Technical Paper 347

LEVEL II

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AD A064264

MISSION/DATA-BASE IMAGERY CORRELATION TECHNIQUES (M/DICT)

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HUMAN FACTORS TECHNICAL AREA

U. S. Army
Research Institute for the Behavioral and Social Sciences

October 1978

U. S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: Technical Paper 347	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): MISSION/DATA-BASE IMAGERY CORRELATION TECHNIQUES (M/DICT)		5. TYPE OF REPORT & PERIOD COVERED: Final Report, 1 May 1973 thru 30 April 1974
		6. PERFORMING ORG. REPORT NUMBER: FR74-1497
7. AUTHOR(s): E. Sewell, Raytheon Company/Autometric; A. Harabedian, Human Factors Research, Inc.; and T. Jeffrey, ARI		8. CONTRACT OR GRANT NUMBER(s): DAHC19-73-C-0050
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Raytheon Company, Equipment Division, Boston Post Road, Wayland, Massachusetts 01778		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62106A, 2Q162106A721, 00, 006
11. CONTROLLING OFFICE NAME AND ADDRESS: Department of the Army, Office of the Assistant Chief of Staff for Intelligence (DAMI), Washington, DC 20310		12. REPORT DATE: October 1978
		13. NUMBER OF PAGES: 56
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): U.S. Army Research Institute for the Behavioral and Social Sciences (PERI), 5001 Eisenhower Avenue, Alexandria, VA 22333		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: --

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Coordinate determination; Stereoscopic data-base photographs; Imagery correlation; Analytical Photogrammetric Positioning System (APPS); Target acquisition; SLAR imagery; IR imagery; Target transfer; Television display; Analytic transformation program

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Analytical Photogrammetric Positioning System (APPS) was developed to determine accurate target location data. APPS operators transfer target locations from mission images to a vertical data-base photograph in determining target coordinates.

The speed and accuracy with which experienced interpreters of side-looking radar, infrared, and television images transferred annotated locations

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20. (continued)

from such sensor images to a vertical data-base photograph were determined. Annotated locations used were A-Type (those on or near a terrain feature identifiable on mission and data-base images) and B-Type (those 200 or more meters distant, on the ground, from such mutually identifiable features). Transfer techniques were of two kinds: (1) direct transfer in which visual correlation of mission and data-base images was used; (2) indirect transfer where the required point was transferred using a photogrammetric transformation method employing auxillary points that were mutually identifiable on mission and data-base images.

Results from nine interpreters are summarized below:

PROPORTION OF TRANSFERS BY ERROR RANGE (METERS)

Transfer Technique	A-Type Locations 25%	50%	75%	B-Type Locations 25%	50%	75%
Direct	0-21	0-34	0-52	0-39	0-75	0-130
Indirect	Same as above			0-35	0-54	0-64

The improved accuracy of the indirect method for B-Type locations requires more time. Direct transfer required about 1.3 minutes per target on the average while indirect transfer per target on the average was five times that amount or 6.5 minutes per target.

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Office, Deputy Chief of Staff for Personnel
Department of the Army

October 1978

Army Project Number
2Q162106A721

Contract DAHC19-73-C-0050
Surveillance Systems

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FOREWORD

The Human Factors Technical Area is concerned with the demands of the future battlefield for increased man-machine complexity to acquire, transmit, process, disseminate, and utilize information. The research is focused on the interface problems and interactions within command and control centers and is concerned with such areas as topographic products and procedures, tactical symbology, user-oriented systems, information management, staff operations and procedures, and sensor systems integration and utilization.

One critical aspect of intelligence information from aerial sensor is the accurate location of targets. Recently, the Army has developed the Analytical Photogrammetric Positioning System (APPS) which provides an improved capability for target positioning. However, there are several unknown factors in this system associated with the human interface. The present publication deals with the determination of the speed and accuracy with which operators can transfer terrain positions displayed by side-looking airborne radar, infrared, and television sensor systems to small scale data base vertical photographs. A technique for improving the performance accuracy of the operator of the APPS is described. The "indirect transfer" method resulted in a substantial improvement in location accuracy not only for conventional photography, but also for radar and infrared imagery and, in addition, provides the operator with a measure of the transfer accuracy.

Research in the area of sensor systems integration and utilization is conducted as an in-house effort augmented through contracts with organizations selected for their unique capabilities and facilities for research on sensor systems. The present study was conducted by personnel from Raytheon Company/Autometric and Human Factors Research Inc. under contract DAHC19-73-C-0050 with program direction from Dr. Abraham H. Birnbaum. The effort is responsive to requirements of Army Project 2Q162106A721, the U.S. Army Engineer Topographic Laboratory, Ft. Belvoir, Va., and the Assistant Chief of Staff for Intelligence. Special requirements are contained in Human Resource Needs 73-65 and 74-19.

JOSEPH ZEIDNER
Technical Director

MISSION/DATA-BASE IMAGERY CORRELATION TECHNIQUES (M/DICT)

BRIEF

Requirement:

To determine how fast and accurately experienced operators can transfer target positions from side-looking radar imagery, infrared imagery, and a static TV display of photographic imagery to data base photography. To develop techniques and procedures that assist the Analytical Photogrammetric Positioning System (APPS) operator to correlate mission imagery with data base imagery and so enhance the accuracy with which he can transfer targets from mission to data base imagery.

Procedure:

Three alternative transfer approaches were evaluated early in the program with the objective of selecting one that would assist the operator in accurately transferring targets: Optical-mechanical scaling and restituting equipment; electronic image correlation techniques; and analytical transformation techniques. An analytical transformation technique (indirect transfer) was determined to be the most useful for transferring targets from a variety of reconnaissance imagery.

Mission and data base imagery was selected, and a pilot experiment was conducted to establish the procedures for the main experiment. In the main experiment nine subjects directly and indirectly transferred 20 points from three types of side-looking radar and two types of infrared imagery to data base photography. Eight subjects directly transferred 20 points from a static TV display of a vertical photograph to a data base photograph.

Findings:

Indirect transfer substantially improved the location accuracy of targets that were not close to or on a feature identifiable on both the mission and data base imagery. This improved accuracy was achieved with a cost in time: the average time per target was 6.5 minutes for the indirect transfer and 1.3 minutes for the direct transfer.

Target transfers can be made with useful accuracy to a photo data base from radar and infrared reconnaissance imagery having a wide range of scales and ground resolutions. The results of limited experimentation with a TV display were encouraging: though limited to a relatively high resolution vertical photograph, transfer accuracy was excellent.

Utilization of Findings:

Operational personnel can use the test results in estimating the accuracy with which targets can be transferred from side-looking radar and infrared imagery to data base photographs.

The indirect transfer technique can be used to increase the versatility of the APPS for handling a variety of reconnaissance sensor images. Not only will the accuracy of transfer be improved for targets in areas of sparse or confusing image detail, but the operator will be provided with coordinate residuals which are a measure of the transfer accuracy. The availability of these residuals should give the operator a greater degree of confidence in his work than when using the direct transfer technique. For many targets, especially those appearing on non-photographic sensor records, reliable transfers would not be possible without the indirect technique.

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INTRODUCTION

Remote Sensors

For several decades the aerial camera has been the primary sensor for collecting tactical and strategic intelligence of denied areas. Aerial films used in these cameras are capable of storing millions of bits of information in a form readily interpretable by image analysts. Even unskilled personnel can read useful information from an aerial photograph because the images of ground objects look like the objects themselves. This seemingly perfect sensor has two major disadvantages: it will not penetrate clouds, fog or smoke; and it requires the object to be well illuminated, preferably by the sun. Even though this latter disadvantage can be overcome somewhat by using pyrotechnic and electronic flash equipment and low-light level amplifiers, photography is essentially a daytime reconnaissance tool.

Two other remote sensors are becoming increasingly important to military reconnaissance to supplement aerial photographic reconnaissance. One is side-looking airborne radar (SLAR) equipment and the other is infrared (IR) scanner equipment. A third reconnaissance tool that has promise is airborne television which provides real-time reconnaissance plus the possibility of low-light level operations.

Side Looking Radar - Side looking radars are capable of all-weather, day or night operation. They detect the presence and location of physical objects by transmitting a short pulse of electromagnetic energy in the direction of the object and sensing the energy as it is reflected back from the object; the narrower the beamwidth, the shorter the pulse, the smaller the area in which the beam strikes and reflects, the higher the resolution. Though higher frequencies usually provide better resolution, they are more susceptible to atmospheric attenuations.

Radars are classified as either conventional (non-coherent) or coherent systems. The conventional radars use a physical antenna of limited size. The range resolution of these systems depends upon pulse width and is, essentially, a constant for a particular system. Azimuth resolution is dependent upon antenna beam width and deteriorates with range. Coherent systems use a synthetic antenna aperture generated by the motion of the aircraft. The resolution of such systems may be constant in range and azimuth, and is significantly better than that of conventional systems. Coherent systems record a Doppler phase history and require coherent processing to convert the recorded signal data to a high resolution graphic. Both the conventional and coherent systems may have a moving target indication (MTI) capability.

When operated in the MTI mode, the radar equipment produces two records--the fixed target indicator (FTI) record, which is the more familiar radar record and a subdued FTI record on which the moving targets are imaged. The subduing of the radar background causes the returns from the moving targets to stand out more clearly. Moving objects can thus be detected and recorded even though the radar would be unable to detect the same objects if they were stationary.

Infrared - Even though IR imagery looks like photographic imagery there is more difference than meets the eye, especially in its geometry and its spectral sensitivity. A short description is given of the special properties of IR that make it unique in providing certain kinds of intelligence information.

