ANALOG GRAPHIC PROCESSING FOR 3-D TERRAIN DISPLAYS, PROFILES, AND ELEVATION LAYER TINTS

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This report briefly describes a computerized technique for transforming digital elevation data into gray-level-encoded film. This film is then used for near-real-time analog graphic (nondigital) processing for the display of terrain perspectives, profiles, and elevation layer tints. This report concludes that this approach offers considerable potential, at base and/or field levels, for producing special map graphics, displays, and analyzing terrain conditions for line-of-sight problems or nap-of-the-earth flight plans.

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PREFACE

Authority for conducting the effort described in the report is contained in Project 4A762707A854, "Military Geographic Analysis."

The experiments described were conducted by Lawrence P. Murphy, Project Engineer, and Edward G. Trelinskie, Computer Equipment Analyst. This task was performed under the general direction of Mr. Bernard B. Scheps, Chief, Technology Development Branch, and Mr. Alphonse C. Elser, Chief, Geographic Information Systems Division.

The authors wish to acknowledge the invaluable work of Dr. Bryce L. Schrock, Advanced Technology Division, Computer Sciences Laboratory, in developing computerized techniques for processing and printing elevation data as gray-level-encoded information on film. Without this transformation of data, the effort described in this report could not have been accomplished.

The work was performed during the period of March 1975 through April 1975.

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I. INTRODUCTION

Introduction. A considerable amount of interest has been expressed by military and civilian personnel that use terrain data and maps for a technique that rapidly depicts elevation data as terrain profiles and as oblique perspective views. To date, the emphasis has been placed on time-consuming and tedious manual techniques, or on costly computer-processed terrain displays.[1,2] This research paper reports on an analog graphic processing technique for the real-time generation of terrain perspective views and profiles when terrain data are available as gray-level-encoded information on film. Although analog in nature, the technique described in this report relies on computer processing to reformat the digital terrain data into a gray-level-encoded input film. As a fallout of this research effort, a technique for extracting elevation layer (gradient) tints was also devised.

Objectives. The objectives of this work were twofold:

1. To demonstrate that terrain (elevation) data can be satisfactorily gray-level-encoded (formatted by a computer) and printed in linear gray levels on film for subsequent analog (TV) processing and display.

2. To confirm that analog processing of gray-level-encoded terrain data film(s) permits near-real-time generation of oblique perspective views and terrain profiles from any viewing direction or for any line segment in the TV-displayed map area.

Background. To date, requirements by land combat forces have not been formally documented for terrain model oblique perspective views, profiles, or determinations of line-of-sight (LOS) conditions. Statements of need have been made verbally by combat users at DOD conferences and at demonstrations and briefings for R&D tasks at the U. S. Army Engineer Topographic Laboratories (ETL). Although not formally accepted at this date, a general requirement for

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1 Richard A. Clark, "Computer Generated Profile Maps," Papers from the 1970 ACSM-ASP Technical Conference, 7-10 October 1970.
2 Kurt Brassel, James Little, Thomas K. Peucker, "Automated Relief Representation," Annals of the Association of American Geographers, Vol 64, Number 4, December 1974.

terrain relief sketches and landform guides is evolving through development and acceptance of special use topographic products (e.g., Special Infantry Support Products).

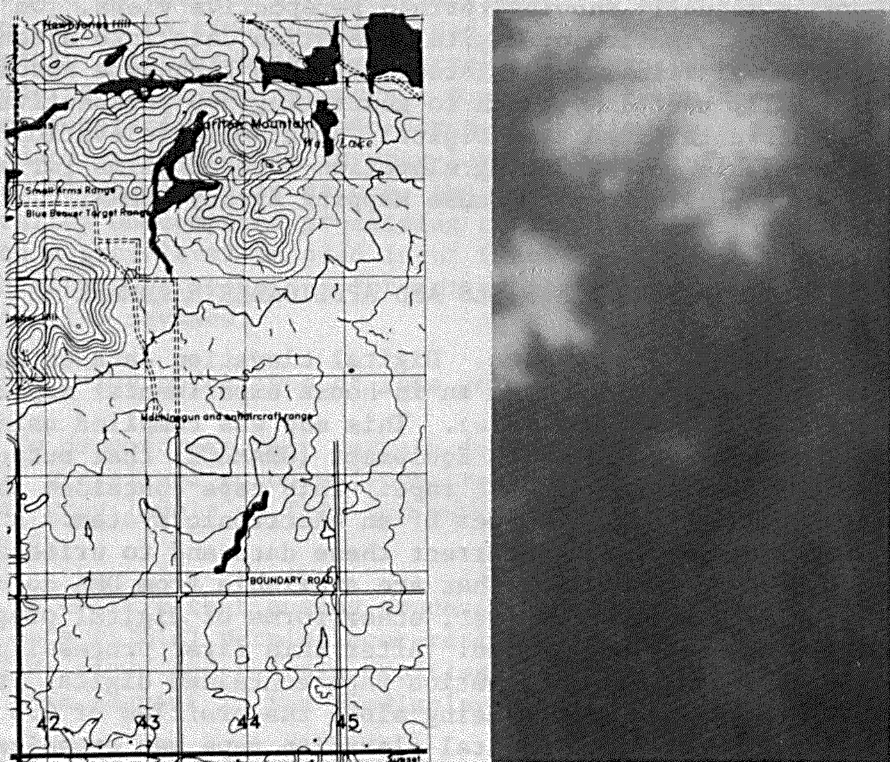
Using state-of-the-art components embedded in the ETL experimental Automated Image Data Extraction System (AIDES), it was observed that gray tones in a conventional aerial photograph could be displayed as a false three-dimensional (3-D) display of the terrain. From this observation, it was deduced that a transformed film input, with linear gray tones substituted for elevation data, would then promote a 3-D display actually showing terrain perspective views. On this basis, the transformation of digital elevation data into a test sample gray-level film was initiated. If this technique resulted in a potentially useful approach to generating 3-D perspective views, it was further determined that Digital Topographic (elevation) Data (DTD) is available for producing elevation-encoded films for a large number of maps published by Defense Mapping Agency (DMA).[3]

II. INPUT MATERIALS AND APPLICABLE HARDWARE

Input Materials and Preparation. Digital elevation data on magnetic tape were available at ETL from an in-house experimental map compilation (Cache, Oklahoma, 1:50,000 scale). This map was compiled using Universal Automatic Compilation Equipment (UNAMACE) that outputs digital profile data on magnetic tape. This tape contained the usual noise and occasional error spikes of an electronic system. A computer program was used to correct these data and to write a new smoothed tape. The DTD tapes that are available from DMA do not have this noise problem. However, other forms of digital preprocessing of the DTD tapes may be required. After this first processing step, the noise-corrected, Cache elevation tape contained digital profile spacing of 0.5 mm and point spacing along the profiles of 0.5 mm for the entire map area. This digital elevation tape was organized in an X-Y matrix with only the elevation value, Z, recorded.

The map area was then subdivided into small rectangular sections because of the size limitations of the digital film printing device. The elevation values for the map section designated as area 15 (figure 1) were accessed on the data tape, assigned (quantized) to a gray-level value of 0 to 63, and rewritten as a final gray-level-encoded magnetic tape. The final tape was organized in an X-Y matrix, with gray-level values in place of the Z data for map area 15 only.

