SOFTCOPY METHODS OF CARTOGRAPHIC DATABASE MAINTENANCE

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ABSTRACT

Several automated techniques can be used in the cartographic change detection process to enhance productivity and accuracy, in support of geographic database maintenance. A series of experiments was performed to test the feasibility of using various change detection techniques in an automated cartographic production environment. Detected changes were flagged as feature updates to a geographic database. A hardware/software configuration testbed was constructed to simulate an automated production environment. Softcopy imagery and map/chart data were used to represent newly arrived source material. The geographic database was populated with cartographic feature vectors and attributes, henceforth referred to as Cartographic Feature Data (CFD). Production cartographers served as the experiment subjects to assure an operationally valid test sample. Results of the experiments are summarized on the following topics: Display Methods, Data Digitization, Image Manipulation, Zoom Factors, and Change Classification.

INTRODUCTION

Cartographic production agencies are rapidly incorporating softcopy technology to depart from the manual cartographic methods employed for years. An integral component of the softcopy movement is the digital cartographic feature database. The database is composed of geographically referenced and attributed feature data. It can be generated from a variety of sources including: maps/charts, imagery, reference graphics and textual sources. Feature data can be digitized and attributed to populate the database.

Once populated, changes to the digital database must be made as new source becomes available, in order to maintain the currency and accuracy of the database. The same types of sources used to populate the database can be exploited to maintain the geographic database. Raster scan digitizers provide a means to generate softcopy digital images of the hardcopy source material. The digital images can then be registered to a geographic frame of reference. Subsequently, the images may be displayed using methods that facilitate comparison with features in the geographic database. Anomalies can be identified and annotated in softcopy.

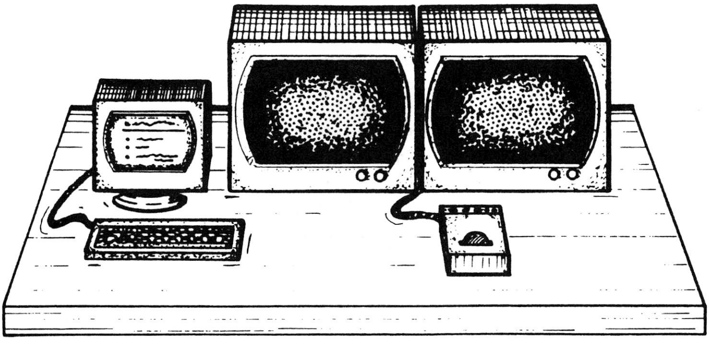
The softcopy concept described is the basis for the set of change detection experiments reported upon in this paper. The objective of the experiments was to test the feasibility of using various techniques to facilitate the change detection process in a softcopy environment. Analyst productivity and accuracy were also evaluated for given techniques. A description of the experiment design and implementation methodology and the experiment hardware/software configuration is presented. Each of the four change detection experiments are summarized to include: 1) a definition of the objectives; 2) the dependent and independent variables; 3) the experiment scenario; and 4) the results of the experiment.

EXPERIMENT DESIGN AND IMPLEMENTATION METHODOLOGY

Design of each of the four experiments began with determination of the independent variables to be manipulated and the dependent variables to be measured. A scenario was conceived which would support mensuration of data under the various states of manipulation. Using the scenario, data flow diagrams were developed to support the design activity and progress to implementation. A simple man-machine interface, which allowed option selection using hierarchical menus, was chosen for all of the experiments. This approach was selected to minimize: 1) the amount of time spent on implementation of the experiment software; 2) the amount of time required to orient the subjects; and 3) the influence of the man-machine interface on the outcome of the experiments.

EXPERIMENT WORKSTATION CONFIGURATION

The experiments were conducted on a workstation composed of the following hardware components: 1) VAX computer; 2) two high-resolution color image display monitors driven by a Gould IP-8500 image processor; 3) VT 220 alphanumeric CRT terminal; and 4) trackball graphic data entry and pointing device. The workstation is illustrated in Figure 1.



- ***ALPHANUMERIC MONITOR WITH KEYBOARD***
- ***TWO 1024 x 1024 IMAGE DISPLAY MONITORS***
- ***TRACKBALL BOX WITH FUNCTION KEYS***

Figure 1. The Experiment Workstation

Training Methodology

A Video Cassette Recorder (VCR) was used to train the experiment subjects regarding the objectives of the experiments. In addition, the hardware and software components of the experiment configuration were explained in the training video. The subjects were briefed on the specific tasks required of them for each experiment. The use of video tapes for training provided commonality between the experiment subjects in terms of introducing the experiments to each of the subjects. The video tape training was supplemented with hands-on training for each subject. The hands-on training allowed the subjects to work at the workstation with a training set that was developed for each experiment.

