CARTOGRAPHIC DATA ENTRY THROUGH AUTOMATIC FEATURE TRACKING

K. Stuart Shea
PAR Government Systems Corporation
1840 Michael Faraday Drive, Suite 300
Reston, Virginia 22090

ABSTRACT

Many cartographic systems currently rely on raster-scan digitizing to convert analog source material to digital form. Raster technology is very effective at rapid and accurate digitization of large volumes of cartographic data. At the same time, existing raster-to-vector (R-V) conversion processes rely on an inordinately large amount of human post-scan editing to coherently sort and combine the short, unattributed lineal segments into single cartographic spatial entities. The Automatic Feature Tracking (AFT) system addresses one of the major causes of this bottleneck in the digitization process—skeletonization. This is accomplished by **directly** converting *symbolized* linear features on a raster map image into sets of *x,y* coordinates. The system relies on Template Matching and Feature Tracking techniques to locate feature centerlines. This paper briefly reviews the history of map digitization techniques, illustrates inadequacies of those past approaches, and presents the AFT system as an alternative to the R-V conversion routines in existing raster digitization systems.

INTRODUCTION

The Evolution of Map Digitization

Since its inception in the early 1960's, digitization processes have seen many technological advances (Boyle, 1979, 1982). Many innovative techniques have been explored and expensive hardware developed to aid in the conversion of hardcopy graphics to digital form. Cartographers have witnessed this technological transition first-hand (Penney, 1979). Early cartographic digitization efforts began by paralleling the traditional use of the information in drafting vectors. Preservation of the vector-nature of the data functionally was similar to intuitive cartographic production processes. Although originally collected by hand, the manual digitization task was so laborious that special digitizing equipment was soon developed. Over the last 25 years, the resulting equipment—manual digitizers—has evolved considerably. From the mechanical, arm-type digitizers of the early 1960's, to present-day electromagnetic induction free-cursor digitizers, this maturation continues.

As the need for more types of digital cartographic data emerged, practitioners were also experiencing a growing dependency on the digital information. It soon became obvious that the existing manual digitization techniques could no longer support the requirements of the cartographic community. The late 1960's and early 1970's saw a movement away from vector-oriented data collection systems, and significant attention was placed upon raster digitization. Initial application of raster data to cartography was limited to the area of production; specifically, to the generation of color film separates. As a means for *mass digitization*, though, the benefits were much more obvious. Cartographers agreed with alacrity that raster scanning was the preferred method of data capture for the future.

Nonetheless, raster scan digitization met with many obstacles: 1) the very nature of raster data violated the traditional mind-set of cartography being a vector-based process; 2) features were no longer identified as discrete elements; 3) vector, coordinate geometry representation for data storage was more efficient; and 4) existing manipulative processes continued to be vector-oriented (Peuquet, 1979, 1982). Despite these apparent shortcomings, the raster data capture movement persisted and continues to date. This is primarily borne of necessity because: 1) raster data collection speeds far exceed those of manual digitization; 2) it generally removes the operator from the conversion loop, thereby eliminating humans frailties in the digitization process (such as physiological and psychological deficiencies); and 3) achievable accuracy is much greater. As a result, raster scanning is now finding its way into many mapping producers' mass digitization systems.

Shortcomings in Existing Raster-to-Vector Conversion Techniques

Until such time as raster data can be efficiently stored, manipulated, and exploited in the production process, the major remaining obstacle in its outright acceptance as the preferred method of data capture exists in the conversion of the scanned data into the familiar spatial format of vector-based lineal chains (Fegeas, 1983). Raster-to-Vector (R-V) conversion processes are numerous and have been well defined in the literature. Peuquet (1981) suggests that a generic R-V process can be divided into three basic operations: 1) skeletonization; 2) line extraction, or vectorization; and 3) topology reconstruction. A major disadvantage of existing R-V conversion routines is that they do, in fact, follow these steps, and do not effectively exploit the inherent symbolic nature of the cartographic features in the raster map image. This is partly due to the fact that past R-V conversion efforts have primarily focused on routine cartographic symbolized features (such as primary/secondary roads, contours and polygons)—those with simple linework—and have generally ignored those problems dealing with complex, highly stylized symbolized lines (such as railroads, cased roads, trails, and intermittent drains).