Infrared radiation is electromagnetic energy of wavelengths between the visible and the microwave regions of the spectrum; that is, 0.72 - 1000 microns. All objects whose temperatures are above absolute zero (0° Kelvin or -273° Centigrade) emit infrared radiation. Like visible light, infrared radiation travels in straight lines outward from the source; it can be focused by lenses or mirrors; it can be dispersed by prisms; and it is propagated in a vacuum as well as in physical media such as liquids, gases, or solids. The amount and spectral distribution of the radiation emitted by an object depends upon its temperature and surface characteristics. Much of the radiation emitted by an object is not available at the detecting equipment due to atmospheric attenuation. The atmosphere does not absorb uniformly all infrared wavelengths. Instead, most absorption occurs at definite wavelengths or "bands". Thus, there are areas of the spectrum, called window regions, where the atmosphere is effectively transparent. To detect infrared radiation after it has passed through an atmospheric path, detectors that are sensitive to radiation in these window regions must be employed.

The surface temperature of objects depends, among other things, upon their physical structure, composition, and ability to absorb solar radiation. Of course, the surface temperatures of various objects on the earth's surface are different. Since the temperature and surface conditions of objects on the earth's surface differ, their infrared characteristics also differ in intensity and spectral distribution.

For reconnaissance purposes, infrared radiation is recorded on film by an electro-optical device called a scanner, which detects radiation over a very small angular field of view. Since most reconnaissance systems require large area coverage, the small field of view is made to cover a large area by scanning it across the ground. The scanner's detector output is used to intensity-modulate a glow tube or a cathode ray tube. The light from the tube is then focused on film in a manner which reproduces the original scan. The density of the film image is thus proportional to the detector output, or more basically, to the apparent temperature of the area on the ground within the field of view at any one instant. The result is a thermal map which shows variations in the surface temperature of the terrain below the aircraft.

Television - Airborne television (TV) can be used for military operations in many ways. One use is in low-light level conditions. Systems have been built for nighttime use for navigation, reconnaissance and strike missions in counterinsurgency operations. The output of the system can be viewed locally on a CRT, transmitted to a remote TV receiver or recorded on film by means of a recording camera. Use can be made of a high resolution return beam vidicon for imaging the scene of interest. This record also can be viewed locally on a CRT or transmitted to a remote image recorder or display. Further, TV can be used for transmitting photographic, radar, infrared, or other graphical records from one station to another.

Photography - Conventional photography is the prime remote sensor reconnaissance tool for daytime and clear weather operations. Since optimum ground resolution is provided by photography it is an obvious choice for data bases. A data base must have high ground resolution and high geometric fidelity so photography from precision cartographic cameras is preferred. Usually, data bases are made from six-inch focal length, 9" x 9" format photographs that have been related to each other and to ground control through aerotriangulation.

Background

Autometric completed for ARI a study to determine how fast and accurately points could be transferred from various types of reconnaissance photographs to a photo data base. In that study it was learned that ground resolution and background density are two major factors in transfer accuracy.

It was found that, with one exception, ground resolution of the mission imagery did not appear to be a significant factor. The reason seemed obvious. Because most reconnaissance photographs (mission imagery) have scales considerably larger than the 1:100,000 data base scale currently being recommended for the APPS, their ground resolutions are better than that of the data base. In the transfer process the limiting factor apparently was the ground resolution of the data base, not the ground resolution of the mission imagery. The one exception, where ground resolution was a significant factor, was the Far position of the Low Pan mission imagery. The ground resolution for that photography was so poor that even a small degradation caused a significant loss of the detail useful for accurate point transfer.

Something akin to ground resolution becomes a significant factor when working with non-photographic sensor records. Since SLAR and IR sensors record information that is different from that recorded by the photographic camera (radar reflectance, temperature of objects) there are many images on the non-photographic mission imagery that do not have corresponding images on the photographic data base. For example, a building imaged by a camera would not show on an IR record if its temperature was the same as the temperature of the surrounding terrain. Or, a relatively small object, having a high radar reflectance, might be imaged on the SLAR record but not on a photographic film. These record differences often make it impossible to make direct visual transfers to acceptable accuracies. It is obvious that SLAR, IR and TV offer new dimensions for reconnaissance beyond those provided by photography. However, new transfer techniques are needed for targets in areas of sparse background density and for targets appearing on these non-photographic sensor records.

One immediate need for new target transfer techniques is for use with the Analytical Photogrammetric Positioning System (APPS)[1/] recently developed at the U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia. The APPS consists essentially of a mirror stereoscope mounted over a coordinate measuring system whose outputs are fed to an interface unit and then to a programmable desk calculator. Two overlapping data base photographs are mounted on the two stages of the mirror stereoscope. After an indexing and checking routine, index marks are placed over a point of interest and the attached calculator computes the X, Y, and Z ground coordinates of that point. In the previous study for ARI it was determined that one major source of error in target location is the transferring of a target image from a reconnaissance record to the APPS data base.

OBJECTIVE

The primary objective of this study was to determine the accuracy and speed with which trained image interpreters can transfer target positions on SLAR, IR, and static TV mission imagery to photographic data base imagery.

The secondary objective was to develop techniques and procedures that assist the operator to correlate mission imagery with data base imagery and so enhance the accuracy with which he can transfer targets from mission to data base imagery.

METHOD

General

From the study of alternative transfer techniques[2/] came the conclusion that the analytical transformation technique should be used in

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1/ Described more fully in Appendix A.
2/ See Appendix B.

the main experiment. Experienced subjects transferred points from IR and SLAR mission imagery to a photo data base using both the indirect (analytical transformation) and direct (image association) technique. Points were transferred from the TV imagery using the direct technique only. The APPS equipment was used for the pilot and main experiment.

Development of Experimental Materials

A considerable amount of care was taken in selecting the imagery for this study. Since only a limited number of different kinds of tests could be made it was important that each mission image contain a variety of terrain and cultural features, be of good operational quality, and be representative of operational scales. In addition, ground areas covered by the mission image must be covered by high quality frame photography at a scale of about 1:100,000. All the sensors selected, except the AAS-27 Infrared set, have previously been used operationally or have been tested by the Army. The types of mission imagery selected and the geographic location covered by each image are described below.

1. AN/APS-94 Side-Looking Radar, 1:250,000 Scale, Phoenix, Arizona - both MTI and FTI.

The APS-94, a conventional (non-coherent) side looking radar, is the primary reconnaissance radar sensor used by the Army. The MTI mode of operation is used almost exclusively by the Army for detecting the presence of targets. Targets are located by correlation between the radar record and a map. Usually, only severely limited positional accuracy is attained.

2. AN/APQ-97 Side-Looking Radar, 1:160,000 Scale, Phoenix, Arizona - FTI only.

The APQ-97 is a conventional (non-coherent) side looking radar, with interferometric capability, developed by the Army for topographic mapping applications. It is fairly representative of the state-of-the-art of non-coherent radars. Isolated targets such as vehicles, factories, bridges, etc. can often be detected even though they cannot be identified.

3. AN/APQ-152 Coherent Side-Looking Radar (TOPO II), 1:100,000 Scale, Phoenix, Arizona - FTI only.

The APQ-152 is a mapping radar, with an interferometric (terrain elevation determination) capability, being investigated by the Army. Its basic resolution is much superior to that of the APS-94 radar. A large variety of terrain and cultural features can be seen on the imagery. Isolated targets such as automobiles, tanks, artillery pieces, etc. can often be detected even though they cannot be identified.

4. AN/AAS-24 Infrared Sensor, Large Scale (1:8,000), Nighttime Operation, Addison Field, Dallas, Texas

The AAS-24, developed for the Army represents the state-of-the art for operational airborne infrared equipment. The normal operating altitude for this sensor is 500 feet to 3000 feet. The imagery selected for these tests was recorded at 2700 feet, resulting in a scale along the flight path of about 1:8,000. A nighttime record was used since the principal operational use of IR sensors for reconnaissance is at night.

5. AN/AAS-27 Infrared Sensor, Small Scale (1:60,000), Nighttime Operation, Alexandria, Virginia

The AAS-27 is an experimental IR sensor developed for the Air Force. The imagery used for these tests has a scale along the flight path of about 1:60,000. A nighttime record was used.

6. TV Display, 1:5,000 Scale, Ft. Belvoir, Virginia

A closed-circuit, 525 line scan television camera and receiver produced the mission imagery from a 1:20,000 scale near-vertical photograph mounted over a light table.

Except for the TV imagery, all of the mission images were printed on glossy photographic paper. The imagery displayed on the TV was printed on transparent photographic material. The data bases were at a scale of 1:100,000 and were printed on a pigmented film base material.

Twenty target points were marked randomly on each of the SLAR and IR mission images. With the exception of the TV imagery, no effort was made to choose Type A[3/] and B[4/] points, as had been done in the photographic study. However, the points were classified as A or B points after they were marked. An extra step was required to mark all selected points on the APS-94 imagery. The points first were marked on the MTI record, whose image detail was subdued during the acquisition phase so the moving targets' images would stand out on the record.

3/ Type A points - Points located on a feature identifiable on both the mission and data base photography.

4/ Type B points - Points which are more than 200 meters distance on the ground from a point identifiable on both mission and data base photographs.

The background detail was so sparse that it was not possible to transfer points directly from the MTI record to the photo data base. Instead, the points were transferred to the FTI record by superposing the MTI with the FTI and marking the points on the FTI record with a sharp needle. Transparent prints were used for this, and each point was transferred after matching the detail immediately surrounding it. A precision comparator was used to measure the coordinates of four reference marks and the 20 points on the MTI record. Coordinates of the same reference marks (images identifiable on both the MTI and FTI records) and the 20 points were measured on the FTI record. Transformation parameters between the MTI and FTI records determined for the reference marks, were applied to the coordinates of the points on the FTI record. This provided the coordinates of all points for the FTI record in the MTI coordinate system. The transfer error was found by taking the absolute difference in X- and Y-coordinates for each point. The mean transfer error for 28 points was 20 meters on the ground.