EXPERIMENT #1: IMAGERY CHANGE DETECTION TECHNIQUES

This experiment focused on determining how well an analyst could detect changes between vectors, (representing the features of the cartographic feature database), and a softcopy raster digital image display of monochrome imagery.

The independent variables for this experiment were: 1) display method; and 2) availability of a cartographic feature filtering function. The dependent measures for this experiment were: 1) speed of change detection; 2) accuracy of change detection; 3) use of a zoom/scroll function; 4) use of an image enhancement function; and 5) use of a cartographic feature filtering function.

The scenario for the experiment was as follows. Each analyst was exposed to four complete images and then corresponding features, extracted from a cartographic feature database. The images were segmented into patches, in one-quarter increments. The analyst viewed each of the four image patches and the corresponding feature data, using one of four display methods per image. Access to zoom, scroll, cartographic feature filtering, image enhancement functions was permitted at all times during the experiment. As the analyst detected changes between the database and the raster image, he/she used an electronic grease pencil function to annotate the change. After the analyst examined all four patches of a single image, a new image was displayed using a different display method. The process cycled until the analyst had examined all four images.

The display methods used were: 1) Split Screen; 2) Side-by-Side; 3) Overlay Superposition Method #1; and 4) Overlay Superposition Method #2. Each of the four display methods are presented in Figure 2. It is important to note that although the two overlay superposition methods appear very similar, Method #1 presented a reduced-resolution overview image on the left monitor, while Method #2 presented an overview line graphic. Both images appearing on the left monitor had a graphic monocle indicating the area of coverage displayed in full-resolution on the right monitor.

EXPERIMENT #2: MAP/CHART CHANGE DETECTION TECHNIQUES

This experiment was identical to Experiment #1 with the exception that the primary comparison source used was rasterized map/chart data. The use of rasterized map/chart source did not require the image enhancement capabilities, such as manipulation of the grayscale, which were provided in Experiment #1.

The objectives, dependent/independent variables, and the scenario were identical to Experiment #1. Reference the Experiment #1 description for details.