Existing maps contain a wealth of information which is ignored and eventually eliminated in most R-V conversion techniques. It would be more advantageous to eliminate the skeletonization process, and vectorize the raster data by exploiting the symbolic nature of each feature to discriminate it from its surroundings. By operating on symbolized features instead of skeletonized features, this direct conversion would also eliminate a number of weaknesses which result from other skeletonization techniques. Consider, for example, the flaws which result from converting the following feature types:

- *Railroads.* Railroad features are converted to a dash-tick-dash-tick representation wherein each dash and perpendicular tick would be separate vectorized features. An operator is required to combine these numerous segments into a single entity and tag it as a single railroad feature.

- *Cased Roads.* The actual feature location is the center of the casing yet, typically, skeletonization routines capture the two "parallel" lines as distinct features. These two distinct lines must subsequently be tied together to represent a single cased road.

- *Intermittent Drains.* The dash-dot-dot-dot-dash symbology sequence for this type of feature complicates normal R-V conversion. The dots are normally discounted as noise in the skeletonization process, and the dashes end up as individual linear features requiring subsequent tagging as a single drainage feature.

Besides the problems that arise due to different symbol types, many anomalies found on paper maps contribute to the degradation of digital data quality during the digitization process. Manual lineal digitizing systems, as well as typical R-V conversion systems, have not overcome the influence of these anomalies and, in fact, magnify their impact on the integrity of the data collected. For example, the following inadequacies exist in standard skeletonization routines:

- The wholesale skeletonization of an entire data file, in which all features are converted to a one (1) pixel width, typically causes the generation of stubs, gaps, and unthinned data elements.

- Pre-processing the source documents, such as in the creation of film positives for scanning, may be required and involves a significant amount of effort (Antell, 1983).

- The algorithms are highly sensitive to local variations in line width or breaks/gaps in line and will influence the positional accuracies of vectorization (Selden, 1986).

- Scanning noise caused by blemished manuscripts, or folds in the original source, will adversely affect the conversion.

Future developments of advanced mass digitization systems must be able to meet the growing need for, and reliance on, digital cartographic data. The digitization process must be accomplished with limited human intervention while exploiting the rapid data entry capabilities of raster scanning. It is obvious that the current R-V conversion systems are failing in their claims of reducing the human bottleneck; too much effort is often required in subsequent editing/cleanup tasks to make the systems viable. PAR Government Systems Corporation (PGSC) has identified feasible solutions, and has implemented streamlined techniques to minimize, if not eliminate a major cause of the digitization bottleneck. The integration of these techniques into a cohesive testbed for enhanced feature discrimination forms the basis of the Automatic Feature Tracking (AFT) system.

AUTOMATIC FEATURE TRACKING

AFT System Overview

The AFT algorithm uses Template Matching and Feature Tracking techniques to locate feature centerlines in a raster map image. Each of these important aspects of the system is described below.

Template Matching. The template matching technique is the key to the AFT algorithm. A raster template is compared to a feature and, if the two match, a point is saved to describe the feature's location. The AFT system operates on raster-scanned binary images in which the features are represented by ones, and the background by zeroes. A template matching algorithm that exploits this parity of values operates by comparing templates with the same values (of 0 or 1) to the map image. Thus, the template matching technique compares a template array to a subarray of the map image. If the corresponding pixels of the template and the map subimage are nearly identical, the correlation between the two is high, and the template location is considered a match for a coordinate depicting the feature.

Binary template matching, however, is not perfect. Features do not generally align themselves with the orthogonal nature of raster data. Linear features represented in raster format often have jagged, stair-step edges. These jagged edges are irregular and unpredictable. Similarly, in many cases the line width of the feature varies because of scanning noise, drafting inconsistencies, and damage to the original manuscript. In an attempt to bypass these problems, a ternary template matching technique provides more flexibility. The ternary template array consists of three values: 1) ones (feature of interest); 2) zeroes (background); and 3) twos (a special value). To accommodate for feature boundaries which are not perfectly parallel and not of uniform width, the neutral (2s), or "don't care" zones, do not contribute to the correlation calculation used by the template matching algorithm.

Extensive experimentation has been conducted to determine the appropriate template design for a number of lineal features on a variety of raster-scanned source materials. Figure 1, for example, illustrates the ternary template matching technique with a template designed for a dashed line.

