Map Scanning for GIS Applications

A. N. Williamson
U. S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

ABSTRACT: Recent improvements in optical document scanning systems greatly increase the attractiveness of this technology as a cost effective tool for satisfying the enormous appetite for information that is characteristic of today's geographic information systems (GIS). However, effective use of this technology necessitates a basic understanding of the different scanner types, how they function, data forms, and the information content of scanner output files. This paper presents an overview of scanners, their use for digitizing information for input to a GIS, and some essential software tools for effective use of scanned data for GIS input.

INTRODUCTION

GEOGRAPHIC INFORMATION SYSTEMS (GIS) provide a convenient way to store vast amounts of locationally defined information for a region, access and use the stored data to solve a multitude of problems, and portray the results in the form of tables and/or maps or map overlays. However, one of the major impediments to using this technology is the high cost of data input (Cobb and Williamson, 1985).

Traditionally, data have been encoded using a digitizing tablet. The result is an *x,y* coordinate for each of a series of points on the tablet. Each point, or series of points, may be appended with an attribute code to identify a line, point, or polygon being digitized. However, digitizing in this manner can be very costly in terms of both time and money, depending upon the complexity and size of the document being encoded (Williamson and Britsch, 1989).

Scanners and scanning services now on the market may produce a useful alternative to tablet encoding. Scanners can encode a 15-minute quadrangle map in less than ten minutes. Resolutions as high as 1000 points (pixels) per inch, or even greater, are commonplace. And color recognition is possible with some scanners (Williamson, 1985).

Thus, it would appear that contemporary scanners and scanning services might offer a cost-effective alternative to the otherwise costly process of encoding mapped information by manual methods. The discussion that follows presents some considerations for selecting the best encoding method for use in connection with GIS-related projects. These can in no way be considered exhaustive or complete, because this very dynamic technology results in new software and hardware innovations being announced almost daily.

SCANNER OPERATION

The primary function of any scanner is to convert measured quantities of light to electrical analogs. The light that is measured may be light that has been transmitted through the material, as would be the case when film transparencies are scanned, or the light that is measured could be that which is reflected from the surface of a map or photograph. For GIS and other computer applications, the electrical analogs are subsequently converted to a binary form suitable for computer processing.

If the output of the scanner is to be used as input to a GIS, care must be taken to preserve the spatial integrity of the item being scanned. Preservation of the spatial integrity is normally accomplished by describing the scanned document as an orthogonal array of grid cells (raster array). Each grid cell represents an instantaneous field of view within which the scanner makes a measurement. The manner in which the grid cell is defined depends upon the particular scanner being used. However, scanners, in general, fall into one of three types: flying spot, push-broom, or rotating drum.

FLYING SPOT SCANNER

A typical flying spot scanner (Figure 1) is mounted on a rack in such a way that the scanner's optical system can view a document located on a flat surface beneath the scanner. The distance from the scanner to the document can be varied to facilitate encoding documents of different sizes. A view finder located on the scanner allows the document to be viewed and properly aligned by an operator before encoding is accomplished.

Encoding takes place when a light-sensing spot (the instantaneous field of view) is deflected systematically over the document. As the spot is deflected, light reflected from the document is detected by a light-sensing device, such as an image orthicon tube, a vidicon tube, or a charge-coupled diode (CCD) detector array. In the scanning process, the document is described as a

FIG. 1. Example of a flying spot scanner.

0099-1112/92/5808–1199$03.00/0

set of contiguous pixels in an orthogonal array. Each pixel in the array is given a value that depends upon the amount of reflected light that is detected.

The source of illumination is normally two or more lights that can be positioned manually to provide the best overall illumination for the geometry of the scan.

Typically, a flying spot scanner describes a document being encoded as a 512- by 512- or a 1024- by 1024-pixel grid array. The size of the document that can be encoded and the area covered by each grid cell (resolution element) depend upon the distance from the scanner to the document.

If the scanner model includes appropriate filters, color separations can be produced from the scanned data. However, it is important to know that detectors commonly used in flying spot scanners may be spectrally less sensitive to blue and green than to other colors. As a result, some type of compensation may be required to correct for this trait.

The basic output from flying spot scanners is in a raster format. However, some models provide the capability to convert the data to a vector (or arc-node) format internally before the data are available for output. Data from flying spot scanners have been used for many years as input to image processing and remote sensing software systems, and more recently for GIS applications.

FIG. 2. Example of a push-broom scanner.