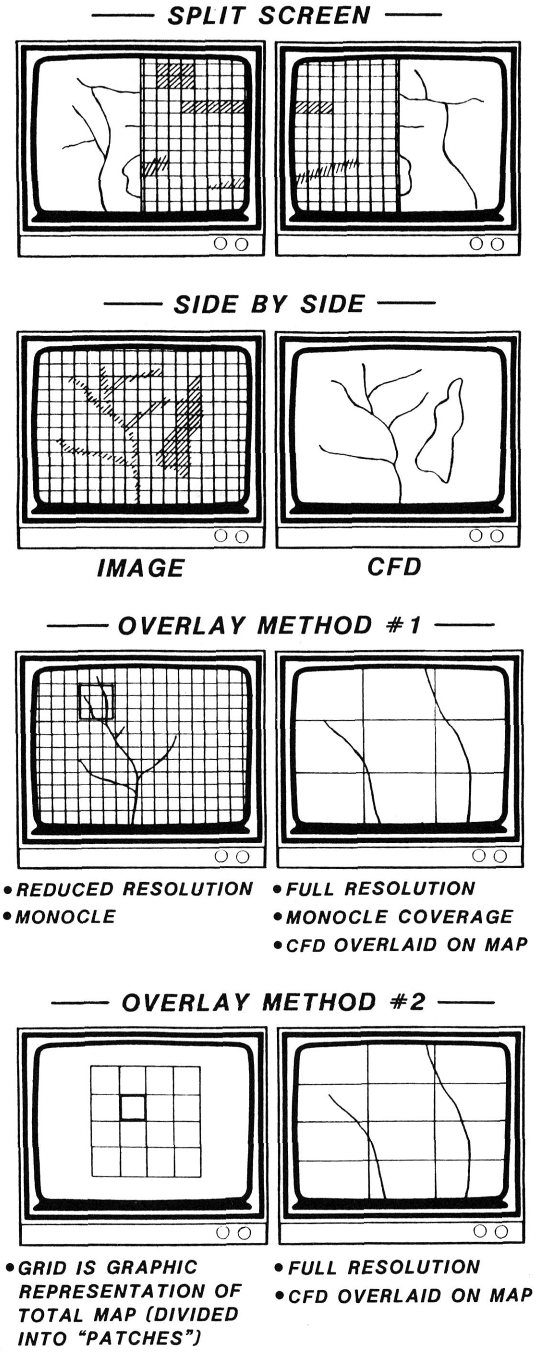


Figure 2. Display Techniques

EXPERIMENT #3: THE EFFECT OF RESOLUTION ON MAP/CHART CHANGE DETECTION

The purpose of this experiment was to evaluate the effect that varying the resolution of softcopy map/chart data has on the accuracy and productivity of softcopy change detection. Experiment #3 built upon the results of the first two experiments by taking advantage of the findings that indicated Overlay Superposition Method #1 to be the optimal display technique.

The dependent variables for this experiment were: 1) image resolution; 2) map/chart image number; and 3) experience of the cartographer. The independent measures for the experiment were: 1) speed of change detection; 2) accuracy of change detection; 3) use of the zoom/scroll function; and 4) use of the display toggle functions.

The scenario for the experiment was as follows. Three map sections were raster-scan digitized at each of three resolutions: 256 lines/inch, 384 lines/inch, and 512 lines/inch. These images were then displayed on the workstation using Overlay Superposition Method #1 along with the corresponding database features. Each subject viewed the three images at only one of the candidate resolutions. Viewing options to manipulate zoom/scroll, toggle various displays on/off, and filter the cartographic feature displays were available at all times. The analyst used the tools to perform change detection between the raster source and the database. The changes detected were marked as described in Experiments #1 and #2. The presentation combinations of resolution and image number were varied to normalize "learning curve" phenomena that would skew the results.

EXPERIMENT #4: CHANGE APPLICABILITY

The Change Applicability experiment was designed to determine how identified feature changes impact the database from the perspective of product generation. Given the case where several products are produced from a single database, a change may not impact all of the products produced. Obviously, product scale is a major factor regarding applicability of change to a product. If a change can be codified to a fine level of attribution, a generic feature-to-product content look-up table can be created which determines product applicability of a change.

The independent variables manipulated in this experiment were: 1) source type (imagery or map/chart); 2) method of codification (automated or manual); and 3) level of subject cartographer's experience. The dependent measures were: 1) speed of change codification or applicability assessment; 2) accuracy of change codification or applicability assessment; and 3) use of image display manipulation tools (e.g., zoom/scroll, feature filter, and image enhancement).

The scenario was as follows: The experiment subjects were presented a mix of softcopy images that are map/chart and imagery based. Feature changes on the image were annotated with Minimum Bounding Rectangles (MBRs). The experiment was designed to resume where the other experiments ended. That is, changes had already been discovered and automated. Now the subject must determine the nature of the change and the impact that change has on a given set of cartographic products. Two separate groups were established to test two distinct techniques. The first group categorized the change and determined applicability aided by softcopy product specifications. The second group categorized the change using a generic attribute coding system that forced the subject to classify the change into a feature type. A look-up table was constructed that mapped feature types to products. Therefore, once the change was classified, the applicability to the given set of products was determined automatically by invoking the look-up table. The look-up table was constructed by extracting product-specification data and incorporating that data as the relation criteria.

EXPERIMENT RESULTS

The experiment results were based on the following:

a. Statistical analysis of subject performance;
b. Subject preference data from questionnaires;
c. Experiment proctor observations.

Display Methods

The variance of performance noted for the display methods tested proved to be insignificant. That is, the variance for speed and accuracy between the four display methods was minimal. The raw scores for the Side-by-Side display method ranked slightly higher than the others; however the difference was less than the computed standard deviation. Given the small sample size (12 subjects for CD1 and CD2) the insignificance of variance was not a surprise.

Thus, the recommendation to provide more than one display method is supported on the basis of analyst preference versus statistical results. Based on the data extracted from the experiment questionnaires and proctor observations, the following conclusion was formulated: "The individuality of each analyst is a significant factor in determining the most favored display method". For example, although the Overlay Method #1 proved to be the most preferred, a subset of analysts preferred the Side-by-Side method. It appeared that the optimum method of display was highly situation-dependent. Factors such as feature density, type of feature, and characteristics of the geographic area in which the change occurred, had a significant effect on the analysts' ability to discriminate changes. Therefore, it is recommended that more than one display method be provided to support softcopy change detection in a production system. This would provide flexibility and enhance user acceptance of a softcopy system.