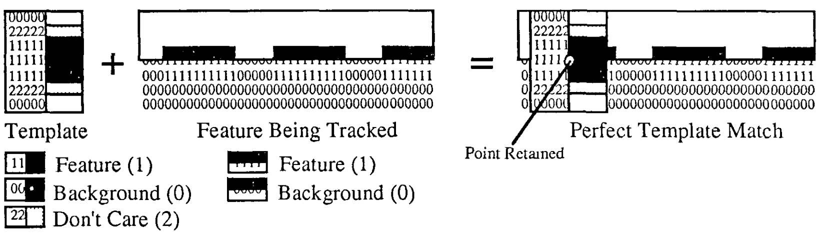

Figure 1. **Ternary Template Matching.** AFT fits a square or rectangular template to match the inherent feature characteristics in a raster map image. Here, the 2s compensate for the intermittent and highly sinuous nature of dashed lines.

Template design parameters are based upon a variety of feature characteristics and differ considerably between feature type. Templates are created to match the physical characteristics of the feature (such as the width or degree of sinuosity). These templates are then iteratively optimized by experimentation to compensate for tracking failures which may result from sharp turns, obstacles, feature look (dashes, dots, crossings), and feature continuity. This process continues until the designed template successfully tracks the feature in question. The template can then be used for subsequent tracking on the same product.

When the appropriate tracking template is placed over a subarray of the map image, a correlation procedure determines the *best fit* of the template to the feature. The template is rotated to check the correlation at many orientations. This allows the algorithm to detect changes in the alignment of the feature. A file of pre-rotated templates is created in advance in order to eliminate the need to perform template array rotations during template matching and tracking. While matching is in progress, the current feature orientation is determined by comparing a subset of these pre-rotated templates to the feature. The orientation with the highest correlation value is chosen.*

In many cases, when the template is initially placed on the feature for comparison, it can be placed 2-3 pixels off-center, and an inappropriately low correlation value may be result. To compensate for this problem, a template matching search window is used. This search window consists of an array of locations where the template will be compared, resulting in only a slight corrective procedure for template centering. Combined with template rotation, this process allows the algorithm to compensate for small changes in the location and alignment of the feature.

Feature Tracking. Once an adequate template-to-feature match is initially obtained in a local search window, the second major part of the AFT system, feature tracking, takes over. Here, the current orientation of the template and a user-specified projection distance is used to predict the next position in which to continue the template matching procedure. Figure 2 illustrates the basic algorithm approach for feature tracking.

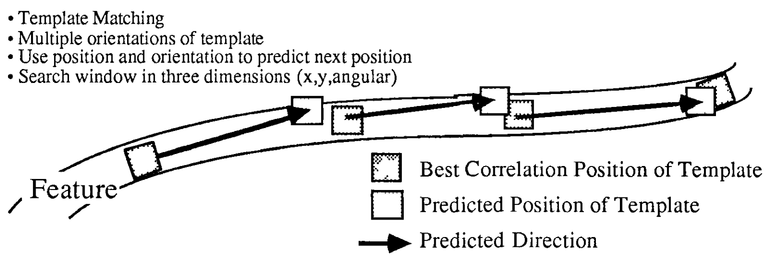

Figure 2. **AFT Feature Tracking Approach**. The template matching algorithm selects a predicted position based upon the current position and orientation of the template. The template is projected down the feature and the template is rotated and translated until a sufficiently high correlation of template-to-feature is achieved. This location now becomes the new anchor position for the subsequent projection.

The main algorithm used during feature tracking is known as **AutoProject (AP)**. This process governs the template matching algorithm by providing the locations in which there exists a high degree of probability that a feature will be present based upon past experience. AP uses known characteristics of the feature (such as degree of sinuosity or maximum radius of curvature at the source's scale) to predict a new location of the feature being tracked some n-pixels away from the current position. The AP algorithm is illustrated in

*The parameter files associated with the AFT system allow one to specify a *sufficiently acceptable figure of merit* (correlation) which will not require the "highest" correlation.

Figure 3. The AP process is repeated until an individual feature is tracked from a user-selected starting point to ending point.