3 Defense Mapping Agency, Catalog of Maps, Charts, and Related Products, General Information 3, Section 1, Jan 75.



NOTE: Due to reproduction processes, gray tones are incorrectly shown in the above elevation film.

Figure 1. Map Area 15 (reduced) and Gray Level Encoded Elevation Film

The gray-level-encoded data tape was then used to control the ETL digital film writing system, DICOMED, in writing the gray-level elevation film (figure 1). The elevation film was exposed point by point to permit the final film densities to range from the film fog base (approximately 0.02D) to 1.5D (diffuse density) for the highest to lowest elevations in that order. The digitally written film was developed using controlled photographic processes to maintain this gray-level range. This film density range was selected to allow for the best video (TV) scanning and display response. A generalized flow diagram of the ADP operations is shown in figure 2. Excluding data smoothing (not required for DMA DTD tapes) and film photographic processing, the total on-line computer (CDC 6600) processing time was approximately 2 minutes, or less than that for areas that are similar to the Cache Map, Test Area 15 (figure 1).

Applicable Hardware. Processing elements selected for analog graphic processing and displaying were originally a part of the ETL AIDES. AIDES is an experimental analog/digital image processing device for extracting, merging, and displaying data from multiple (four) gray tone or binary images. A description of AIDES has been published in a prior research note.[4] The free-standing processing elements that were reconfigured from AIDES for analog graphic processing and displaying are shown in figure 3 and are described as follows:

Input Elements. A vertically mounted Cohu television camera, Model 6150, acts as the primary input medium to the process. The function of this device is to raster scan a film image of gray-level-encoded elevation data, converting the film image to a composite video signal and transferring this signal along with synchronization signals to the processing elements. A mechanical stage that is capable of being rotated through 360 degrees and is illuminated by a Richards Model GFL 940 light table serves as a holding device for the film image.

Processing Elements. Processing the composite video signal encompasses certain tasks, such as the random selection of terrain profiles, the generation of variable perspective views, and the isolation of contiguous elevation layer tint bands. To extract terrain profiles the video cursor circuits contained within a Tektronix Video Hard Copy Unit, Model 4602 was used. This unit also served as a signal amplifier for the 3-D display module circuits. The isolation of contiguous elevation layer tints was accomplished by using signal thresholding (gray level slicing) techniques. The

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4 L. P. Murphy and Edward G. Trelinskie, "Preliminary Image Data Extraction Experiments with the Phase 1, Automated Image Data Extraction System-I," ETL-RN-74-7, December 1974.