Transfer Procedure

Previous point transfer tests showed that, generally, the direct technique of transferring is inadequate for points in areas of sparse background detail. In one phase of this study alternative point transfer methods were investigated. In that phase, it was concluded that a 6-parameter analytical transformation technique was the most suitable and that to be of practical value, all coordinate measurements for the transformation should be made on the APPS.

The following is a brief description of the APPS measuring components and of the transfer procedures used in this experiment.

The APPS has two stage plates for holding a pair of photographs. Figure 1 is a schematic diagram of the stage plates over the datagrid.

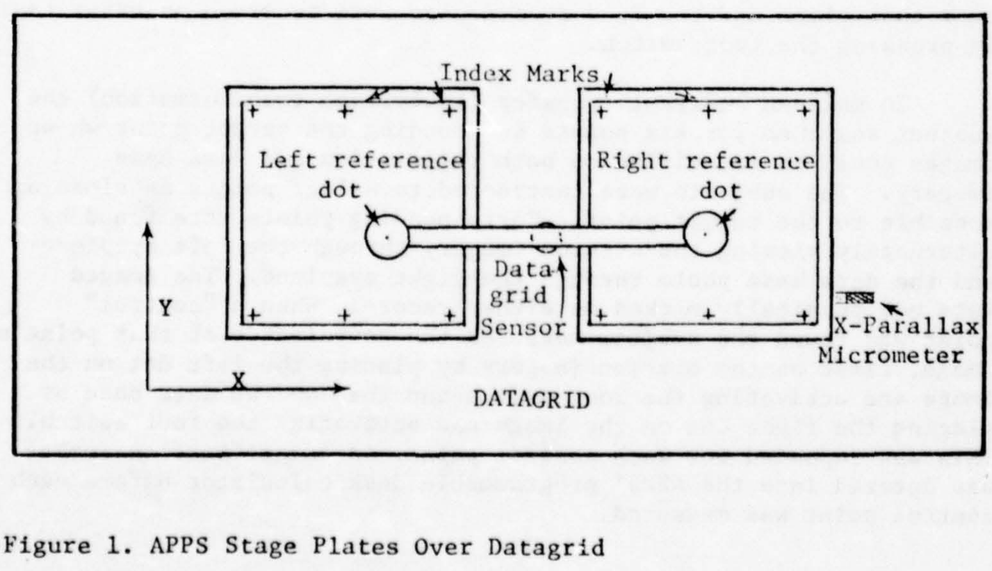

Figure 1. APPS Stage Plates Over Datagrid

The stage plates are mounted on a carrier and can be moved together in X and Y. One plate can be moved relative to the other by X and Y micrometer screws. Under the plate carrier is a data-grid that senses and records movements of the carrier. Mounted directly over the two stage plates are two glass discs with a reference dot in the center of each. These discs are stationary; that is, the plates can move under them. The dots are on the bottom of the discs and about ½ mm above the surface of the data base photographs.

Each data base photograph has six index marks (only four are used for each stereo model) to which all auxiliary data such as position, attitude, and camera constants are referenced. Additionally each data base photo has at least one check point whose X, Y, and Z coordinates were determined during the aerotriangulation phase. For the normal APPS operation, a stereo-pair of photos is mounted on the two stage plates. After initial measuring of the index marks and the check point, coordinates of any point in the overlap area can be found by placing the reference dots on the images of the point of interest and activating the foot switch.

For these tests one data base photograph was mounted on the right hand stage plate and fastened securely. All index marks were measured and recorded. The mission imagery was placed on the left hand stage plate and moved so the particular point to be transferred was beneath the left hand reference dot and the approximate location of that point on the data base was beneath the right hand dot. To make a direct transfer the operator first viewed the mission imagery through the left eyepiece and then the data base through the right eyepiece. After alternately viewing the mission imagery with one eye and the data base with the other, the subject selected the place on the data base that he judged to correspond to the point of interest on the mission imagery. The right hand dot was positioned over that place and the X, Y coordinates were recorded on paper tape by pressing the foot switch.

To make an indirect transfer (analytical transformation) the subject searched for six points surrounding the target point whose images could be identified on both the mission and data base imagery. The subjects were instructed to select points as close as possible to the target point. Corresponding points were found by alternately viewing the mission imagery through the left eyepiece and the data base photo through the right eyepiece. The images were not physically marked on either record. When a "control" point was found the subject measured the coordinates of that point's image, first on the mission imagery by placing the left dot on the image and activating the foot switch and then on the data base by placing the right dot on the image and activating the foot switch. This was repeated for each control point. An identification number was entered into the APPS' programmable desk calculator before each control point was measured.

The desk calculator, which contained a 6-parameter transformation program, was activated and the transformation made. The x- and y- residuals for each control point were printed on paper tape after the transformation was completed. The left dot was then positioned over the target point, the computer was activated, and the x and y coordinates of the target point, in the data base coordinate system, were printed on paper tape. Usually, if the values of the residuals were greater than 0.010 inches, new control points were selected and the transfer process was repeated.

Point Location Standards

Point Location Standards (school solutions) were established for all points on each frame of mission imagery. Since the tests were to be conducted with the APPS equipment it was advantageous to develop the location standards in the coordinate system of the APPS so direct comparisons could be made. Location studs were fastened to the right stage plate so each subject could reposition the data base accurately. The school solutions were developed by making repeated local analytical transformations for each point and by direct transfers, when possible. Special care was taken in mountainous areas of the TOPO II stimulus imagery. For points in these areas both the radar and data base were viewed in stereo so points could be transferred with greater certainty.

Location Error Computation

Each subject transferred all points annotated on the SLAR and IR images to the appropriate data base images by Direct Technique and the Indirect Technique separately. Only the Direct Technique was used for the TV imagery. The location error in two dimensions (x and y) was determined for each point for every subject by taking the absolute difference between the school solution and the observed solution.

Pilot Experiment

A pilot experiment was conducted to determine the suitability of the procedures planned for the main tests. The 6-parameter transformation program, written for the APPS programmable calculator, was tested for adequacy and speed, using photo, SLAR and IR mission imagery. Time trials were run to provide data useful in planning the main tests. The subjects felt their efficiency dropped off appreciably after 3 to 4 hours continuous operation. No objective quantitative data were collected to verify this. The pilot experiment showed that the Indirect Technique proposed for use with the APPS equipment is useful for transferring points in areas of sparse background density, so no changes were deemed necessary for the main experiment.

Main Experiment

Subjects and Subject Training. Eleven (11) subjects, provided by the contractor, participated in the experiment. Even though all subjects were familiar with several types of mensuration equipment, none had previous experience with the APPS equipment. Some of the subjects were experienced image interpreters, others had limited interpretation experience but were experienced photogrammetrists.

Since only one APPS was available, the subjects were tested one at a time. Each subject was instructed on the use of the APPS. The instruction was sufficiently detailed to permit him to turn on the equipment, load the computer programs, zero the equipment and make appropriate data-base checks, and produce the measurements in the proper formats.

Experimental Design. The nine subjects transferred all of the points from each type of IR and SLAR imagery to the data base using two transfer techniques--Direct and Indirect. They completed the two IR images first, the three SLAR images next, and the one TV image last. Six of the nine subjects and two additional subjects (eight subjects) transferred the points from the TV imagery.

The order of the two IR images, the three SLAR images, and the two transfer techniques was counterbalanced to the degree possible across groups of subjects. This was done to control for the possible effects of time-related variables such as boredom, fatigue, and learning. Because there were nine subjects, complete counterbalancing was possible only for the order of the SLAR imagery. The order of the IR images and the transfer techniques was partially counterbalanced.

Table 1A shows the order in which the three SLAR images were presented to each group of subjects. An equal number of subjects (3) were presented with each SLAR image, first, second, and third.

Table 1B shows the transfer technique used first by Mission Image and Groups. One subject from Group 1, two from Group 2, and one from Group 3 used the Direct Technique first with the APS-94 and APQ-152 imagery and the Indirect Technique first with the APQ-97 imagery. Two subjects from Group 1, one from Group 2, and two from Group 3 or a total of five subjects (Group B) used the Direct Technique first with the APQ-97 imagery and the Indirect Technique first with the APS-94 and APQ-152 imagery.

Table 2A shows the order in which the two IR mission images were presented to each of the groups. The five subjects in Group 1 were given the AAS-24 imagery first and the AAS-27 imagery second; the four subjects in Group 2 were given the imagery in reverse order.

Table 2B shows the transfer technique used first by Mission Image and Groups. Three subjects from Group 1 and two from Group 2 or a total of five subjects (Group A) used the Direct Technique first with the AAS-24 imagery and the Indirect Technique first with the AAS-27 imagery. Two subjects from Group 1 and two from Group 2 or a total of four subjects (Group B) used the Direct Technique first with the AAS-27 imagery and the Indirect Technique first with the AAS-24 imagery.

Variables. There was one independent variable, transfer technique, for each IR and SLAR image. There was no independent variable for the TV image since the purpose of the experiment was merely to estimate the location error.

There were two dependent variables for each type of imagery: the location error (in inches), which was then scaled into meters on the ground; and the time (in seconds) required to transfer a point.

There were two control variables. One was the type of point, A and B. These points were labeled in terms of significant background detail, i.e., point/environs. The other was the order of the IR images, the SLAR images, and the transfer techniques.