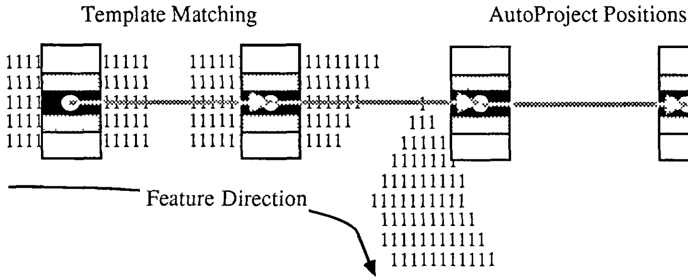

Figure 3. **AutoProject Algorithm**. In this illustration, the template has been projected along a feature. The initial AP has located the feature. Two subsequent projections, though, have failed because of a change in feature direction.

When there are features with gaps, such as dashed lines, or features which have a high degree of complexity/sinuosity, such as intermittent drains, two variations on the AP algorithm control the tracking. The **Increased Area Search (IAS)** and **Center of Mass (CM)** algorithms are used to jump over gaps and locate features when an adequate template-to-feature match cannot be found during the normal AP sequence. The feature location program control logic dictates whether or not these secondary algorithms are invoked, depending on a set of pre-defined parameters. These parameters also include include algorithm-specific control values such as the initial and secondary projection distances, angular "look" of the projection, and required correlation values.

AFT System Design

The AFT system is divided into two main program categories: **feature tracking** programs and **map template utility** programs.* The heart of the feature tracking programs is the feature location program, and controls the logic used while tracking linear features.

AFT System Operations Concept. A typical operational mode using the feature tracking system involves: 1) displaying a portion of a raster map image on an interactive graphic display device; 2) obtaining a starting point on the desired feature to be tracked (using a graphic input device); 3) capturing a point from the display to indicate the direction in which the feature is to be tracked; 4) entering the type of linear feature that is being discriminated (such as a railroad or trail); and 5) running the feature location program.

AFT Tracking System Output. Tracking of the features commences from the user-specified starting point to the stopping point (if one was specified), or until the algorithm reaches the end of the feature. Output from the feature tracking software includes a summary of the tracking results (*Results Report*) and a file containing the actual tracked coordinates (*Automated Results*). Figure 4 is a sample of the report format used in the AFT system.

*The AFT system consists of 11 main programs, 130 subroutines, 20 command files, and 70 other required support files, totalling approximately 12,000 lines of executable FORTRAN 77 code. This does not include any device drivers or graphic interface packages.

RESULTS REPORT type	NORMAL
RESULTS REPORT file name	xxxxxxxx
TEMPLATE name	xxxxxxxx
AUTOMATED RESULTS file name	xxxxxxxx
Feature Search window dimensions (#row, #column)	zzzz, zzzz
Template angular window size	zzzz z
Sufficiently acceptable figure of merit	z zz
Minimum figure of merit allowed	z zz
Maximum local search for iterations allowed	zzzzz
Increased area search type	NONE
Number of times projection should be used	zzzzz
Projection distance to be used	zzzz z, zzzz z, zzzz z

MAP IMAGE and RELATIVE START-STOP PARAMETERS

MAP IMAGE file name	xxxxxx
Current track position (row, column, angle)	zzzzz, zzzzz, zzzz z
Feature stopping position (0,0 = ignore)	zzzzz, zzzzz
Maximum feature points to generate (0 = ignore)	zzzzz

Tracking Results Summary
(u = updated position, + = unacceptable point)

	Previous			Current				Distance
	Row	Column	Angle	Row	Column	Angle	Correlation	between points
u	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z
u	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z
	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z
u	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z
+	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z
	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z
u	zzzzz	zzzzz	zzzz z	zzzzz	zzzzz	zzzz z	zzzz z	zzzz z

Figure 4. **Sample NORMAL RESULTS REPORT Format.**

Contemporaneous Tracking Results Viewing. Management of the graphics display is an important operational aspect of the AFT system and is controlled by a separate program. During the feature tracking process, the correct map view display is automatically maintained and the digitized coordinates are plotted over the raster representation of the feature being tracked while the feature location program continues. These two processes communicate with each other through a shared common storage region and through operating system-supported event flags which alert each process to its counterpart's state. When tracking begins, an image view monitor plots track coordinates on the current map view. As soon as a track coordinate gets close to the edge of the current display window the feature location program will automatically display the next map view so that tracking progress can continue to be monitored. As tracking of a feature nears this *trigger region*, a new image view window is displayed with at least $1/4^{th}$ of the previous image view window retained for reference purposes.