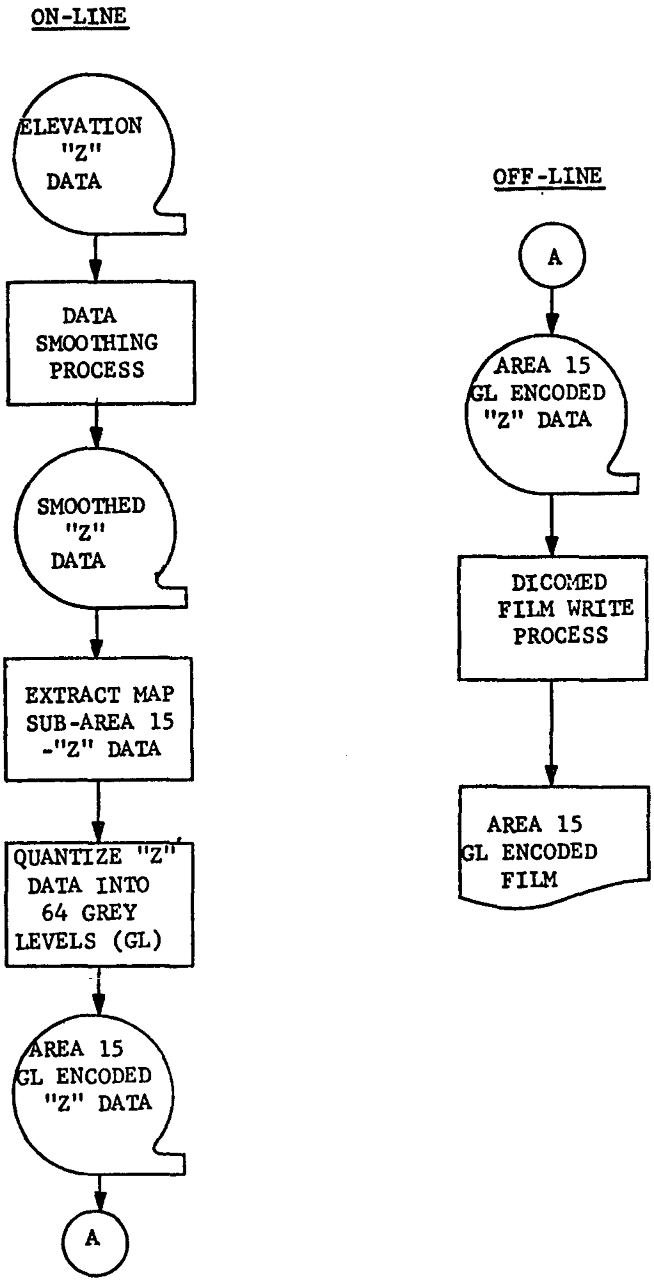


Figure 2. ADP Steps to Produce Elevation Encoded Film

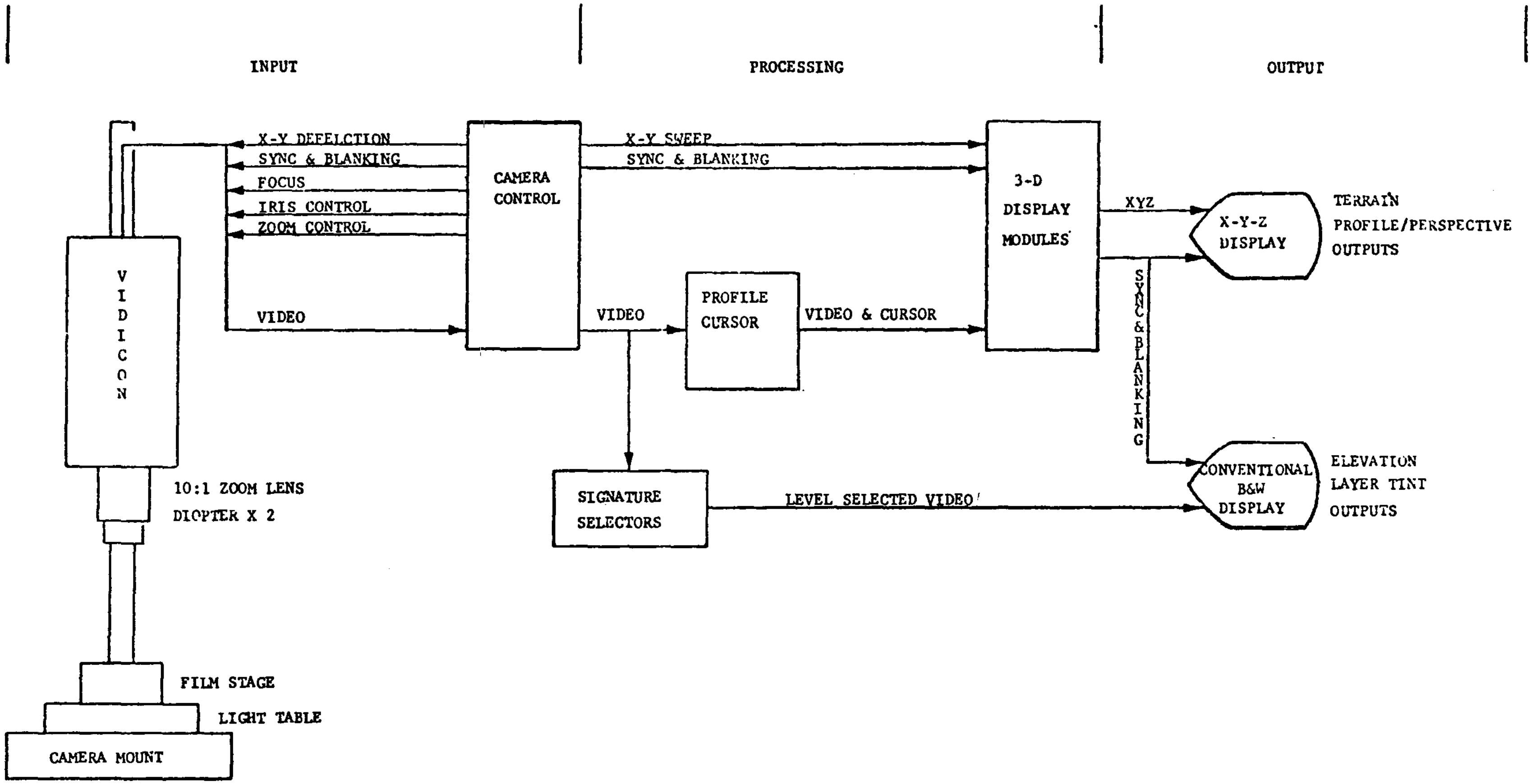


Figure 3. Analog Graphic Processing Elements

circuitry required to perform this function is contained within the AIDES Signature Selector/Level Selector assembly.

Generation of the variable perspective views was implemented by displaying the composite video on an XYZ monitor while establishing deflection control for the monitor with special raster forming circuitry. An XYZ monitor treats each video line like a densitometer trace and displays the entire image area as a closely packed series of parallel densitometer traces. The XYZ monitor will also display a gray-tone input image conventionally.

Output Elements. Two cathode ray tube (CRT) displays were used for viewing the results achieved through processing of the composite video signal. Terrain profiles and perspective views were displayed on a Hewlett Packard XYZ display, Model 1300A. A conventional Kintel monochrome TV monitor, Model DRM-8C, was used to provide a standard gray-tone display of the scanned input image and to display the binary (black and white only) elevation layer bands as generated from the composite video signal. The displayed results were photographed with a conventional still-film camera on Polaroid materials (Type PN).

III. EXPERIMENTS

Procedure. The elevation-encoded film for map area 15 was used at the light table for scanning by the TV camera. This single-film input was used as the source of video information for all experiments that were performed in the order that follows:

Terrain Perspective 3-D Displays. The light-table illumination level, the vidicon signal gain, and the display brightness and contrast were subjectively adjusted for the best appearance of the output at the XYZ display. The gray-level film was oriented under the vidicon to permit the displayed image to be in the conventional map reading position, that is, north at the top of the display. The vertical deflection of the 3-D display was adjusted so that the perspective view filled approximately 75 percent (three-fourths of full vertical sweep) of the display. At this point, the 3-D perspective view (figure 4) on the XYZ display looked quite similar to an oblique aerial photograph (30- to 40-degree depression angle). However, the display resulted in an oblique parallel perspective view rather than the convergent oblique view that is acquired with an oblique aerial camera. The video signal gain was subjectively adjusted to approximate a 5:1 vertical exaggeration of the relief along each horizontal line in the display. The output image at the XYZ display was photographed with Polaroid film (Type P/N). The gray-level elevation film was then rotated manually at the film stage to 45, 90, 180, and 270 degrees from the original north-south orientation (see figure 4). A Polaroid