Preparation of the Data for Statistical Analysis

The measure of each subject's location error and transfer time performance for each mission image was the median error and time for the A points and for the B points. The median rather than the mean

Table 1

EXPERIMENTAL DESIGN FOR THE SLAR MISSION IMAGERY

A. Order of the Mission Imagery by Groups

MISSION IMAGERY	ORDER		
	1st	2nd	3rd
AN/APS-94	Gp_1[a]	Gp_3	Gp_2
AN/APQ-97	Gp_2	Gp_1	Gp_3
AN/APQ-152	Gp_3	Gp_2	Gp_1

[a]3 subjects per group (Gp)

B. First Transfer Technique By Mission Image and Groups

MISSION IMAGERY	TRANSFER TECHNIQUE USED FIRST	
	DIRECT	INDIRECT
AN/APS-94	Gp A[a]	Gp B[b]
AN/APQ-97	Gp B	Gp A
AN/APQ-152	Gp A	Gp B

[a]4 subjects in Gp A
[b]5 subjects in Gp B

Table 2

EXPERIMENTAL DESIGN FOR THE IR MISSION IMAGERY

A. Order of the Mission Imagery by Groups

MISSION IMAGERY	ORDER	
	1st	2nd
AN/AAS-24	Gp_1[a]	Gp_2[b]
AN/AAS-27	Gp_2	Gp_1

[a]5 subjects in Gp_1
[b]4 subjects in Gp_2

B. First Transfer Technique By Mission Image and Groups

MISSION IMAGERY	TRANSFER TECHNIQUE USED FIRST	
	DIRECT	INDIRECT
AN/AAS-24	Gp A[a]	Gp B[b]
AN/AAS-27	Gp B	Gp A

[a]5 subjects in Gp A
[b]4 subjects in Gp B

was used because the distribution of scores across points was positively skewed for many of the subjects.

Each subject's mean error and time scores were based on the number of A and B points shown in Table 3. In addition, four points in the APQ-152 imagery were located in mountains. These points were not classified as either A or B points. They were unique in the sense that, because of relief displacement, the Indirect Technique could not be used effectively unless control points could be found at approximately the same elevation as the target point. Except for the TV imagery, each subject had a Direct and an Indirect Technique error and time score for each point type.

Table 3

NUMBER OF POINTS ON WHICH EACH SUBJECT'S ERROR AND TIME SCORES WERE BASED

MISSION IMAGERY		POINT TYPE	
		A	B
IR	AN/AAS-24	8	12
IR	AN/AAS-27	10	10
SLAR	AN/APS-94	9	11
SLAR	AN/APQ-97	4	16
SLAR	AN/APQ-152	11	5
TV		7	13

Means of the subjects' median errors were used in testing the statistical significance of the effects of Transfer Technique (independent variable) and the Order (control variable). A statistical test (analysis of variance) was used to test the statistical significance of these variables and to determine whether or not the levels of the variables should be combined for descriptive purposes.

RESULTS

Location Errors

The location errors for each of the mission images are described in the following six sections. Within each section, the results for the A points are presented first, and those for the B points, second. For each point type, there is a table of the location error means for the variables of Transfer Technique and of Order, a statistical test (analysis of variance) of the effects of these variables, and a description of the location error in the form of cumulative percentage distributions. Descriptive statistics based on the cumulative percentage of error were considered more appropriate than those based on the normal distribution assumption because the distributions of location error were skewed.

A cumulative percentage distribution of location error was computed separately for the Direct and the Indirect Technique if the effect of Technique was statistically significant ($p<.05$); if not, the two techniques were combined into a composite cumulative percentage distribution.

AN/APS-94 Imagery. Table 4 shows the error means for the AN/APS-94, A points. This table and those that follow show the mean error for the two techniques by the order in which they were used. Recall that one group of subjects used the Direct Technique first and the Indirect Technique second, and the other group used the techniques in reverse order. In this table and those that follow, the means in one set of diagonal cells are from one group and the other set from the other group of subjects. For example, the means of 42.6 and 37.6 meters are from one group and 30.2 and 34.0 meters are from the other group.

Table 4

MEAN LOCATION ERROR (METERS)
FOR THE AN/APS-94 IMAGERY--A POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	42.6	34.0	38.3
INDIRECT	30.2	37.6	33.9
MEAN TOTAL	36.4	35.8	36.1

Inspection of Table 4 shows that the Indirect mean total was slightly less than the Direct mean total and that there was essentially no difference between the Order mean totals.

An analysis of variance of the data (Table 5) indicated that the effects of Techniques and Order were not statistically significant. The data from the two techniques were combined.

Table 5

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/APS-94 IMAGERY--A POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	282.7	<1.00
Subj.w.Groups	7	296.3	
Within Subjects	9		
Method	1	85.1	<1.00
Order	1	1.7	<1.00
Error (within)	7	122.1	

Figure 2 shows the cumulative percentage of location error (in meters) for the A points. The figure may be interpreted as follows: if the interest is in the typical or average error on these points, select 50% (the median) on the ordinate and read the value of the abscissa (location error) that corresponds to the point where 50% intersects the function.

In Figure 2 the 50% value is 34 meters. This means that half of the errors were less than and half greater than 34 meters. If the interest is not in the average performance, but rather in some point better than average, select, for example, 75% on the ordinate and determine the corresponding value on the abscissa. In Figure 2, that value is 52 meters. In other words, 75% of the errors were less than and 25% were greater than 52 meters. Interpretations may be made in the same way for other percentages.

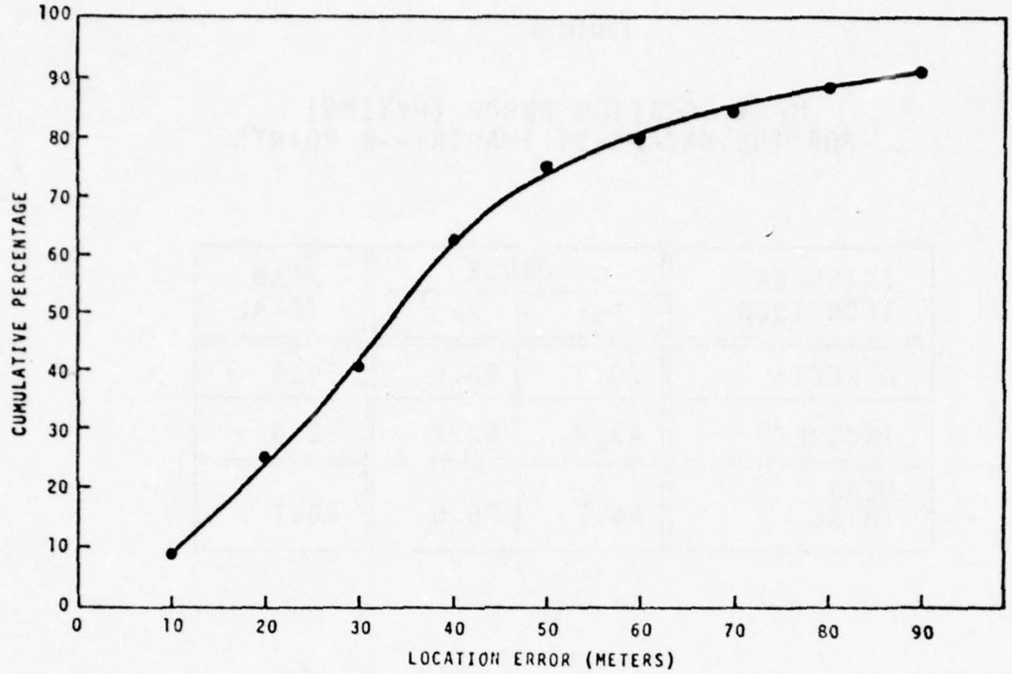

Figure 2 . Cumulative percentage of location error: AN/APS-94 imagery--A points; Direct and Indirect Technique combined.

Table 6 shows the error means for the AN/APS-94 imagery, B points. The mean error was larger on the 2nd trial (75.5 meters) than on the 1st trial (56.7 meters), but an analysis of variance (Table 7) showed that the difference between these means was not statistically significant. The mean error was larger for the Direct Technique (79.6 meters) than for the Indirect Technique (52.6 meters) and the difference between means was statistically significant ($p<.05$). The data from the two techniques were *not* combined.

Table 6

MEAN LOCATION ERROR (METERS)
FOR THE AN/APS-94 IMAGERY--B POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	70.4	88.8	79.6
INDIRECT	43.0	62.2	52.6
MEAN TOTAL	56.7	75.5	66.1

Table 7

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/APS-94 IMAGERY--B POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	0.8	<1.00
Subj.w.Groups	7	540.0	
Within Subjects	9		
Method	1	3234.0	7.70*
Order	1	1566.7	3.73
Error (within)	7	420.1	

*p<.05

Figure 3 shows the cumulative percentage of location error for the AN/APS-94 imagery, B points. The median error for the Direct Technique was 75 meters and for Indirect Technique, 54 meters.

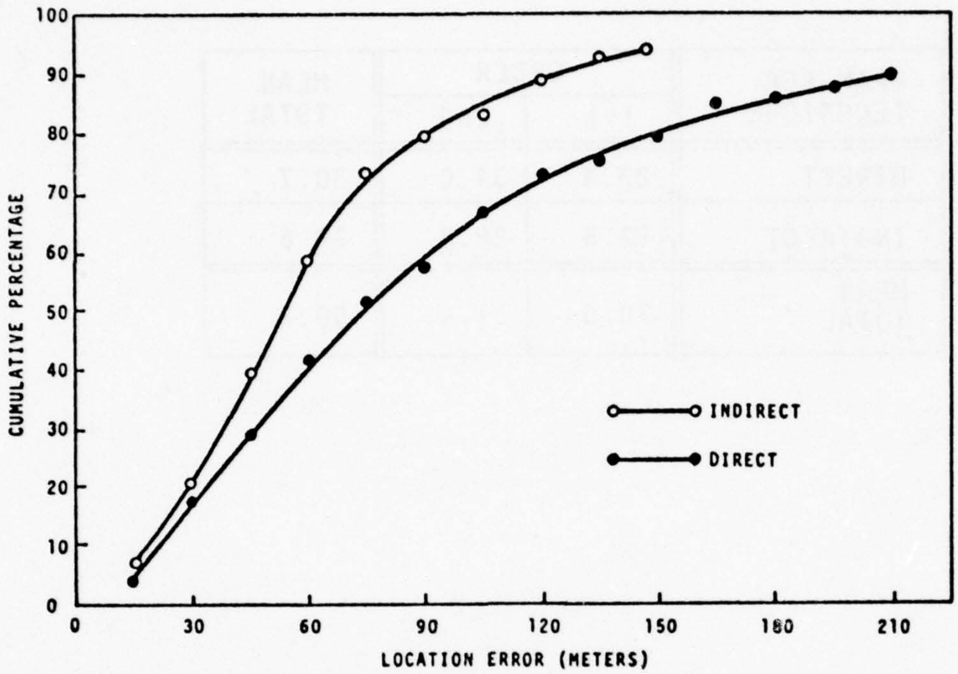

Figure 3. Cumulative percentage of location error: AN/APS-94 imagery--B points.

