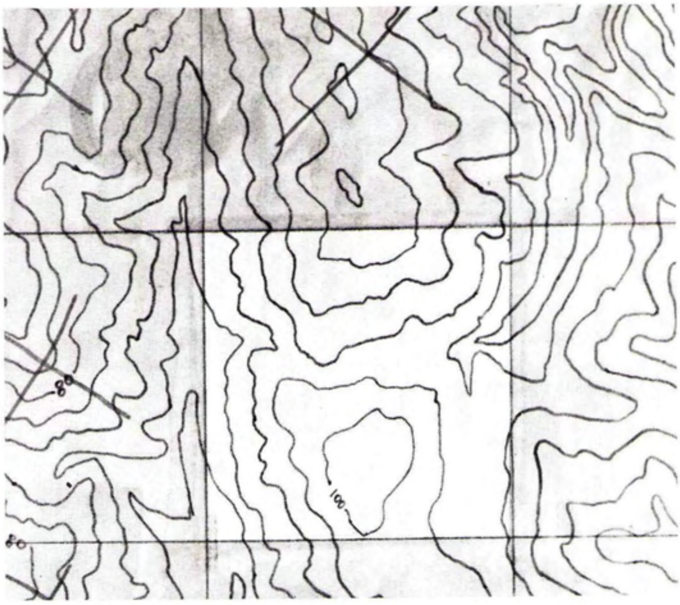

FIG. 8. The lighter shaded area in the center can be edge-matched automatically to the adjacent previously completed areas.

previously scanned area (Figure 8). Assume that we're working on the lighted section shown here, and suppose further that the adjacent sections marked with an *X* have already been processed. After the section has been cleaned up, the computer automatically assigns elevations to and tracks these continued lines. This means that on the average about half of the lines will be tagged and tracked without the operator having to go through the regular processes. This should be quite a time-saving feature. On the left of Figure 9 is a section just after the operator has cleaned it up. On the right is the section showing the work to be completed after the computer has automatically processed the continued lines.

OUTPUT FORMAT

The drum scanner looks at 160,000 points per square inch of the input sheet. If the section size is 1×1-inch, the computer stores

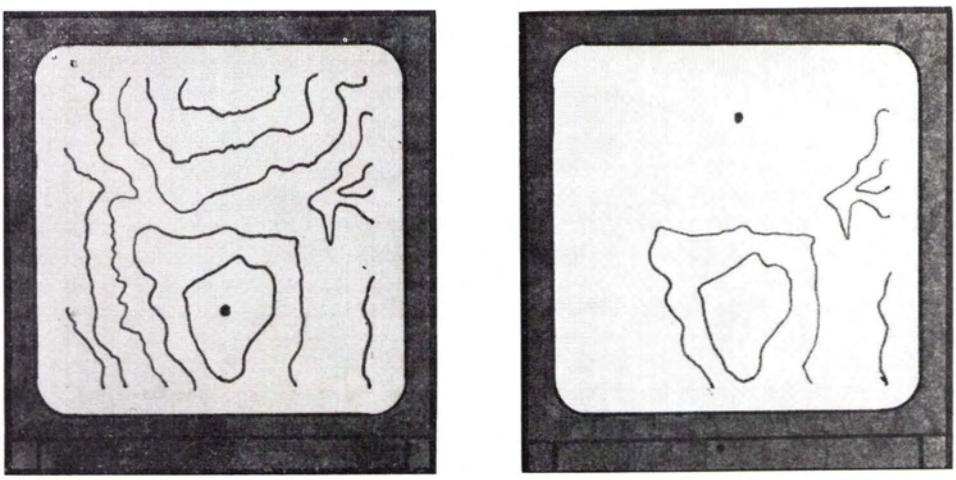

FIG. 9. The section on the left has already been "cleaned up"; that on the right shows the area remaining to be completed.

FIG. 10. Color separation drawings for drainage could also be digitized.

and processes the data at this density. It is not desirable, however, to record on magnetic tape any more data than is absolutely required. (If all the scan data were stored on tape, this would amount to about 115 million points for a 24×30-inch sheet.) It was, therefore, decided to output the data in the form of profiles at a maximum resolution of 100 profiles per inch. These recorded data points represent the centerline points of the contour lines where they intersect the profile lines except adjacent points along the centerline of the contour line are never farther apart than $\sqrt{2}$ per number per inch. This eliminates gaps in the data where a line is parallel to the profile line. As indicated above, the output resolution is variable in minimum steps of 1/400 inch to a maximum density of 100 profiles per inch. (The minimum density is two profiles/map.) This format was chosen because of current AMS requirements for digitized map data. Other more desirable, or perhaps more compact, formats could be obtained by changing the computer programs. This profile format should allow us to easily store one map sheet on one 2,400-foot reel of magnetic tape (at 556 bpi).

OTHER USES

So far I've discussed the ACD only with respect to digitizing contour lines. I'm sure, however, that you have seen that the ACD is in essence a general purpose graphic data processor. The major restriction is that the input be a high-contrast positive. We are developing two of the ACD systems. After engineering tests at GIMRADA, one system will go to AMS for production of digitized terrain data. The other system will remain at GIMRADA for use as a general purpose graphic data processor for research in the automatic cartography area. One use will be to study the problems of digitizing map features such as roads and streams. Figure 10 shows the color separations for streams that could be digitized. Another application to be investigated is that of using the ACD as an editing device. This would require the software to include a read-from-tape-and display mode as well as all the editing functions that are now available.

CONCLUSIONS

The ACD system is basically a second-generation graphic data processor. It has combined the efficient capabilities of the digital computer with those of the operator to produce reliable as well as efficient results. The routine, repetitive, time consuming tasks, such as line tracking, bookkeeping, and formatting are performed by the computer; the more difficult decision making task, map interpreting, is left to the human operator.

See announcement of 1968 Congress in Switzerland on page 104.