PUSH-BROOM SCANNER

Push-broom scanners (Figure 2) typically are comprised of a linear array of CCD detectors located at a fixed distance from an aperture over which the document to be digitized is passed. Illuminating and digitizing geometry are fixed and cannot be changed by the operator. During encoding, the document is moved over the aperture at a constant rate of speed by a set of pinch rollers.

A typical push-broom scanner can accommodate a document up to 36 inches wide. The maximum length of the document is determined by the storage capacity of the computer controlling the scanning process. Once scanned, the document is represented digitally by a raster array of grid cells arranged in an orthogonal array. Some models convert the data to vectors before the output is available to the user. The normal output resolution is either 200 or 400 dots per inch.

As with many light sensing detectors, the CCDs used in push-broom scanners are only minimally sensitive to the blue and green wavelengths and have maximum sensitivity to the longer wavelengths of red and near-infrared. There are no push-broom scanners known to be capable of producing color separations.

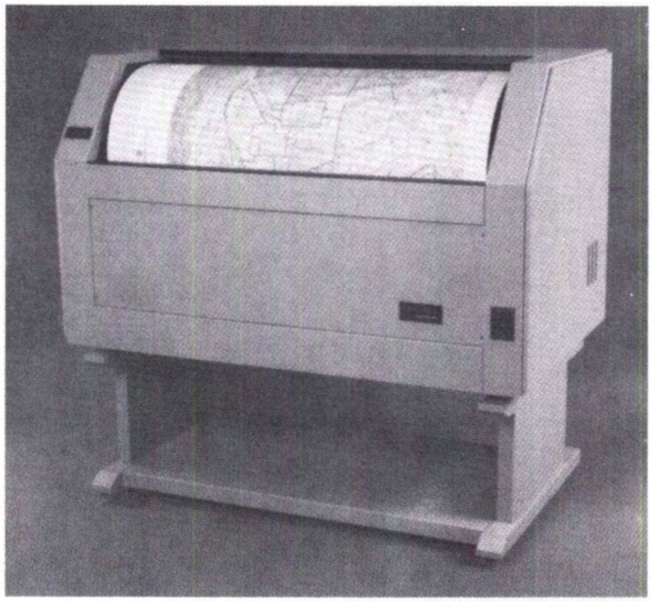

FIG. 3. Example of a drum scanner.

DRUM SCANNER

A typical drum scanner (Figure 3) is comprised of a drum, a carriage, and associated electronic control equipment. The document to be scanned is mounted on the drum. The detector and associated electronic components and the illuminating source are mounted on the carriage in such a way that the instantaneous field of view of the optical system will be uniformly illuminated. As the drum rotates, a measurement is made of the reflectance within each pixel in a series of contiguous pixels defining a single scan line. If the drum scanner is capable of doing color separations, the measurements along the first scan line are made through an appropriate color filter, and then repeated for each of either two or three additional filters. The carriage is then advanced one increment and the scanning process is repeated for the next line. The process is repeated until the desired area of the document has been covered. One large format scanner now on the market actually measures 1000 scan lines at a time. At the end of each scan line, the carriage advances a distance equal to 1000 scan lines before beginning measurements on the next 1000 scan lines. The result of scanning is a set of measurements that define the reflective characteristics of the scanned document as a grid array of contiguous pixels. The measurements are arranged in such a way that the geometric fidelity of the scanned document is preserved.

A typical scanner is designed to encode a document in no more than 10 minutes. The pixel size may be as small as 1.5 μm. The largest known scanner can encode a document as large as 1.1 m by 1.6 m. As with other scanners, the drum scanners may have reduced sensitivity to the shorter wavelengths of blue and green light depending upon the type of detector used. The basic output of a drum scanner is a raster format, but some drum scanners can convert from raster to vector and can degrade the effective pixel size by re-sampling before producing an output to be used in a GIS.

AVAILABLE SOFTWARE SOLUTIONS

GIS REQUIREMENTS

The National Science Foundation defines a GIS as "a computerized database system for capture, storage, retrieval, analysis, and display of spatial (locationally defined) data." If we accept this definition, we find that, in order to meet the data requirements for a GIS, our scanner must be able to faithfully capture the details of our map or chart, as well as retain the spatial integrity of the data, preferably to within established USGS map accuracy standards. There are, indeed, a number of other factors that should be considered before a commitment is made to scanning as the data input method of choice.