AN/APQ-97 Imagery. Table 8 shows the error means for the AN/APQ-97, A points. It is apparent from inspection that the larger mean total for the 1st compared with the 2nd trial and for the Indirect compared with the Direct Technique is due solely to the large mean error of 112.5 for the Indirect-1st condition. The analyses of variance (Table 9) showed that the effects of Technique and Group were indeed statistically significant ($P < .05$), and the effect of Order approached statistical significance ($F = 5.53$, $P < .10$).

Even though the Technique effect was significant, the data from the two techniques were combined for several reasons: There was a negligible difference between Techniques means for Group A (27.4 and 28.8 meters). Although the difference between means for Group B was large (112.5 and 34.0 meters), inspection of the subjects' scores revealed that two of the subjects made very large errors on two of the four points, resulting in a large median error for each of these two subjects. Consequently, the mean error for the Direct-1st condition was considerably larger than that for the Indirect-2nd condition. In addition, the median errors of the cumulative percentage distributions for the Direct and the Indirect Techniques differed very little (about 3 meters).

Table 8

MEAN LOCATION ERROR (METERS)
FOR THE AN/APQ-97 IMAGERY--A POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	27.4	34.0	30.7
INDIRECT	112.5	28.8	70.6
MEAN TOTAL	70.0	31.4	50.7

Table 9

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/APQ-97 IMAGERY--A POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	8159.5	7.13*
Subj.w.Groups	7	1144.4	
Within Subjects	9		
Method	1	6372.9	5.92*
Order	1	5955.2	5.53
Error (within)	7	1077.2	

*p<.05

Figure 4 shows the cumulative percentage of location error for the AN/APQ-97 imagery, A points. The median error was 29 meters.

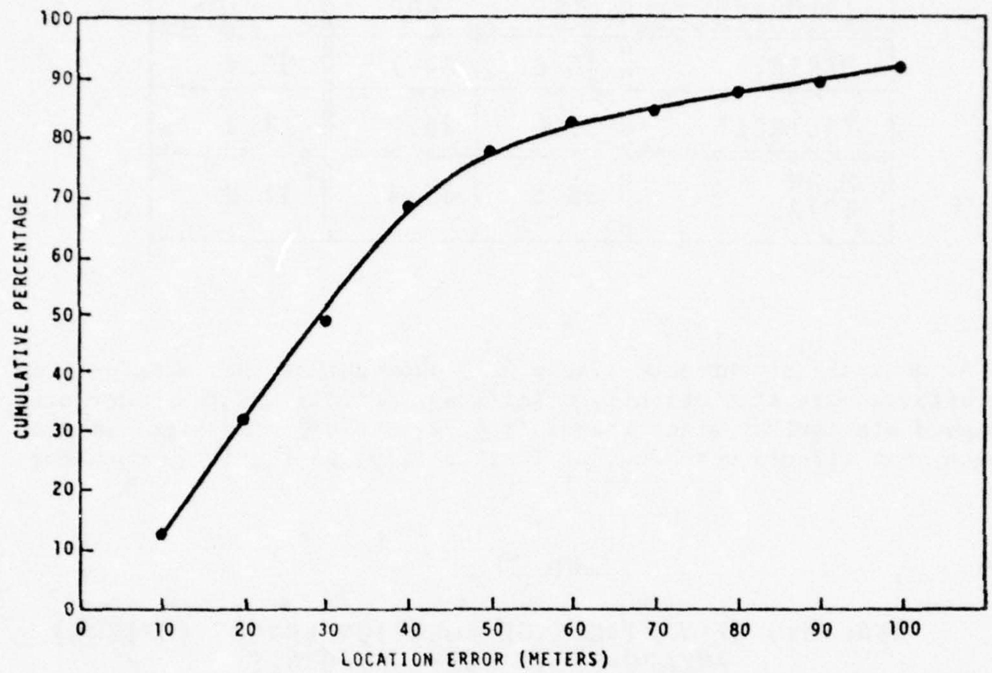

Figure 4 . Cumulative percentage of location error: AN/APQ-97 imagery--A points; Direct and Indirect Technique combined.

Table 10 shows the error means for the AN/APQ-97 imagery, B points. The larger mean total for the Direct compared with the Indirect Technique and for the 2nd compared with the 1st trial was due, in part, to the large mean for the Direct-2nd condition. But, note also that both 1st and 2nd trial Direct means were larger than the corresponding Indirect means.

Table 10

MEAN LOCATION ERROR (METERS)
FOR THE AN/APQ-97 IMAGERY--B POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	46.0	84.7	65.4
INDIRECT	31.0	26.2	28.6
MEAN TOTAL	38.5	55.4	47.0

An analysis of variance (Table 11) showed that the Technique and Group effects were statistically significant ($p<.01$) and the Order effect approached statistical significance ($F=4.74$, $p<.10$). The significance of these mean effects were due, at least partly, to the large mean for

Table 11

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/APQ-97 IMAGERY--B POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	1892.2	18.64 **
Subj.w.Groups	7	101.5	
Within Subjects	9		
Method	1	5402.2	22.38 **
Order	1	1145.2	4.74
Error (within)	7	241.3	

** $p<.01$

the Direct-2nd condition. But, because the Direct means were larger on both trials than the corresponding Indirect means and because of the significant Technique effect, the data from the two techniques were *not* combined.

Figure 5 shows the cumulative percentage of location error for the AN/APQ-97, B points. The median error was 56 meters for the Direct Technique and 27 meters for the Indirect Technique.

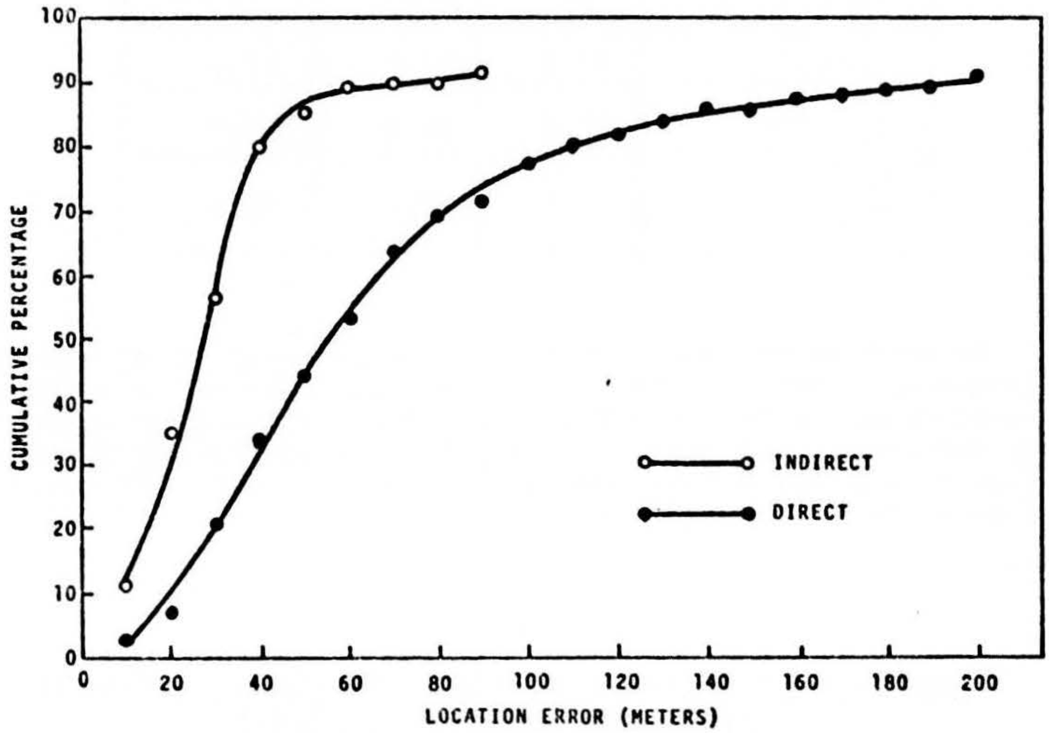

Figure 5 . Cumulative percentage of location error: AN/APQ-97 imagery--B points.

AN/APQ-152 Imagery. Table 12 shows the error means for the AN/APQ-152 imagery, A points. Though the mean for the Direct-1st was somewhat larger than that for the Indirect-1st, there was essentially no difference on the 2nd trial.

Table 12

MEAN LOCATION ERROR (METERS)
FOR THE AN/APQ-152 IMAGERY--A POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	31.5	23.6	27.6
INDIRECT	21.5	24.2	22.8
MEAN TOTAL	26.5	23.9	25.2

An analysis of variance (Table 13) showed that the effects of Technique and Order were not statistically significant. In addition, a t-test of the difference between the Direct-1st and Indirect-1st means did not appraoch statistical significance ($t=1.07$, $df=9$:a t-ratio of 2.26 is required for significance at the .05 level). The data from the two techniques were combined.

Table 13

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/APQ-152 IMAGERY--A POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	126.0	<1.00
Subj.w.Groups	7	191.2	
Within Subjects	9		
Method	1	97.2	1.59
Order	1	29.5	<1.00
Error (within)	7	60.8	

Figure 6 shows the cumulative percentage of location error for the AN/APQ-152 imagery, A points. The median error was 21 meters.