Post-Tracking Results Viewing. In certain cases, it is desirable to view a previously created track. This is especially useful if the user has not requested visual monitoring of the track coordinates during the initial tracking process or if tracking was performed as a batch operation. Many viewing options are available including displaying multiple tracks on the same map view, or that of viewing a long, continuous track.

System Parameter Files. The AFT system was designed to be a modular, system-independent utility. As such, most of the controlling logic for the software is governed by parameter files. These files enable the system to be modified for: 1) new products and features; 2) multiple scan resolutions; and 3) variegated human interaction preferences in the operation of the tracking programs. Parameter files are usually created prior to running the feature location program. The following are examples of AFT parameter files:

- *Current Image View Parameters* file indicates the current or latest map image file name and the area in which tracking is occurring.

- *Relative Starting/Stopping Parameters* file contains the feature tracking start point, the initial tracking direction, and an optional stopping point.

- *Restart Parameters* file contains all information required to reinitiate tracking when the system is interrupted from processing by user request or operating system failure. This file is automatically created each time tracking is initiated. If the track being monitored is not following the intended path, the operator may abort the tracking and manually traverse the trouble spots on a failed tracking attempt. When tracking is reinitiated, it will automatically access the restart parameters and continue tracking.

- *Operation Parameters* file controls certain operational functions of the feature location program; for example, whether or not to graphically display the tracked coordinates during feature tracking.

- *Feature Parameters* files contain the parameters which indicate the methods used to track a particular type of linear symbology. A different feature parameters file is normally created for each type of feature to be tracked.* The *Feature Parameter* files are one of the most important aspects of the AFT system. If a feature parameters file does not exist, the feature parameters must be manually entered. The system also supports a *training* capacity mode—such as when a new product or feature type is being tracked for the first time—wherein parameters are omitted from the feature parameters file and replaced by an "ask operator" signal value. This allows that particular parameter to be fine-tuned through repetitive adjustment since the operator will be queried for that parameter each time the feature location program is invoked. It should be noted, though, that operator interaction is the exception; in a typical operational scenario, the feature parameters are stored for automated use.

AFT System Summary

The AFT system has demonstrated the ability to track a variety of symbolized linear feature types (railroads, cased roads, dashed lines, intermittent streams, and cut-and-fill contours) as well as simple linework (index, intermediate, and supplementary contours). Table 1 provides a sample timing summary from a number of tracking experiments conducted with the AFT system.

Feature Type	CPU Time
Railroad	12 seconds
Cased Road	13 seconds
Dashed Line	16 seconds
Intermittent Stream	11 seconds
Cut & Fill Contour	14 seconds
Index Contour	12 seconds
Supplementary Contour	16 seconds
Intermediate Contour	11 seconds

Table 1. **AFT Tracking Timing Summary**. This table illustrates the amount of time required to track a two-inch segment of each feature type in a batch-mode environment on a time-shared VAX-11/780 system.

It is important to realize that these timing results represent the conversion of a single feature running throughout a complex raster map image with the dimensions of approximately 25,000 by 40,000 pixels. Thus, vector representations of each of these features were collected without a wholesale vectorization of the entire map image, and without the need to undergo post-scan editing to remove noise. The quality of the vectorized line data from the feature tracking process is also exceptional. Most R-V conversion or manual digitization standards require that centerlines be collected to within 1/2 of a line width from the centerline of the feature originally being digitized.The tracking results consistently exceeded that tolerance.

*These files have proven to be very robust for a given type of feature, regardless of the map or chart source. PGSC has designed feature parameter files which have worked on a number of products, with each product originally being scanned on different scanners.