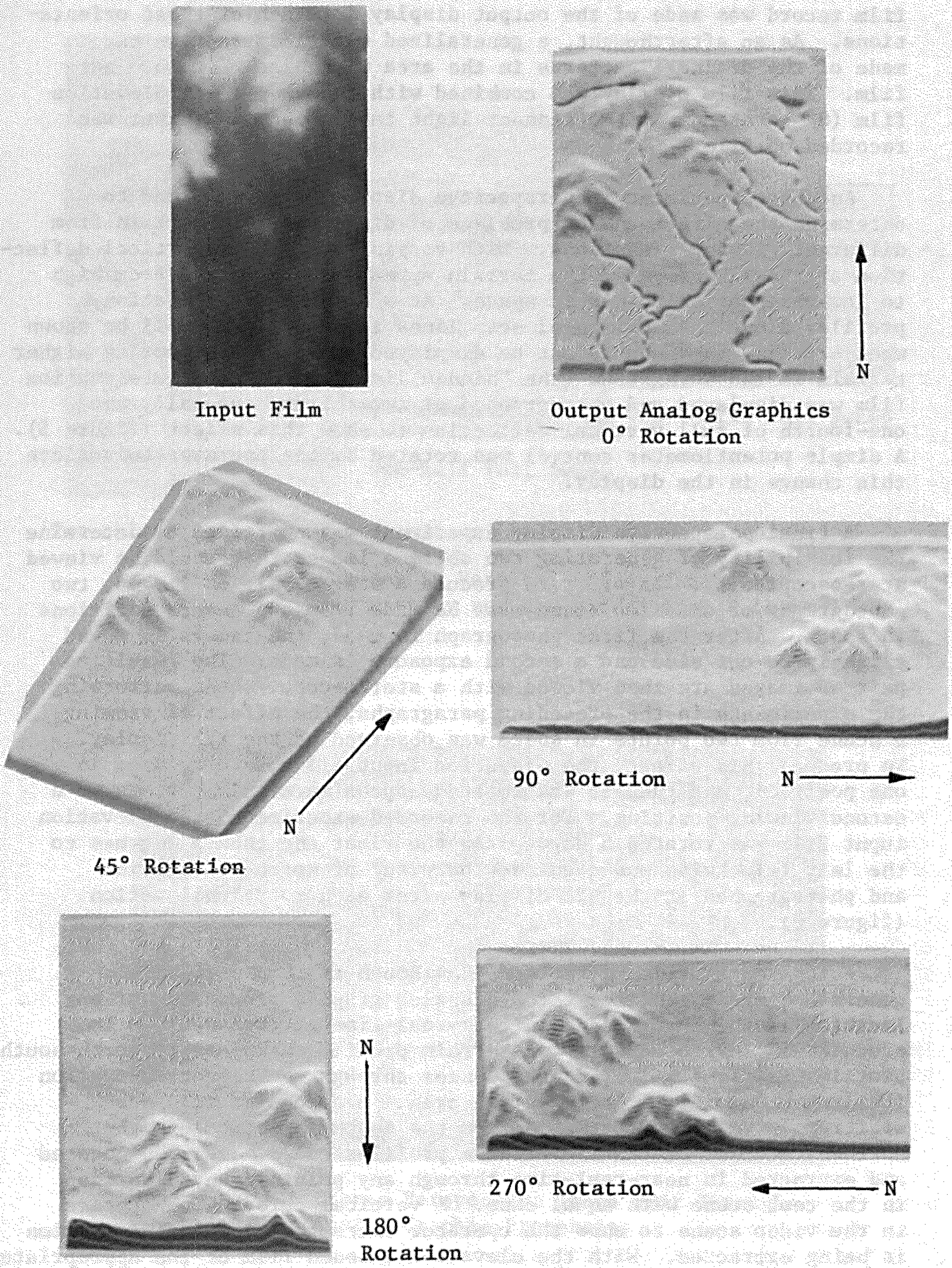


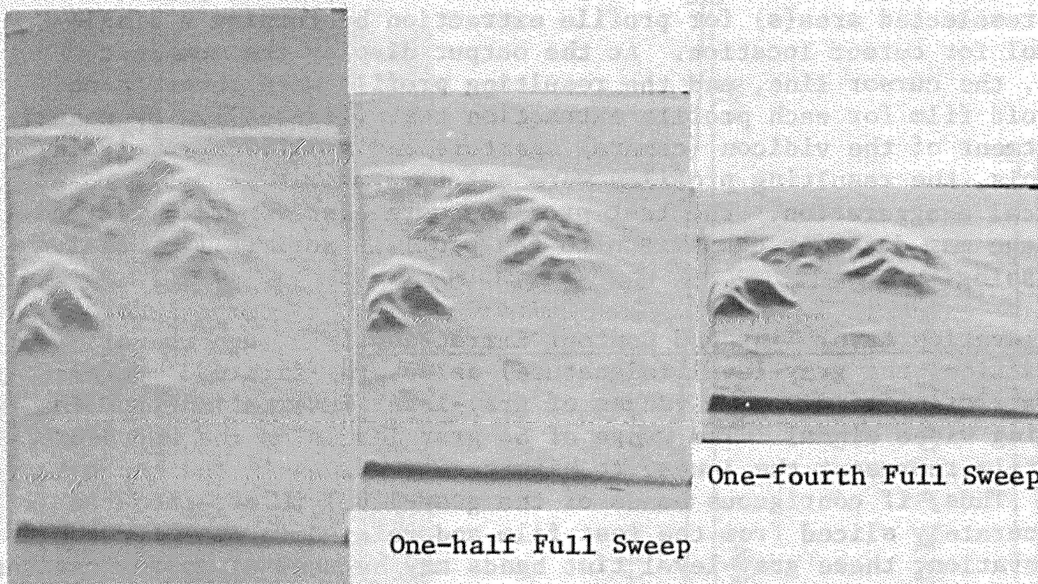
Figure 4. Oblique Perspective Views from Various Directions

film record was made of the output display for each of these orientations. As an afterthought, a generalized manual extraction was made of the drainage patterns in the area with black ink on clear film. This film overlay was combined with the gray-level elevation film (0° rotation) at the scanner light table, and the output was recorded on film.

Another experiment in perspective displays was performed to determine the effect and/or problems of displaying the terrain from different viewing elevations. With varying amounts of vertical deflection at the XYZ display, the terrain appears to be viewed from high to low observation points in space. At a low viewing elevation, profiles along the horizontal scan lines in the display will be shown when actually they should not be displayed because of obscuring higher terrain in the foreground (the "hidden line problem"). The elevation film was displayed and photographed at two-thirds, one-half, and one-fourth of full vertical deflection to show this effect (figure 5). A simple potentiometer control was rotated by the operator to achieve this change in the display.

A final perspective display experiment was performed to determine the feasibility of generating two oblique images that could be viewed stereoscopically. In order to produce a stereo pair of images, two photographs of the same scene must be made from two camera positions in space. After the first photograph is made, the camera is moved slightly to one side and a second exposure is made. The resulting pair of images are then viewed with a stereoscope. When performing the experiments in the preceding paragraphs, the effect of viewing a scene from two points in space was observed at the XYZ display. To produce this effect, the elevation input film was displayed in one position, and then it was rotated approximately 10 degrees to a second viewing position. For the recorded experiment, the elevation input film was rotated 5 degrees to the right and then 5 degrees to the left (clockwise and counter-clockwise) of north orientation and photographed at the XYZ display after each rotational motion (figure 6).

<u>Automated Profile Extraction</u>. Although it is possible to generate terrain profiles through analog graphic processing at any location in the input scene in near-real-time, it was decided to process and to record only two terrain profile examples. A north-south profile was first selected that passes through the highest elevation (Carlton Mountain) in the map test area. A second profile was arbitrarily selected that runs from the southeast corner to the northwest corner of the map. These profiles could have been located and extracted in near-real-time through any point in any direction in the test scene with equal ease. A vertical cursor line appears in the video scene to show the operator where the profile information is being extracted. With the elevation-encoded film at the appropriate



One-fourth Full Sweep

One-half Full Sweep

Two-thirds Full Sweep

Figure 5. Changes in Vertical Deflection of the 3-D Display and the Hidden Line Problem

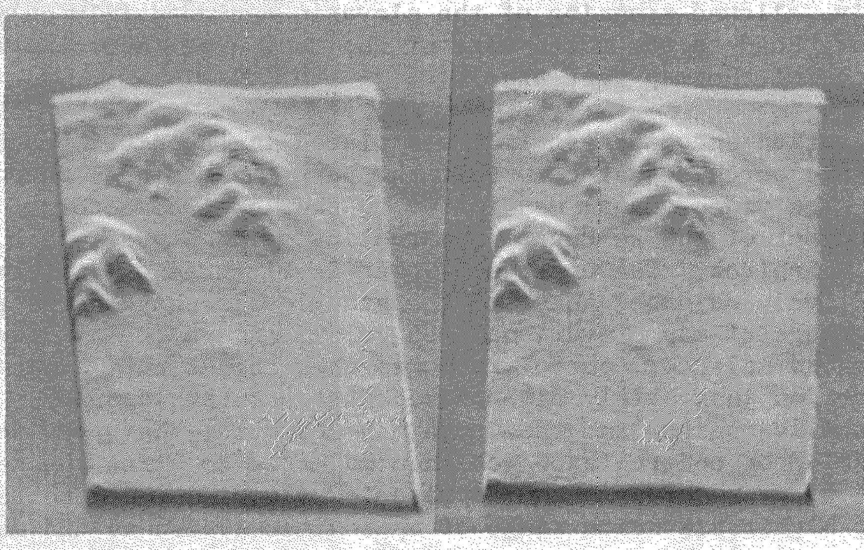


Figure 6. Stereo Perspective Image Pair Through Analog Graphic Processing

orientation angle on the film stage, the line cursor was placed over the preselected area(s) for profile extraction by turning a single control for cursor location. At the output display the combined 3-D image, the cursor line, and the resulting profile were recorded on Polaroid film for each profile extraction test (figure 7). By manual adjustment of the vidicon (camera) aperture and amplification (gain) controls, the resulting profiles were set to approximate a 5:1 vertical exaggeration. The test profiles were also manually plotted from the map data for comparison to the profiles derived from analog processing.

Elevation Layer Tint and Contour Extraction. Through manual interaction, the gray-level (signature) selectors (figure 3) permit the extraction of discrete ranges of gray-level information from the incoming video signal. The range of 64 gray levels on the encoded test film represent the lowest to highest elevations in the map test area. Thus, if contiguous bands of the gray-level information can be accurately sliced from the test film and related to specific ranges of elevation, these gray-level tint bands may be used as approximations of elevation layer (gradient) tints.