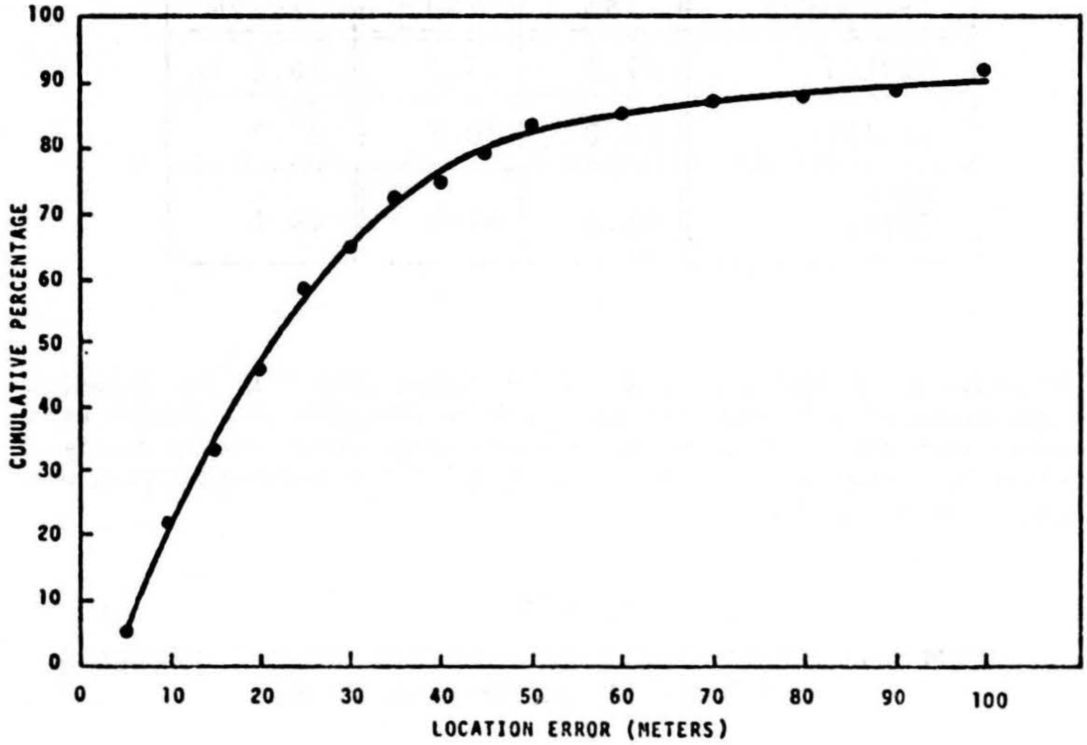

Figure 6 . Cumulative percentage of location error: AN/APQ-152 imagery--A points; Direct and Indirect Technique combined.

Table 14 shows the error means for the AN/APQ-152 imagery, B points. The larger mean total for the Direct compared with the Indirect Technique and for the 1st compared with the 2nd trial was due, in part, to the large Direct-1st condition. But, note also that both the 1st and 2nd Direct means were larger than the corresponding Indirect means.

Table 14

MEAN LOCATION ERROR (METERS)
FOR THE AN/APQ-152 IMAGERY--B POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	87.2	53.2	70.2
INDIRECT	23.8	30.5	27.2
MEAN TOTAL	55.5	41.8	48.7

An analysis of variance of the data showed that only the Technique effect was statistically significant ($p<.05$). Because both Direct means were larger than the corresponding Indirect means, and because of the significant Technique effect, the data from the two techniques were *not* combined. (See Table 15.)

Table 15

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/APQ-152 IMAGERY--B POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	1845.0	2.01
Subj.w.Groups	7	915.9	
Within Subjects	9		
Method	1	8246.2	9.00*
Order	1	954.7	1.04
Error (within)	7	915.9	

*p<.05

Figure 7 shows the cumulative percentage of location error for the AN/APQ-152 imagery, B points. The median error was 54 meters for the Direct Technique and 22 meters for the Indirect Technique.

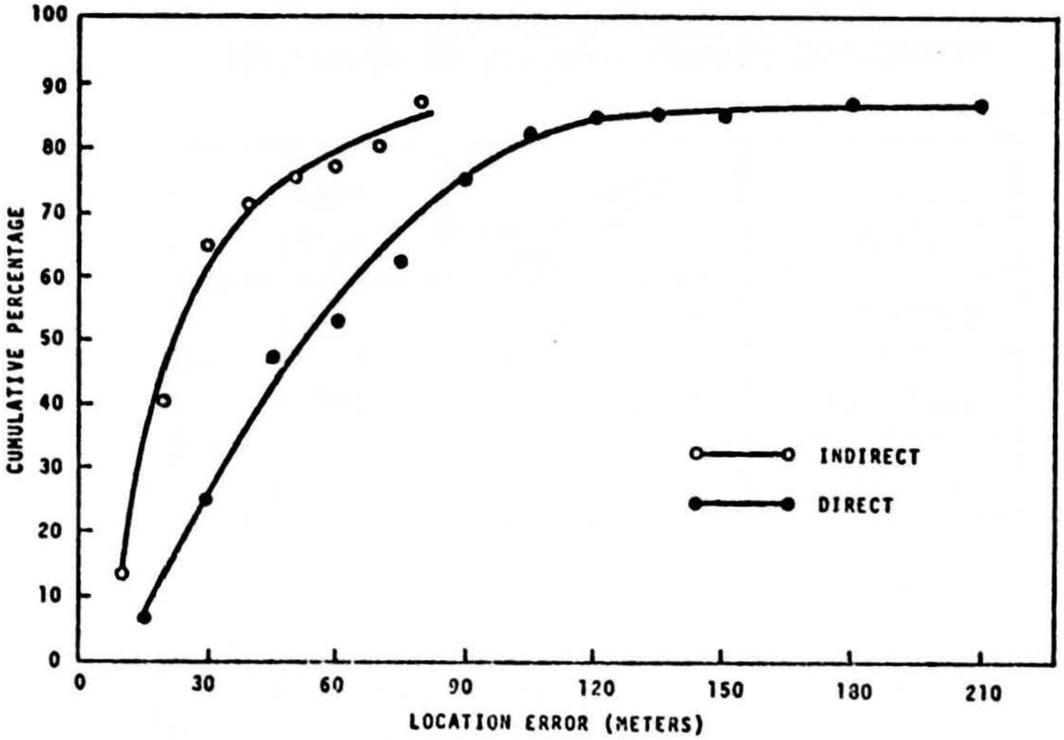

Figure 7 . Cumulative percentage of location error: AN/APQ-152 imagery--B points.

Table 16 shows the error means for the points located in mountains. With the possible exception of the Direct-2nd condition, the error means were considerably larger than those for the B points. Larger errors were expected for these points because of the lack of visual reference points. The smaller mean error for the Direct-2nd condition may have been a result of the subjects becoming very familiar with the terrain features because they used the Indirect Technique first. The Indirect Technique required a more thorough search of the scene for identifiable features than did the Direct Technique because of the need for many control points.

The results in Table 16 seem to suggest that the use of the Direct Technique after considerable familiarity with the scene, may result in smaller location errors than the Indirect Technique.

Table 16

MEAN LOCATION ERRORS FOR THE AN/APQ-152 IMAGERY--POINTS IN MOUNTAINS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	147.0	68.4	107.7
INDIRECT	148.9	177.8	163.4
MEAN TOTAL	148.0	123.1	135.6

Though an analysis of variance (Table 17) indicated that the effect of Technique was statistically significant ($p<.05$), it is apparent from Table 16 that this was due primarily to the smaller mean error for the Direct-2nd condition. It would seem safe to conclude that the location error for these points is large and the use of the Indirect Technique does *not* result in smaller location errors, and, in fact, may result in larger location errors.

Table 17

ANALYSIS OF VARIANCE
OF LOCATION ERRORS (METERS)
AN/APQ-152 IMAGERY POINTS IN MOUNTAINS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	12828.2	4.05
Subj.w.Groups	7	3168.7	
Within Subjects	9		
Method	1	13751.6	6.22*
Order	1	2750.1	1.24
Error (within)	7	2210.0	

* $p<.05$

AN/AAS-24 Imagery. Table 18 shows the mean errors for the AN/AAS-24 imagery, A points. It is apparent from the results that there was little difference between the mean totals for the two Techniques.

Table 18

MEAN LOCATION ERROR (METERS)
FOR THE AN/AAS-24 IMAGERY--A POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	14.1	9.7	11.9
INDIRECT	11.8	14.0	12.9
MEAN TOTAL	13.0	11.8	12.4

An analysis of variance (Table 19) indicated that none of the effects were statistically significant. The data from the two techniques were combined.

Table 19

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/AAS-24 IMAGERY--A POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	54.1	1.55
Subj.w.Groups	7	34.9	
Within Subjects	9		
Method	1	4.3	<1.00
Order	1	5.5	<1.00
Error (within)	7	8.7	

Figure 8 shows the cumulative percentage error for the AN/AAS-24 imagery, A points. The median error was 11 meters.