Significance of the AFT Technology

The production programs of the major map and chart producers in the U.S.—the United States Geological Survey (USGS), the Defense Mapping Agency (DMA), and the National Ocean Survey (NOS)—are in a state of transition to all-digital, softcopy production capabilities. This transition includes the establishment of uniform procedures relating to the collection, screening, evaluation, editing, symbolization, retrieval, and exchange of digital source and production data (Franklin and Holmes, 1978). As part of this move to the digital mode, significant efforts are being made to expand and improve mass digitization capabilities (Starr, 1986; Callahan and Broome, 1984). These new capabilities will support the population of multi-product, multi-purpose digital cartographic data bases currently under design. The ability to support a growing dependency on digital cartographic data, coupled with a requirement to meet, or exceed, existing collection system accuracies, will require a rethinking in digitization techniques.

The AFT development is clearly aligned with the current trends at the USGS, DMA, and NOS production centers, and surpasses their accuracy requirements for data collection. The significance of AFT's capabilities are important because of the following:

- Processing of Degraded and Highly Variant Source Materials. Map producing agencies will continue to use a wide variety of hardcopy source materials for inclusion in their digital data bases. Significant among them are the maps and charts produced by and of foreign nations. These maps incorporate a wide variety of symbology schemes consisting of unique line thicknesses, line configurations (regular dashes, irregular dashes, dashes and dots, etc.), and screened lines. In many cases, unsophisticated graphic arts techniques during map production render a wide variation in line quality within the frame of a single map sheet. Infrequent occurrences of damaged maps with stains, pronounced fold marks, and other detrimental effects cause special problems for map conversion activities. Many types of skeletonization and vectorization methods fail or suffer severe throughput degradation when processing damaged or foreign products. The AFT system's unique method of template configuration with non-correlated pixels within the mask effectively accommodates the variances in line quality and performance is not significantly degraded by poorly handled, damaged source materials. In addition, the operator can quickly design and build the correctly configured template along with the modified parameters to allow the data to be processed.

- Discrete Feature Selection. As maps and charts are converted and put into the proposed all-digital production flows, every method of conserving computation power and local data storage becomes significant. Many types of skeletonization and vectorization techniques convert all data within the map frame into vector format. Many of the vectorized features are eventually discarded. This problem represents a significant cost factor in an all-digital production environment. The AFT system's approach avoids the wholesale processing of all the data within the map frame by allowing the operator to select only the desired features for processing and extraction from the map sheet. Savings in processing requirements alone can easily provide a 50% increase in throughput rates.

- Batch Operation. Processing and storage resources are not the only areas where AFT can make a significant contribution to cost control. Future labor savings, perhaps a map producing agency's most costly resource, are of key interest to production planners. Map conversion via manual techniques, that is, table digitizing, is not a cost-effective method of using labor. AFT provides the capability for the operator to enter only the starting position and direction of the feature of interest. AFT does the rest. Experiments have been conducted with a variety of features using AFT in a batch mode and the success rate clearly identifies AFT as a time-saving and labor-saving device.

FUTURE AFT DEVELOPMENTS

System Improvements

The AFT system is by no means static. With the ever-changing digital cartographic production environments at the major map producing agencies, the AFT system remains a dynamic utility. As part of this evolution, many topics are being addressed in future versions including:

- *Feature Parameter Library.* Product-dependent digitization will be supported for a variety of sources (such as DMA's TM-50; USGS's 1:24,000-scale quadrangle maps; and NOS's Nautical and Bathymetric Charts). Feature parameter files, operation parameter files, and templates files are being designed for each product. New parameters and templates can then be added to incorporate new and non-standard map/chart specifications.

- *Automatic Template Generation.* A semi-automated, rule-based approach is being considered to create feature tracking templates. One proposed solution is to have a template creation program query the operator for both general and specific characteristics of the feature. This information includes: 1) an approximation of feature sinuosity; 2) association with other features (e.g. does it cross over other feature types?); and 3) a measure of feature width and shape. The template creation program would then be used to automatically generate an appropriate set of rotated templates.

- *Compatibility with Multiple Data Input/Output Formats.* The AFT software operates using data captured on black and white scanners. System input capabilities are being expanded to include color scanners. Color adds a new dimension to the system. This extra dimension could augment the tracking logic of the AFT by providing only those *layers* within the data base that a particular feature can exist on.

- *Confusion Points Parameter File* . The ability for the cartographer to locate, *a priori*, any obstacles along the feature segment that might cause incomplete trackings for the tracking algorithm as a pre-vectorization step is being included. In places where the algorithm gets confused due to symbology conflicts, one or more additional points could be entered using the stream mode capability of most digitizers. When the tracking algorithm reaches a confusion point, it immediately accepts the point, and reinitiates the tracking afterwards.