Preliminary experiments in processing the video signal from the Cohu camera (figure 3) indicated that this camera produced a video image of poor (nonlinear), gray-scale shading characteristics. Therefore, scanner number two of the AIDES four-channel scanner, which was known to produce a linear response, was used to scan the elevation-encoded test film for the layer tint extraction experiments. However, AIDES scanner number two accepts 70-mm or smaller film formats and, consequently, allowed scanning of the elevation-encoded film only from Boundary Road to the north edge of the test area (approximately three-fourths of the map test area).

The elevation-encoded test film was placed in the AIDES scanner and the light source adjusted so that the peak video signal was at 1.0 volts. The video signal was routed to the level selectors. In turn, the output of the selectors was routed to the Kintel black and white TV monitor. The upper and lower level threshold selectors were subjectively adjusted to slice the gray levels that best approximate the lowest range of map elevations (365 to 395 meters). The lower level threshold selector control knob was then turned until the gray-level extraction just barely disappeared at the output display. By observing the TV monitor and the Cache map contours, the upper level threshold selector control knob was then adjusted to slice the next lighter set of gray tones, which represented all picture elements in the next higher elevation range of approximately 395 to 425 meters. This technique was used sequentially to slice contiguous elevation layer tints of approximately 30 meters of elevation for the map test area. Six contiguous elevation layer tints were extracted and recorded on Polaroid film for the map test area (figures 8 through 10).