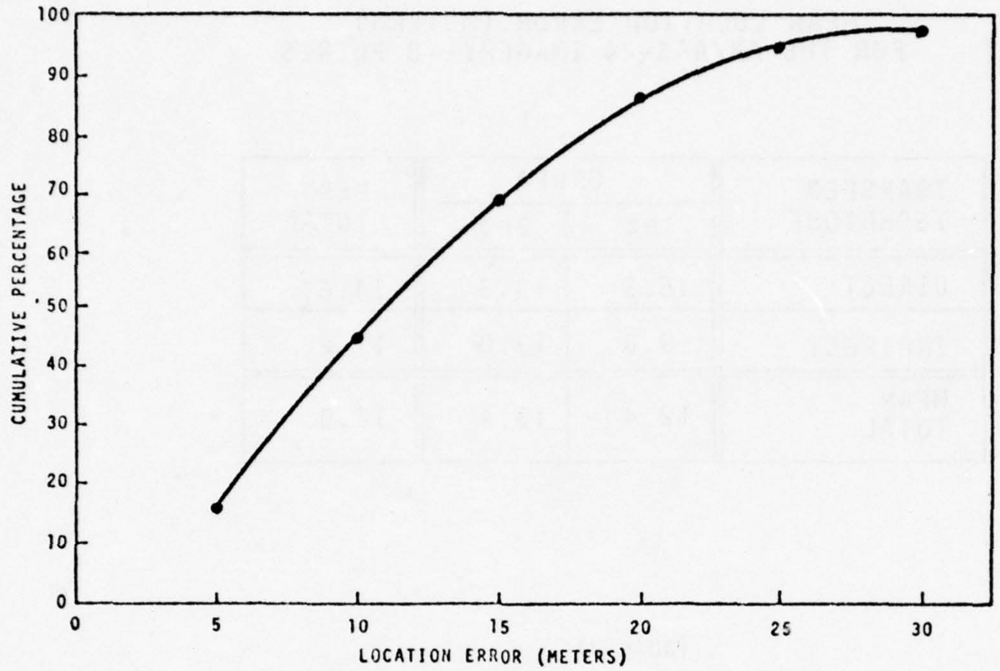

Figure 8 . Cumulative percentage of location error: AN/AAS-24 *imagery--A points; Direct and Indirect* Technique combined.

Table 20 shows the error means for the AN/AAS-24 imagery, B points. Though the difference between the Direct and Indirect mean totals was small (3.4 meters), an analysis of variance (Table 21) indicated that only Technique effect was statistically significant ($p<.01$). The data from the two techniques were *not* combined.

Table 20

MEAN LOCATION ERROR (METERS)
FOR THE AN/AAS-24 IMAGERY--B POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	15.5	13.8	14.6
INDIRECT	9.3	13.0	11.2
MEAN TOTAL	12.4	13.4	12.9

Table 21

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/AAS-24 IMAGERY--B POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	32.4	1.05
Subj.w.Groups	7	30.7	
Within Subjects	9		
Method	1	54.4	13.27**
Order	1	4.4	1.07
Error (within)	7	4.1	

** p<.01

Figure 9 shows the cumulative percentage of location error for the AN/AAS-24, B points. The median error was 14 meters for the Direct Technique and 10 meters for the Indirect Technique.

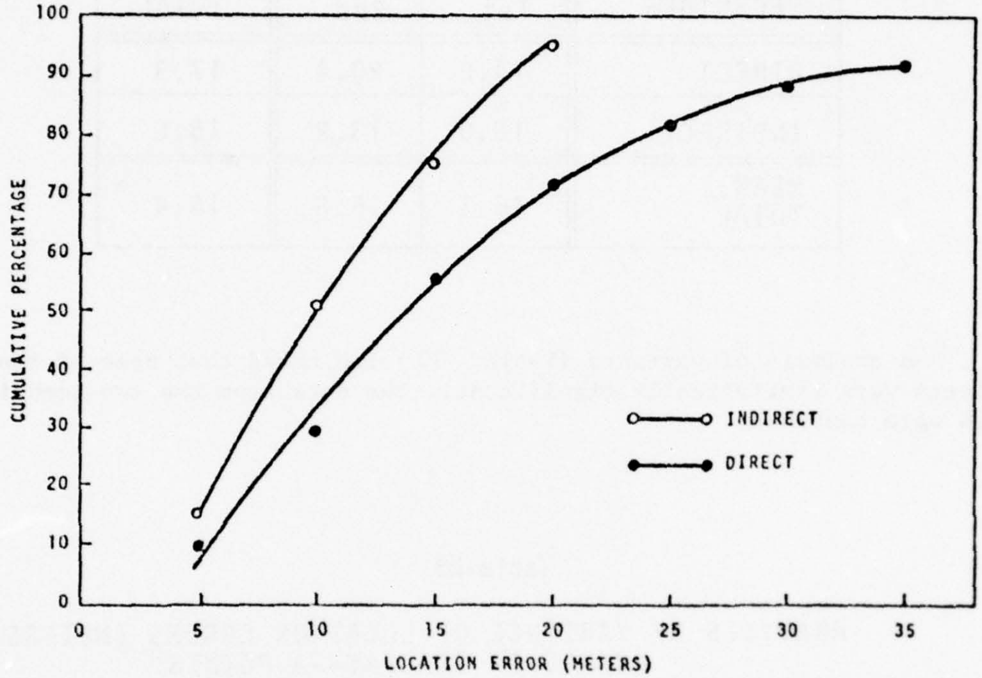

Figure 9 . Cumulative percentage of location error: AN/AAS-24 imagery--B points.

AN/AAS-27 Imagery. Table 22 shows the error means for the AN/AAS-27 imagery, A points. The difference between the mean totals for the Direct and Indirect Techniques and the 1st and 2nd trials was small.

Table 22

MEAN LOCATION ERROR (METERS)
FOR THE AN/AAS-27 IMAGERY--A POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	14.2	20.4	17.3
INDIRECT	18.0	13.2	15.6
MEAN TOTAL	16.1	16.8	16.4

An analysis of variance (Table 23) indicated that none of the effects were statistically significant. The data from the two techniques were combined.

Table 23

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/AAS-27 IMAGERY--A POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	132.9	3.73
Subj.w.Groups	7	35.6	
Within Subjects	9		
Method	1	12.3	<1.00
Order	1	2.1	<1.00
Error (within)	7	37.9	

Figure 10 shows the cumulative percentage of location error for the AN/AAS-27 imagery, A points. The median error was 15 meters.

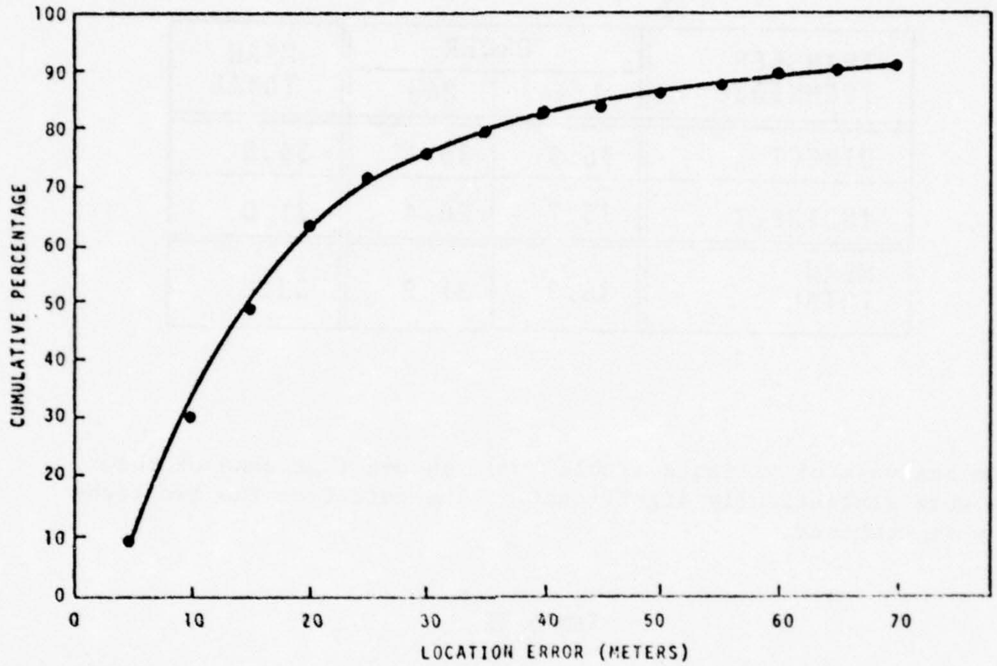

Figure 10. Cumulative percentage of location error: AN/AAS-27 imagery--A points; Direct and Indirect Techniques combined.

Table 24 shows the error means for the AN/AAS-27 imagery, B points. The mean total for the Direct Technique was slightly larger than that for the Indirect Technique and that for the 1st trial was slightly larger than that for the 2nd trial.

Table 24

MEAN LOCATION ERROR (METERS)
FOR THE AN/AAS-27 IMAGERY--B POINTS

TRANSFER TECHNIQUE	ORDER		MEAN TOTAL
	1st	2nd	
DIRECT	36.9	36.1	36.5
INDIRECT	35.7	26.4	31.0
MEAN TOTAL	36.3	31.2	33.8

An analysis of variance (Table 25) showed that none of the effects were statistically significant. The data from the two techniques were combined.

Table 25

ANALYSIS OF VARIANCE OF LOCATION ERRORS (METERS)
AN/AAS-27 IMAGERY--B POINTS

SOURCE	df	MS	F
Between Subjects	8		
Groups	1	81.02	<1.00
Subj.w.Groups	7	88.3	
Within Subjects	9		
Method	1	132.0	<1.00
Order	1	100.0	<1.00
Error (within)	7	138.87	

Figure 11 shows the cumulative percentage of location error for the AN/AAS-27, B points. The median error was 31 meters.