Conclusion

The AFT system is capable of becoming an advanced automated cartographic data entry system utility. The Automatic Feature Tracking system is not the panacea to the entire digitization problem. Instead, the AFT system would serve to enhance the map conversion process by reducing the slow, error-prone, labor-intensive manual digitization processes. The application of automatic procedures, or even semi-automated procedures, can significantly shift the burden of these labor-intensive tasks from the operator to the computer. If a rapid input device like raster scanning could be followed with an automatic feature discrimination system on an edit/tag workstation, great improvements in production throughput rates for product generation can be realized. In most instances, AFT will not supplant existing digitization and edit/tag systems but, instead, will augment each to bring them to their potential.

ACKNOWLEDGEMENTS

The AFT system was developed at PGSC by a dedicated and talented team. Along with the author, Mr. Bradley Barnell, Mr. Andrew Douglas, Dr. Michael Gillotte, Jr., Mr. Steven Haehn, Ms. Marsha Rapke, Dr. Jon Sanders, and Mr. John Snyder comprised the AFT team. The author would like to express his gratitude to them for were it not for their devotion to cartography, the AFT system would not have been realized.

REFERENCES

Antell, R.E. (1983), "The Laser-Scan Fastrak Automatic Digitising System," Proceedings, Fifth International Symposium on Computer-Assisted Cartography, Auto Carto V, Crystal City, Virginia, August 22-28, pp. 51-64.

Boyle, Ray (1979), "Cartography in 1990," Proceedings, International Symposium on Cartography and Computing, Auto Carto IV, Reston, Virginia, November 4-8, pp. 40-47.

Boyle, A. Raymond (1982), "The Status of Graphic Data Input to Spatial Data Handling Systems", in Peuquet, Donna, and John O'Callaghan, eds. 1983. Proceedings, United States/Australia Workshop on Design and Implementation of Computer-Based Geographic Information Systems. Amherst, NY: IGU Commission on Geographical Data Sensing and Processing. pp. 13-20.

Callahan, George M., and Frederick R. Broome (1984), "The Joint Development of a National 1:100,000-Scale Digital Cartographic Data Base," Technical Papers of the 44th Annual Meeting of the ACSM, Washington, D.C., March 11-16, pp. 246-253.

Fegeas, Robin G. (1983), "Modularization of Digital Cartographic Data Capture," Proceedings, Fifth International Symposium on Computer-Assisted Cartography, Auto Carto V, Crystal City, Virginia, August 22-28, pp. 297-306.

Franklin, Dennis P. and Garry L. Holmes (1978). Overview of Automated Cartography Efforts at DMAAC. Proceedings, Sixth International Symposium on Automated Cartography, Auto Carto VI, Ottawa, Canada, October 16-21, pp. 438-447.

Penney, Robert A. (1979), "The Ascendancy of Digital Cartography in DMA's Future," Proceedings, International Symposium on Cartography and Computing, Auto Carto IV, Reston, Virginia, November 4-8, pp. 236-243.

Peuquet, Donna J. (1979), "Raster Processing: An Alternative Approach to Automated Cartographic Data Handling," The American Cartographer, vol. 6, no. 2, pp. 129-139.

Peuquet, Donna J. (1981), "An Examination of Techniques for Reformatting Digital Cartographic Data/Part 1: The Raster-To-Vector Process," Cartographica, vol. 18, no. 1, pp. 34-48.

Peuquet, Donna J. (1982), "Vector/Raster Options for Digital Cartographic Data", in Peuquet, Donna, and John O'Callaghan, eds. 1983. Proceedings, United States/Australia Workshop on Design and Implementation of Computer-Based Geographic Information Systems. Amherst, NY: IGU Commission on Geographical Data Sensing and Processing. pp. 29-35.

Selden, David D. (1986), "Automated Cartographic Data Editing: A Method for Testing and Evaluation," Proceedings, 46th Annual Meeting of the ACSM, Washington, D.C., March 16-21, pp. 5-14.

Starr, Lowell E. (1986). Special Report, Mark II: The Next Step in Digital Systems Development at the U.S. Geological Survey, The American Cartographer, vol. 13, no. 4, pp. 368.