Data Digitization

The 256 LPI resolution is the recommended resolution based on the experiment results. The Analysis of Variance (ANOVA) for total patch time provided the mean time expended by the analysts for each map/chart patch. The mean time for each resolution was calculated. The mean average time per image was calculated by multiplying the 384 and 512 patch times by four (4) (there were four patches per image). The mean average image times for each resolution were as follows:

- 256 LPI: 24.2 minutes
- 384 LPI: 37.3 minutes
- 512 LPI: 40.1 minutes

As expected, the time expended per patch increased as the resolution of the digital map/chart data increased. The analysts were required to review four patches for the 384 and 512 LPI images. The 256 LPI image contained only one patch. Although the 512 resolution patches covered less geographic area than the lower resolutions, analysts did not spend a proportionately lesser amount of time on these patches. Each patch, regardless of resolution, was treated as an individual image, thus the total image time for the 512 resolution was largest.

As a result of time spent on each patch, the number of errors of commission and omission increased as the resolution increased. The number of changes not graded also increased; this was undoubtedly due to CFD misalignment which was more apparent at the higher resolutions.

Analyst preferences for the three resolutions were documented in the experiment questionnaires. The percentages of preference are as follows:

- 256 LPI: 4%
- 384 LPI: 44%
- 512 LPI: 52%

The majority of the analysts preferred the higher resolutions to support the requirements of the experiment. However, the timeline and accuracy data collected support the use of the lower resolution 256 LPI for most products (to the 1:50,000 scale). Higher resolutions would be recommended for 1:24,000 scale products and smaller.

Image Manipulation

The experiment analysts were provided the following toggle capabilities in the experiment:

- CFD Toggle (toggle vectoried CFD)
- Change Annotation Toggle (toggle MBRs)
- Map/Chart Base Toggle (toggle rasterized source)

Change Detection Experiments #1 and #2 tested the feasibility of using CFD toggle. It proved to be a valuable capability and is recommended for a production workstation. The subjects used CFD toggle as their primary change detection technique. Results of Change Detection Experiment #3 were consistent with Experiments #1 and #2 for this option.

The experiment subjects used the CFD toggle capability to create a flicker effect by holding the toggle key down on the keyboard. The flicker effect of CFD over the rasterized base made it easier to compare the CFD with the base. The analysts used the CFD toggle ten times more than the other toggles. It was also noted that the experienced analysts used the CFD toggle much more than the inexperienced analysts. The results of this experiment reinforce the need to provide the CFD toggle capability in a production environment. The other toggles tested should be evaluated to determine the cost impact of providing these capabilities, weighed against the added enhancement of workstation tools.

Zoom Factors

The zoom and scroll factor capabilities were used extensively in the experiments. The use of the zoom capability was inversely proportionate to the resolution. That is, analysts examining the 256 LPI resolution used the zoom capability twice as much as the analysts who viewed 512 LPI resolution patches. In addition, analysts viewing the 384 LPI resolution patch used the zoom capability approximately 1 1/2 times as much as those viewing the 512 LPI resolution patches (see Figure 3). This suggests that the analysts used the zoom capability to create a similar field-of-view image for all resolutions.

Eight zoom factors were provided to the experiment analysts for each resolution. It is noted that zoom factors one through five were used extensively during the experiments. The use of zoom factors six through eight was substantially less. This is due primarily to the fact that the quality of the rasterized graphic diminished at the higher zoom factors. The zoom function was implemented in hardware as a simple pixel replication. At zoom factors above five, a very strong aliasing effect occurred.

Given the heavy use of zoom capability, it is recommended that the capabilities be provided in a production environment. This recommendation is supported by the statistical analysis of subject performance and positive preference responses by the analysts.

Change Classification

The generic code assignment and look-up table based technique is the recommended technique for determining change applicability. The generic codes technique requires the analyst to classify the feature change and tag the change with the appropriate code. After the changes are coded, they are compared to a Change Applicability Matrix (CAM) that maps generic codes to applicable products.

The manual method tested required the analysts to review product-specification help files to aid in the determination of change applicability. In the experiment, a subset of five products was established. Timeline results of experiment subjects did not differ significantly. However, if the set of products was greater than five the analysts would have spent significantly more time using the product-specification method when contrasted with the generic code based method.