The initial product derived from all scanners is a digital record of the gray shade (or, in some cases, black versus white) measured for each pixel in an orthogonal array of pixels that combine to describe the encoded document. However, some scanners (and scanner service companies) are equipped with the capability to do specific data processing during the scanning process before the data are made available to the user. For example, data processing may be accomplished to produce an output in vector form. Or, processing may be accomplished to resample the basic output data to, in effect, enlarge the size of each pixel. Because scanners can produce very large data files, some data compression may be done before the output is available.

Typically, a GIS user wants to use scanner output data to (a) produce a digital replication of a document or a photograph that will accurately overlay an existing USGS or other map, or serve as a backdrop for other digital information; (b) convert maps or other manuscripts to a digital form for input to a GIS; or (c) extract from scanned documents specific information that may be distinguished by colors, textures, symbols, or combinations of these variables. Production of a digitized replication that can be used as an overlay or as a backdrop is the least demanding of any of the uses mentioned. No scale changes are required, no resolution changes are required, and corrections are seldom needed for digitizing errors, i.e., speckling, skewing, and surface deformation.

On the other hand, if the digitized map is to become a part of a GIS, a number of data processing steps may be required. First, the data must be adjusted so that the scale, resolution, and map projection for the digitized input are exactly the same as the scale, resolution, and projection of all other data in the GIS for a given area. To meet this requirement, often lengthy computer processing is required to "correct" the input data. The actual time required, of course, is a function of the size and resolution of the database associated with the GIS. If more than one map has been scanned to cover the area of interest, all of the maps required to cover the area of interest must be "stitched" together digitally to form a seamless composite. This process often requires the capability to correct the data set for holes and for overlaps along the line where the adjacent maps have been digitally joined. If the composite is composed of maps of widely differing vintages, extensive editing of the digital data may be required to correct discontinuities that will invariably be prevalent at the map boundaries.

If the map being scanned for input into a GIS is a contour map, editing must be done to close any discontinuities in the contour line and remove any annotations that fall along a line. All grid cells (pixels) defining each line must be digitally defined according to the elevation being represented (attributed). If the contour line is more than one pixel wide, which is almost certain to be the case, the line must be digitally reduced to the width of one pixel before subsequent analytical processes can take place. Once these steps have been taken, interpolation may be required to determine the elevation of each pixel defining the map.

If the map being scanned for input into a GIS is a polygon map (sometimes referred to as a factor map), a different set of data processing steps is required. First, any notations, i.e., attribute codes or symbols, that appear within each bounded area must be removed from the digital record. Then, each pixel residing within the polygon boundary must be changed from its current value to a value that identifies the attribute. Finally, the boundary lines themselves must be removed from the digital record and the pixel values that define the lines must be replaced with the polygon attribute values.

Thus, it would appear that a large amount of data processing is required to prepare scanner data for input into a GIS. Some of the capabilities that are required exist today. However, other requirements have yet to be developed. The following paragraphs present the current state-of-the-art for managing scanner data that are to be used as input to a GIS for purposes other than for use as a backdrop, or for overlay purposes.

Listed in Table 1 are typical software solutions to address some of the needs of users of scanned maps and other documents. Although some of these were developed specifically for desk-top publishing and automated cartographic applications, they are, nevertheless, useable for GIS data development.

TABLE 1. AVAILABLE SOFTWARE SOLUTIONS

Solution	Description
Raster-to-Vector Conversion	Converts rasterized scanner output to vectors or arc/nodes.
Cut and Paste	Allows sub-set data from a scanned document data file to be excised from the document file and destructively overlayed on another file. This feature is sometimes used to update old documents.
Boolean Operations	Boolean operators (and, or, nor, etc.) are frequently used when data stored in a relational database are being analyzed. A typical example might be identification of habitats for an endangered species of waterfowl when information on surface elevation, environments of deposition, land cover, and soil type are contained in georeferenced layers of a GIS.
Cross-Hatching	Applies cross-hatching to output to identify polygons according to attribute.
Text Editing	Permits text to be typed, edited, and placed digitally on scanned documents prior to output.
Speckle Removal	Like electrostatic printers, scanners sometimes produce "noise" that shows in an output as a random distribution of black specks against a white background. Software can recognize the noise and remove it from the file.
Skew/De-Skew Rotate, Re-Scale	Available software designed to correct for distortion, translation, and rotation errors can perform these operations.
Draw/Edit	Permits points or lines to be placed on a scanned document. Allows the attribute code of individual grid cells or grid cell clusters to be changed.
Attribute Assignment	Assigns an attribute to each grid cell or cluster of grid cells that together define a point, line, or polygon. This process is usually done by an operator working interactively at a work station.