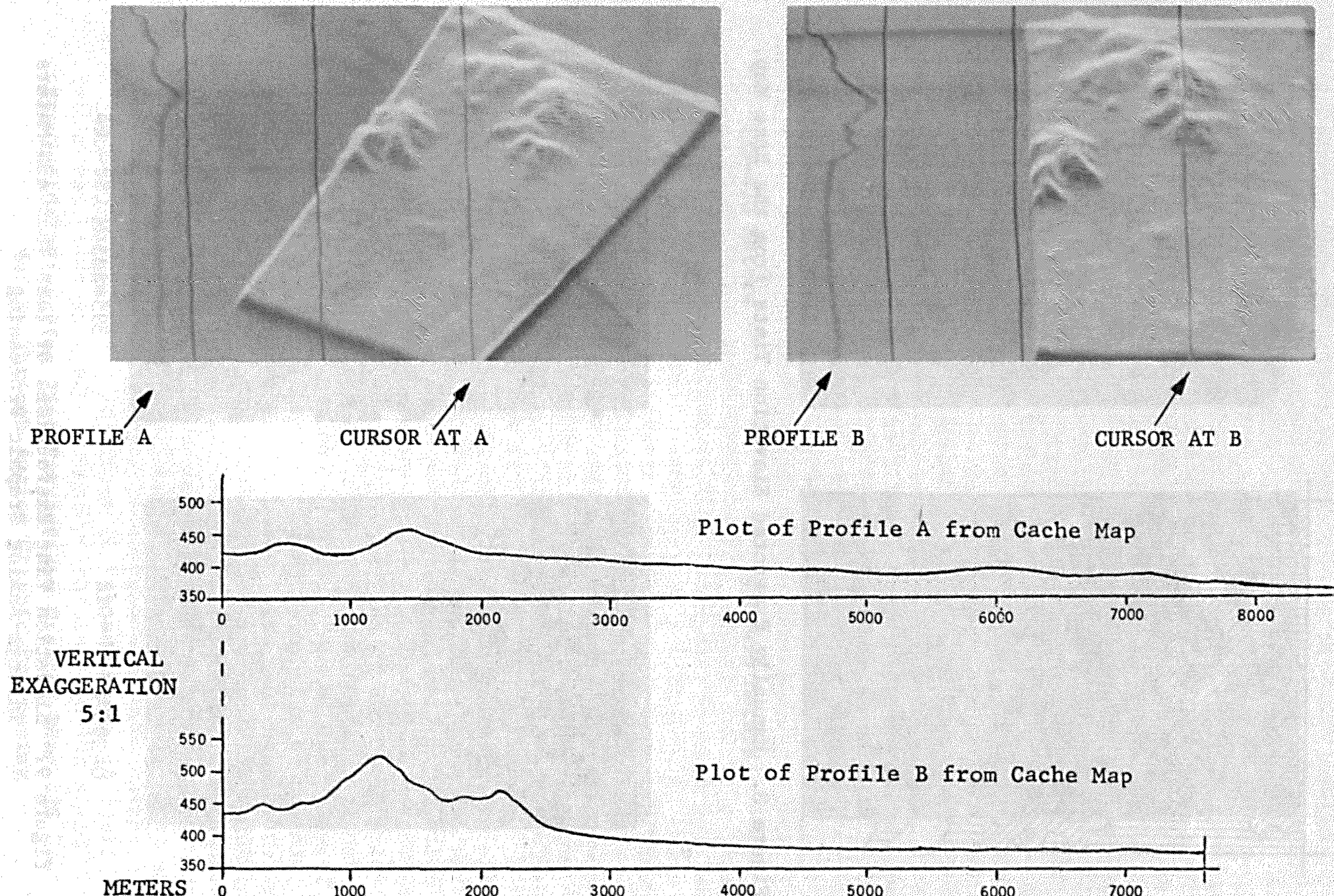


Figure 7. Analog Graphic Terrain Profiles Versus Manually Plotted Profiles

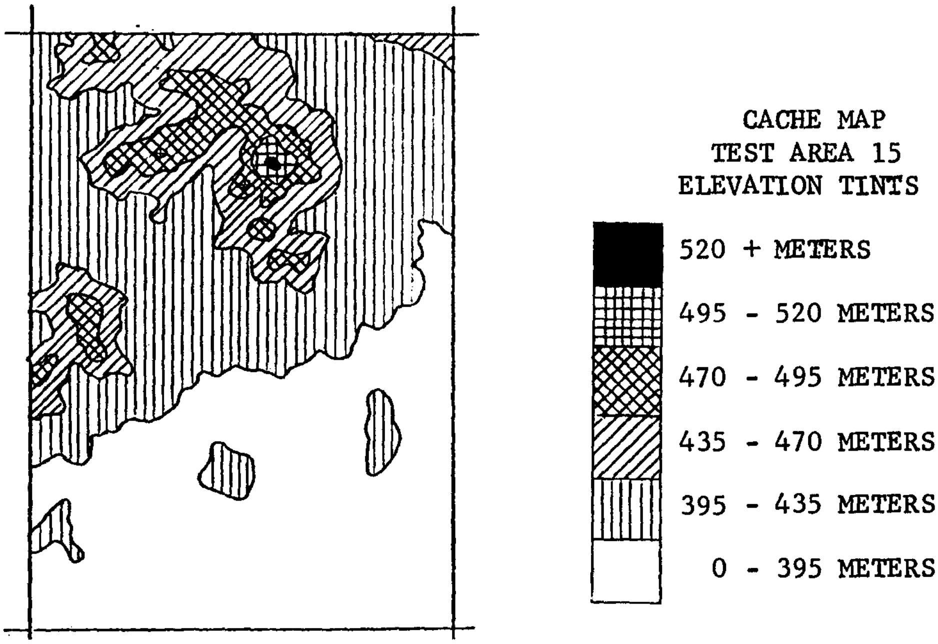
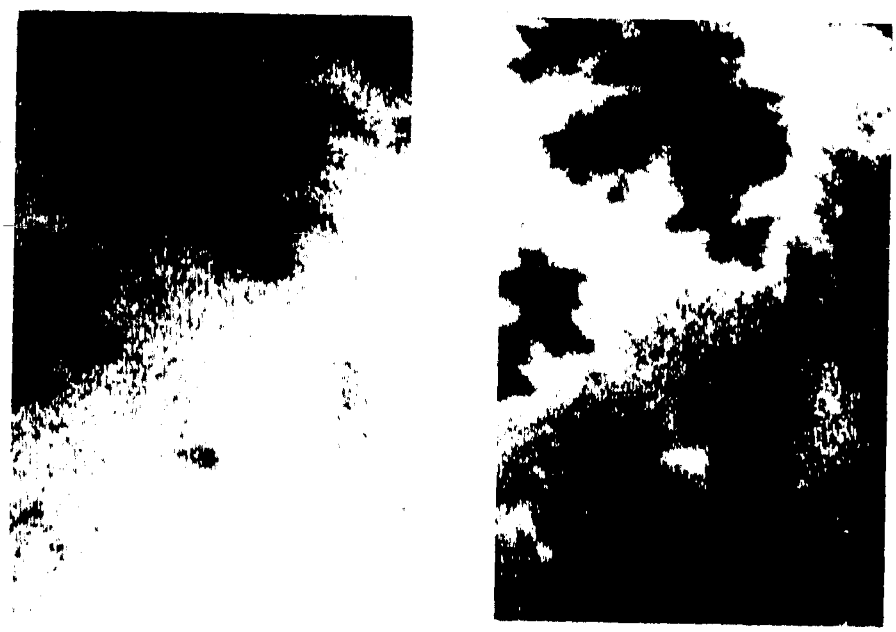


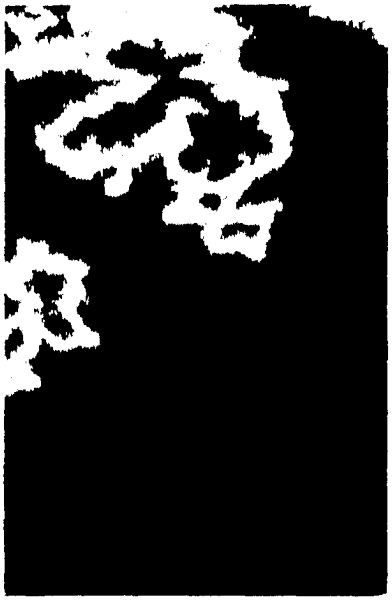
Figure 8. Manually Extracted Elevation Tints from the Base Map.



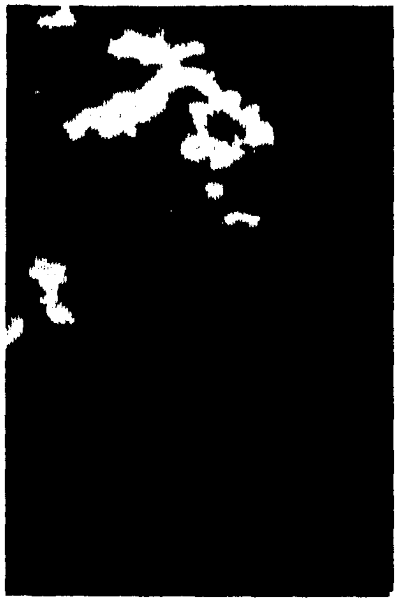
0-395 M

395-435 M

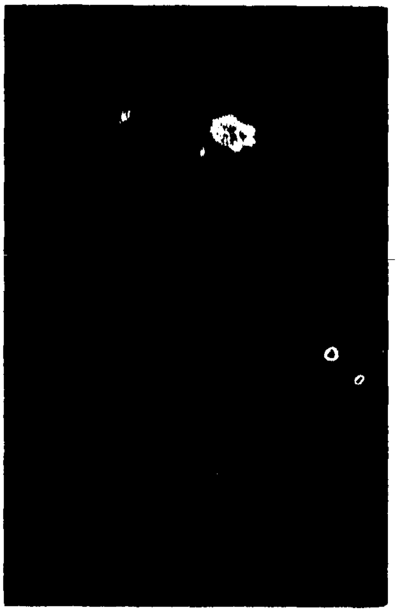
Figure 9. Elevation Tint Extractions of Less Than 435 Meters Through Analog Graphic Processing



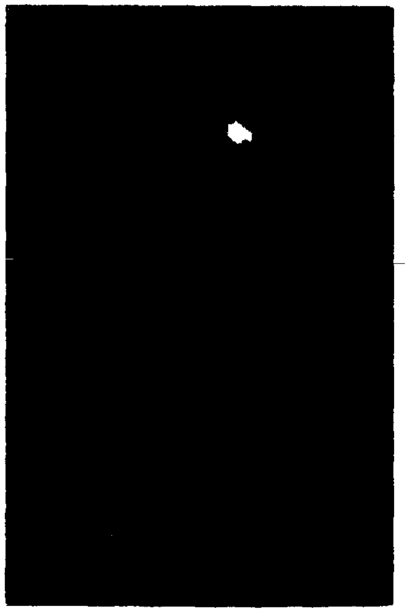
435-470 Meters



470-495 Meters



495-520 Meters



520+ Meters

Figure 10. Elevation Tint Extractions Greater Than 435 Meters Through Analog Graphic Processing

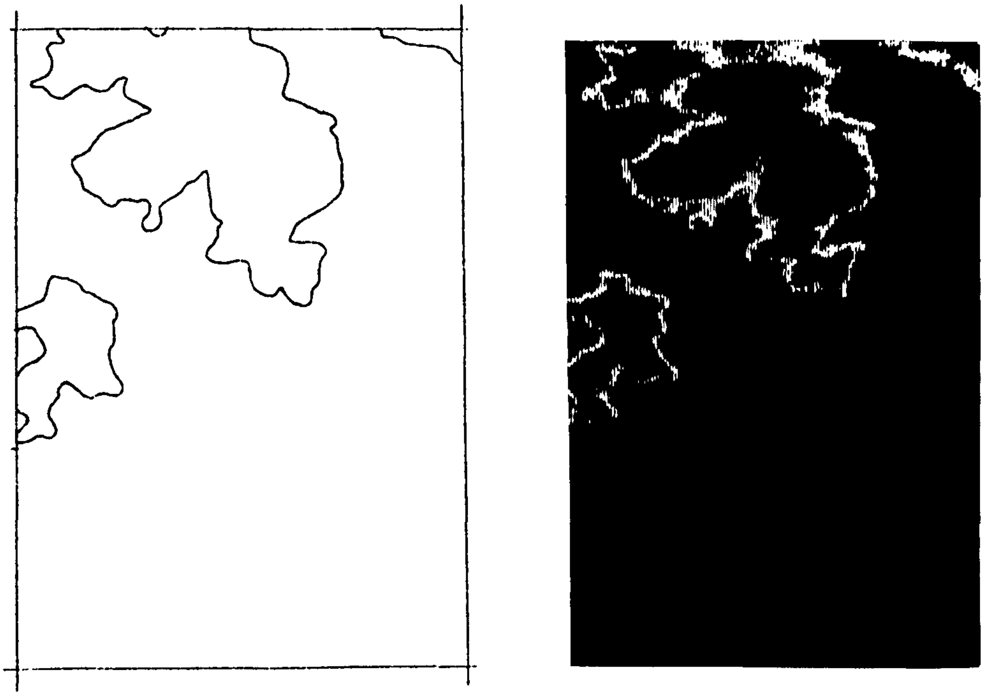
The last experiment performed was to determine if contour approximations could be made by further near-real-time processing of the above elevation layer tint extractions. The two elevation layer tints for elevation ranges of 395 to 435 meters and 435 to 470 meters were made slightly larger by a minor readjustment of threshold controls. The video signals from the elevation encoded film were routed in parallel to two two-level selector units (four such units are available in AIDES). With the readjusted thresholds on the two-level selector units, the resulting layer tints contained a small area of overlap between 430 to 440 meters of elevation. The two binary output signals from the level selector units were then passed synchronously through a logical AND gate (Boolean algebra)*. A logical AND gate accepts two or more binary input signals and only outputs a "one" (image point in this case) when binary points entering simultaneously are all ones. In set notation terms, the AND function is the equivalent of finding the intersection ($\cap$) of two or more sets of data. The final result of this process is the extraction of only the common points in the two overlapping elevation layer tints or, in the above experiment, a narrow width elevation layer tint that approximates a contour between 430 and 440 meters. The output of the AND function was displayed on the TV monitor and recorded on Polaroid film (figure 11).