Accuracy, when contrasted with codification method, is the other important factor for change applicability. Change applicability cannot be performed accurately unless the changed feature is classified correctly. The experiment results indicated that the analysts which used the generic code method scored slightly higher than those who used the product-specification method.

In the product-specification method there are two possible sources of error. The first is the identification of the feature, and the second is the review of product-specifications to determine applicability. For the generic code method, the only source of error is changed feature identification. This assumes that the CAM can be validated to assure correct applicability.

The results of this experiment support the use of a generic coding method in terms of time and accuracy. In addition, the results emphasize the need to provide the tools necessary to assure correct feature identification.

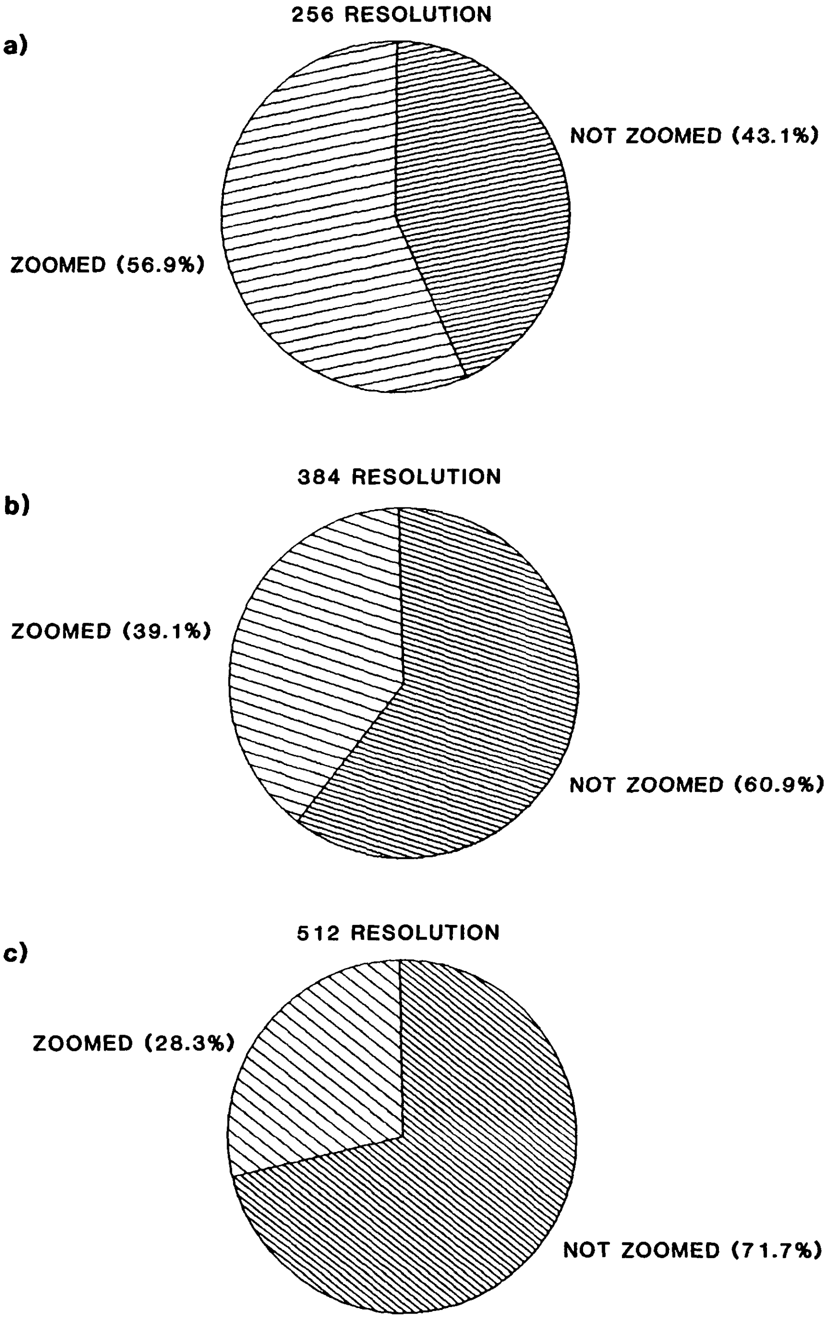


Figure 3. Zoom Usage