SOFTWARE SOLUTIONS NEEDED

Scanner/Monitor Incompatibility

A computer will ordinarily produce a graphic display on the monitor by writing rows of pixels from left to right beginning at the top of the screen, and columns of pixels from top to bottom. This places the first pixel in the upper left, or northwest, corner of the screen and the last pixel in the lower right, or southeast, corner of the screen.

This way of producing a graphic display on the computer screen must be taken into account when data are to be encoded with some scanner types, particularly drum scanners. Most drum scanners encode a document with the top of the drum moving away from the operator and the electro-optical components carriage moving in increments from left to right. If the map north is oriented on the drum so that north is up, the first pixel will be in the northwest corner of the map, but rows will be scanned from the top to the bottom of the map and columns will be scanned from west to east. When displayed on a computer monitor, the map will appear to be rotated 90-degrees counterclockwise and will appear as it would when viewed through the paper on which the map is printed.

If the map is mounted on the drum with north to the operator's right so that scan lines are from west to east, the columns will be from south to north, rather than the desired north to south. If the map is mounted with north to the operator's left, scan lines will run from east to west.

This incompatibility between computer monitor and scanned data can be corrected by (1) copying the scanner data file to a new file wherein rows and columns of pixels are compatible with the monitor output; (2) writing a computer program that will cause the scanner image to be written to the computer monitor in a way that will produce a correct presentation; or (3) using a scanner with an electro-optic carriage that moves from right to left, rather than from left to right.

Attribute Assignment

As shown in Table 1, attribute assignment is now accomplished by operator interaction with the scanned document displayed on a computer monitor. When an unnamed polygon, i.e., a polygon in which the attribute code is not a part of the digital record, is displayed on the monitor screen, the operator keys in the appropriate attribute code. The process is repeated for each polygon on a map until all polygons have been assigned an attribute code. Essentially the same process is used to assign elevations to contour lines that have been edited to correct such things as line discontinuities and textual information on or between line segments. The procedure achieves the required results but is very time consuming for maps with many polygons or contour lines. In fact, studies have shown that, for the more complex maps, manual digitizing on a tablet is more cost effective than scanning and subsequently assigning attribute codes using the processes described above.

A desirable alternative to this process would require development of software that would permit recognition of attributes on the basis of color, texture, and/or map symbology. With this capability, polygons and contour lines could be identified with color codes denoting the attributes.

Recognition of standard map symbology would enable extraction of many mapped features, such as forested areas or marshes, without human intervention.

Removal of Boundary Lines and Annotations

In some GIS applications, boundary lines and annotations shown on a map actually are perceived as occupying space on the ground. Thus, area calculations and other analyses may be adversely effected. Computer programs to remove the lines, annotations, and symbols from the map would negate a time consuming and, thus, costly part of the data development process now encountered in GIS development. Such programs should replace lines with the proper attribute code for polygons on either side of the lines, so that the lines of demarcation separating polygons would only be implied when the attribute code changes.

Contour Line Editing

Contour lines appearing on maps are interrupted frequently by a space in which the contour value is placed. Automated removal of the value and closure of the space in which the value resides would significantly reduce the time required to assign an elevation attribute code to contour lines.

CONCLUSIONS

Scanning has the potential for substantially reducing the costs of encoding maps for GIS input. However, care should be exercised in selecting this option. If the intended use of scanned data is to obtain a backdrop or overlay for other GIS data, required preprocessing of the scanner-produced data before data entry into a GIS will be minimal. However, if scanner-produced data are to be used to extract information that is represented by colors, textures, or symbols; or if the scanner data are to be merged with other scanner data in a GIS, extensive data processing may be required. In addition, preprocessing may be required in order for the scanner data to conform to the input data format, scale, resolution, and projection requirements of the GIS. Some of the software required to accomplish the necessary data processing steps are already available, although in some cases in a primitive form. But in other cases, additional software development is needed to bring full scanner potential to fruition.

REFERENCES

Cobb, S. P., and A. N. Williamson, 1986. The Computerized Environmental Resources Data System (CERDS): A Geographic Information System for Environmental Data on the Leveed Floodplain of the Lower Mississippi River, *Proceedings of the Corps of Engineers 5th Remote Sensing Symposium*.

Williamson, A. N., 1985. *Computer Techniques for Producing Color Maps*, Miscellaneous Paper GL-85-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Williamson, A. N., and L. D. Britsch, 1989. *A Geographic Information System for the Southern Louisiana Deltaic Environments*, Miscellaneous Paper GL-89-25, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.