Results. The results of these experiments are shown in figures 4 through 11. Each of the figure titles indicates the type of analog graphic processing that was performed. Figures 7, 8, and 11 show manually plotted terrain profiles, elevation layer tints, and contours for comparison to similar output graphics that were extracted through analog processing. All analog output images were recorded with a Polaroid camera. These still-film photographic records of the output display that operates at TV rates cannot possibly convey to the reader the degree of near-real-time interaction that an operator can exercise in operating the system. As previously stated, the operator can manipulate simple controls in near-real-time to vary the viewing distance (scale), the look angle, the viewing direction, the vertical exaggeration, the profile location, and the elevation layer tint extraction(s).

IV. DISCUSSION

Evaluation. The results obtained from the preceding experiments are evaluated mainly by subjective analysis. Where profiles, layer tints, and contours can be extracted from the map test area, these

* A complete explanation of electronic logical processing and key to Boolean algebra can be found in most computer technology textbooks.



Extrapolated 435 M Contour ~~from Map~~

Approximated 435 M Contour ~~from Analog Processing~~

Figure 11. Map Contour Compared to Contour Approximation Obtained Through Analog Graphic Processing

graphics are visually compared to the system's outputs. For future work, a quantitative analysis of these outputs should be performed to determine the accuracies and limitations of analog graphic processing of terrain data. The chief purpose of this work was to demonstrate the system's potential for interactive near-real-time processing and display when the input is an elevation encoded film. Generalized comments concerning the experimental results are as follows:

Elevation Encoded Film. The gray-level elevation encoded film (figure 1) was scanned with a microdensitometer to determine if the gray levels were printed on the DICOMED system as specified for the density range of film fog base (approximately 0.02D) to 1.50D. The elevation film was scanned to produce a single densitometer trace through the darkest part of the film (lowest elevations) and through the lightest part of the film (highest elevation). The density range of the film was determined to be 0.18D to 1.30D. This density span is slightly less than specified for printing the film, but it produces acceptable display results as exemplified by the analog processed outputs in figures 4 through 11. It was not determined whether the gray-level points in the elevation film were truly linear in gray-level representation. This could have been determined with ease if a gray-level step wedge had been printed at the edge of the gray-level film at the time the elevation film was made with the DICOMED system.

Terrain Perspective 3-D Displays. The perspective displays of terrain from various directions (figure 4) depict the terrain reasonably well when compared to the map contour information. However, one noticeable fault is the gross vertical exaggeration of the relief when the input elevation film is rotated to 90, 180, and 270 degrees (figure 4). The video signal amplitude should have been lowered to prevent excessive vertical exaggeration. The video signal gain was probably not maintained at the same amplification level for all perspective views in this illustration or the amplification drifted during the generation of the displays. A means for obtaining constant signal outputs and for calibration must be devised. Again, the incorporation of a calibration gray-level step wedge on each film chip may be the required method. In considering that test area 15 represents a semi-arid geographical region, the technique of adding a black line drainage overlay to the elevation-encoded film produced a highly acceptable presentation of locally incised drainage patterns. However, this hastily drawn drainage plate was not extracted from the base map but was drawn by apportioning drainage alignments and positions to a reduced drawing of the UTM grid. Consequently, the errors in drainage alignment, as related to topography at the perspective display, are caused by inaccuracies in the above drainage plate. The drainage overlay could have been printed on the film through ADP and DICOMED processing if the drainage data had been digitized on magnetic tape. In the event that the analog graphic processing described in this report becomes a requirement in the future, a means of symbolizing and displaying planimetry with the perspective terrain display will be needed.

The results of varying (reducing) the vertical sweep deflection at the 3-D display are shown in figure 5. As the vertical sweep is reduced, the perspective image appears to be photographed from a lower altitude at an oblique angle. When the deflection sweep is less than one-half of full vertical sweep, hidden profiles occur that are caused by lower elevations occuring behind higher foreground terrain. The occurrence of these hidden lines in the 3-D terrain display causes ambiguous relief effects and/or falsely highlighted ridges in the display. Consequently, a reduction of the 3-D vertical sweep to less than 50 percent is not recommended with the present brassboard configuration of hardware. However, after these experiments were performed, an American manufacturer has published sales literature that advertises specialized analog graphic 3-D display building block modules (processing circuits). This manufacturer, Optical Electronics, Inc., claims to have circuitry that will remove hidden lines from many images before the image signal reaches the display. Other processing circuits are offered by Optical Electronics, Inc. that they claim will generate oblique convergent grids and images, binocular (stereo) images, and electronically rotated and translated images.

Figure 6 shows the stereogram that was produced by photographing the display twice with an angular displacement of 10 degrees of the perspective image. This stereogram was examined by three photointerpreters who concluded that the image pair provided a good stereo relief presentation. It is interesting to note that Carlton Mountain appears higher in the stereo image than all other surrounding peaks. Since the vertical exaggeration in this stereo pair is consistent from the image foreground to the horizon, it is easier to visually discern which elevation is the highest in the scene. If this image portrayed an oblique convergent perspective with diminishing vertical scale toward the horizon, the highest peak in the area would be more difficult to identify. In this respect, the stereo image pairs that are made from parallel perspective images have advantages over convergent oblique images. On the gently sloping valley floor in the image foreground, several small ridges can be seen stereoscopically and can be related to the elevation tint for 395 to 435 meters. This elevation tint is shown in figure 9 of this report.

Automated Profile Extraction. The two profiles that were extracted through analog processing and through manual plotting are shown in figure 7. Analog profiles are shown at A and B in the gray-tone images in the top half of the illustration; manually plotted profiles from the Cache map are shown in the lower half of the illustration. Since the perspective images were displayed at two-thirds of the vertical scan on the XYZ display, the horizontal scale of the resulting analog profile, which is shown vertically (on end) in the display, is compressed. There are also some horizontal deflection anomalies that show in the display. This horizontal deflection (TV) problem caused some distortions in the lines that appear vertically in the scene and caused some distortions in the analog output profiles at A and B. However, the analog profiles show the same terrain elevation deviations that occur in the plotted profiles. For future tests, the cursor should be positioned over the terrain perspective view (one-half to three quarters scan) at the display for ease of cursor location. The display should then be changed to full vertical deflection (nonperspective display) scan, and the analog profile should then be recorded. Using this procedure, the analog profile would not contain the scale distortion (compression) along the horizontal axis of the output profile. After most of this report was drafted, this processing technique was tested, and it does indeed produce an analog profile that matches the plotted profiles in X and Y scale. It was observed during the profile extraction experiments that the profile cursor can be swept across the terrain display by turning one control knob. The highest and lowest elevation points can be quickly spotted by the analyst while observing the changes in the analog output profile during this excursion of the profile cursor. While observing these profiles at any location in the input scene, a quick approximation of line-of-sight conditions can be made. This operator-analyst role may also be useful in preplanning nap-of-the-earth aircraft flights. Obviously, a straight edge applied to a profile will provide intervisibility and masking information.

Elevation Tint and Contour Extractions. Figures 8 through 11 show analog graphic extractions of elevation tints that were determined both manually and by machine, and the illustrations also show an approximation of a single contour. Figure 8 contains an elevation tint map that was manually extracted from the Cache map test area. These manually derived elevation tints were purposely extracted to match the approximate range (30-meter interval) of elevation tints that were subjectively extracted through machine assisted processing (figures 9 and 10). When comparing the analog graphic elevation tints to the map elevation tints, only minor edge differences are noted for elevation tints representing more than 395 meters of elevation. In fact, only minor touchup of the Polaroid film outputs would be required to make color separation negatives to reproduce a small-scale special graphic from these films. The subtle changes in gray levels in the southern half of the elevation film have made it difficult to separate the 0- to 395-meter and 395- to 435-meter elevation tints. Consequently, some overlap has occurred at the interface of the two lowest elevation tint extractions that would require human judgement and considerable touchup to make small-scale color separation negatives from the Polaroid film records. The Polaroid negatives of the extracted analog graphic elevation tints were registered over a light table and analyzed as part of this evaluation.

Because of the subjectivity of manually setting the gray-level threshold selectors, the analog graphic elevation tints vary in width from 25 to 40 meters instead of the desired elevation tint width of 30 meters. These variations could have been avoided if a gray-level step wedge had been printed at the edge of the elevation encoded film, which related the gray-level steps to elevation. This step wedge could have been selectively sampled with the level selectors for the extraction of a discrete range of gray levels (elevations), and that range of gray levels then automatically extrapolated through the remaining part of the elevation encoded film. Another means of extracting linear (equal width by elevation) elevation tints would be to use a processor, such as the Antech Densicolor Image Processor. The Antech processor automatically quantizes the image signal into 10 linear equidensity slices and then generates a 10-color map of these data on a color TV display. Aside from the Antech system, other analog image processors that perform this function are available on the open market.

The results of near-real-time logical processing to extract an elevation contour from the analog graphic elevation tints are shown in figure 11. The resultant broad width contour is strikingly similar in its shape characteristics to the extrapolated 435-meter contour from the base map. However, the variability of the width and the occurrence of several breaks in the resulting analog graphic contour prevents the direct use of this output as a finished map contour. This analog graphic process and output may be used for other terrain analysis purposes that are still undefined. For instance, the width of this machine processed contour and the width of the foregoing elevation tint can be associated to terrain slope. That is to say that an area of steep slope will have a narrow contour band and an area of gentle slope, a broad band. However, a means must be developed for quickly slicing areas of equal slope or for finding physically equal measures of elevation tint width on the output analog graphics.

Other Processing Concepts and Hardware Options. The basic premise for performing the analog graphic processing described in this report is that a cost effective method can be made available for converting array formatted digital data (elevation or other data) into gray-level encoded films. A file of gray-level encoded films would be compiled at base-plant level with a large digital system. This film file would then be transferred to a field-level unit for interactive analog graphic processing and display. Many configurations and uses of a small analog graphic processing console can be envisioned as follows:

Processing Concepts. The generation of displays, special purpose terrain graphics, and profiles for use in analyzing line-of-sight and nap-of-the-earth flying conditions has been demonstrated in the foregoing work. By magnification (TV zoom) of small areas of the elevation film and subsequent large-scale profile extraction, it may be possible to perform terrain analysis that would be useful for considering wire-guided antitank missile deployment or for antitank missile avoidance. Level slicing of the elevation film could also be useful in military construction analysis to quickly find terrain areas that are subject to inundation when impounding dams are constructed. With the addition of a small analog processing module, the potentially flooded areas can also be measured in near-real-time.[5]

If other input nonelevation data files are located and converted to gray-level encoded film, analog graphic processing for other displays and outputs can be envisioned. For example, a gray-level film that represents built-up area roof surfaces by elevation could be used to provide a series of multidirectional perspective views and stereo image pairs that would be of possible value in radar simulations and in special urban map preparations. A gray-level encoded film that represents population distribution, temperatures or other classic geographic information could be used to provide displays of the type described in this report. This, of course, depends on the cost of making the gray-level film transformations. Many other uses of analog graphic processing can be envisioned by both the military and civilian readers of this report.

Hardware Options. The ETL brassboard hardware configuration (figure 3) contains a minimal set of analog processing elements for performing the experiments described in this report. The ETL brassboard system could be easily housed in space equivalent to one-half of a conventional desk with the light table, TV camera, and displays mounted on the upper desk surface. Optional elements to quantize automatically and to color-code the elevation tints, the several microchip circuits for Boolean logical processing, and the video planimeter would require a slightly larger console cabinet. A review of existing off-the-shelf, commercially made, analog graphic processing modules would, no doubt, result in the purchase of several

5 L. P. Murphy and W. W. Abbey, "An Automated Technique for Measuring Built-up Urban Areas from Map Graphics Through Analog Image Processing," ETL-0012, May 1975.

small circuit boards (see page 21). The overall size and function of the system would vary with the analog processes and the display requirements of the user. Provided that gray-level encoded elevation films or other data encoded films are made available, this conceptualized system could be incorporated into systems proposed for development (e.g., Topographic Support System).

In the event that a more sophisticated system is required, a hybrid (analog and digital) system could be designed that would contain a microcomputer. Existing microcomputer based systems, such as the Tektronix Digital Processing Oscilloscope, could be interfaced with the present analog elements to perform digital storing, manipulating, and plotting of the terrain profiles. An X-Y digitizer could also be interfaced and used for making a rapid determination of distances on maps, graphics, and aerial photographs, which are analyzed at a small layout area on the systems console.

V. CONCLUSIONS

It is concluded that

1. Array formatted digital terrain information can be digitally processed and printed in gray-level codes on film that is suitable for analog graphic processing and displaying at TV rates.

2. Analog graphic (nondigital) processing of gray-level encoded film results in the near-real-time generation of displays of terrain perspectives, profiles, and elevation layer tints.

3. State-of-the-art analog graphic processing offers considerable potential for analysis of terrain conditions for line-of-sight problems or nap-of-the-earth flight planning.