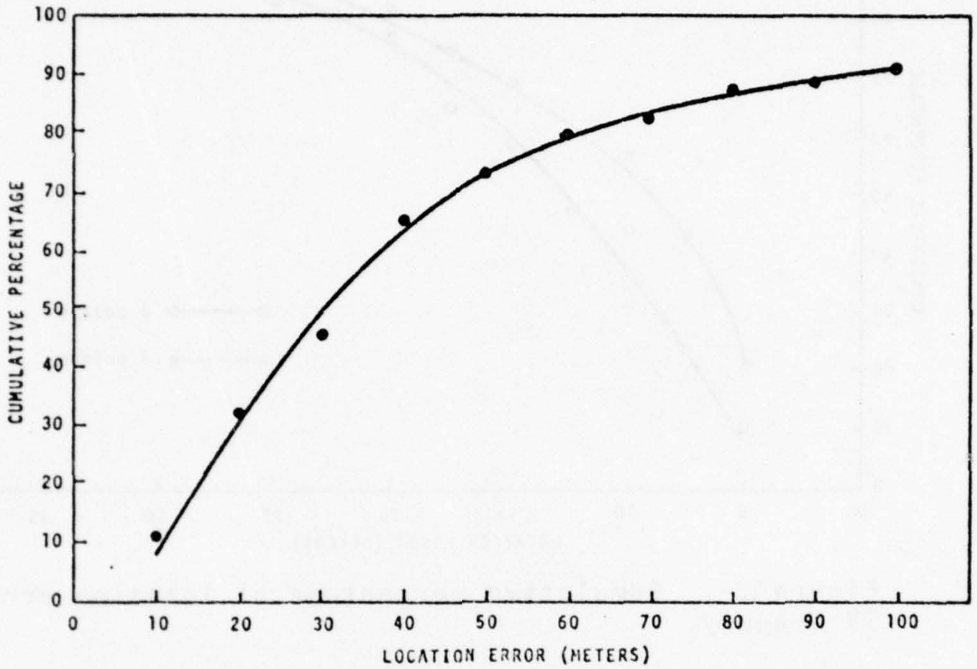

Figure 11. Cumulative percentage of location error: AN/AAS-27 imagery--B points; Direct and Indirect Technique combined.

<u>TV Imagery</u>. Only the Direct Technique was used with TV display of the vertical photograph. Consequently, only the cumulative percentage of error is reported for the TV imagery.

Figure 12 shows the cumulative percentage of location error for the TV imagery. The median error was 9 meters for the A points and 13 meters for the B points.

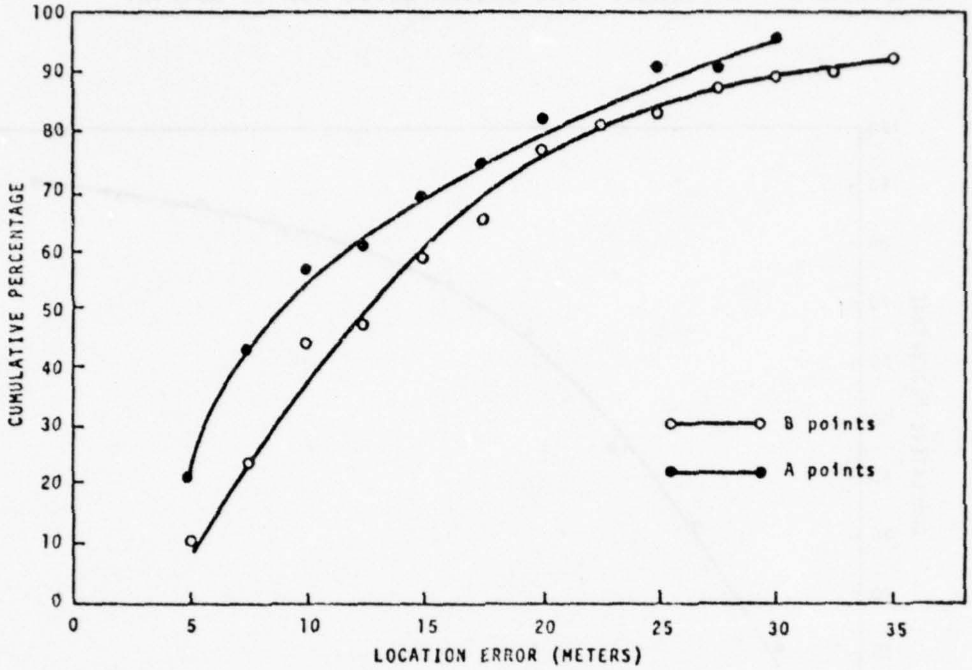

Figure 12 . Cumulative percentage of location error: TV imagery.

Point Transfer Times

Mean times taken to transfer the A and B points from each type of imagery to the data base were comparable so the times for the A and B points were combined.

Table 26 shows the mean time taken to transfer points from each type of mission imagery. Across all types of mission imagery, except the TV, the mean time was 1.3 minutes for the Direct Technique and about 6.5 minutes for the Indirect Technique. Depending on the type of mission imagery, it took from between about 4.5 to 6 times longer to transfer the points using the Indirect Technique than it took using the Direct Technique. This result was expected in that the Direct Technique requires the subject to transfer 1 point and the Indirect Technique requires him to transfer 4 to 6 points.

Table 26

MEAN TIME (MINUTES)
TO TRANSFER POINTS
FROM EACH TYPE OF MISSION IMAGERY

MISSION IMAGERY		TRANSFER TECHNIQUE	
		DIRECT	INDIRECT
SLAR	AN/APS-94	1.4	6.5
	AN/APQ-97	1.6	7.7
	AN/APQ-152	1.4	7.5
IR	AN/AAS-24	0.7	4.3
	AN/AAS-27	1.4	6.3
TV		.9	N/A

SUMMARY AND DISCUSSION

Table 27 is a summary of the location error results. The table shows, for each type of mission imagery and for the A and B points separately, whether or not the two transfer techniques were combined in computing the cumulative percentage distribution, and the location errors, in meters, corresponding to each of three selected cumulative percentages. Each percentage and corresponding location error may be interpreted as follows. For example, consider the AN/APS-94 imagery, A points: 25% of the errors were less than 21 meters, 50% were less than 34 meters, and 75% were less than 52 meters.

Except for the AN/APQ-97 imagery, the results showed that the effect of Transfer Technique for the A points was not statistically significant for each type of IR and SLAR imagery. Even though the effect of technique was significant for the AN/APQ-97, the data from the two techniques were combined because of the reasons stated previously in the Results Section. Consequently, Table 27 shows only the combined indirect and direct errors for the A points for each type of IR and SLAR imagery.

The indirect transfer of A points was not significantly better than the direct transfer probably because of the accuracy limits imposed on both A points and control points. That is, because useful control points must *also* be on identifiable features, they carry the same problems of transfer as do A points.

With the exception of the AN/AAS-27 imagery, indirect transfer of B points improved location accuracy. For the AN/AAS-24, the AN/APQ-97, and the AN/APQ-152 imagery, the indirect transfer accuracy of B points was comparable to the transfer accuracy of A points. For the AN/APQ-94 imagery, indirect transfer (median error, 54 meters) was more accurate than direct transfer (median error, 75 meters), but indirect transfer of B points was *not* as accurate as the transfer of A points (median error, 34 meters).

The AN/AAS-27 imagery presented some unexpected problems, especially with the indirect transferring of B points. The image was extremely contrasty; the man-made objects (roads, railroads, buildings, airstrips, etc.) and bodies of water were almost white and the intervening areas were very dark. Several of the B points were in the dark areas where few surrounding control points could be found. In some instances control points could be found only on one side of the point of interest. Most of the points that exhibited large indirect transfer errors also had large transformation residuals, which means that the subjects could not find good control points. In addition, the imagery was so compressed near the edge of the format that the six-parameter transformation program apparently was inadequate for transferring points in these areas.

The results indicate that experienced operators can transfer points from operational infrared imagery (AN/AAS-24) and from TV imagery of vertical photographs with acceptable accuracy. Regardless of the transfer technique used and the type of point transferred, 75% of the location errors were less than anout 20 meters.

As expected, the location error for the SLAR imagery, and particularly for the lower resolution AN/APQ-94 imagery, was larger than it was for the IR and TV imagery. But, even the location accuracy of points transferred from SLAR imagery may approach acceptable limits if the operator is given a means for indirect point transfer. This is particularly true for the higher resolution radar imagery (AN/APQ-97 and AN/APQ-152). Disregarding the type of point, 50% of the errors were less than about 30 meters and 75% were less than about 50 meters. For the lower resolution radar imagery (AN/APS-94), 50% of the errors were less than about 55 meters and 75% were less than about 65 meters.

Mountainous areas present special problems for analytical transformations. All types of remote imaging systems (photo, IR, SLAR)

Table 27

SUMMARY OF RESULTS FOR LOCATION ERRORS

MISSION IMAGERY		POINTS	TRANSFER TECHNIQUE	ERROR (METERS)		
				25%	50%	75%
SLAR	AN/APS-94	A	COMBINED	21	34	52
		B	DIRECT	39	75	130
			INDIRECT	35	54	64
	AN/APQ-97	A	COMBINED	16	29	48
		B	DIRECT	34	56	93
			INDIRECT	17	27	39
	AN/APQ-152	A	COMBINED	11	21	39
		B	DIRECT	30	54	90
			INDIRECT	12	22	48
IR	AN/AAS-24	A	COMBINED	6	11	16
		B	DIRECT	8	14	22
			INDIRECT	6	10	15
	AN/AAS-27	A	COMBINED	8	15	30
		B	COMBINED	17	31	53
TV		A	DIRECT	5	9	18
		B	DIRECT	8	13	20

produce imagery having displacements due to terrain relief. For example, the image of a mountain peak is displaced away from the photo or IR sensor and towards the radar sensor.[5/] To make a proper analytical transformation the control points must be at approximately the same elevation as the point being transferred. Special techniques must be developed to be used in mountainous areas.

There is little doubt that indirect transfer improves location accuracy of targets that are not located on features identifiable on both the mission and data base imagery. But this improvement is achieved at a cost in the time it takes to make the transfer. The results showed that it takes about five times longer to make an indirect transfer than it does a direct transfer. Averaged across the mission imagery, the mean time taken to transfer points was 1.3 minutes for the Direct Technique and 6.5 minutes for the Indirect Technique. Whether or not the improved accuracy warrants the additional time required would seem to depend on the operational context in which the transfers are made; that is, the accuracy required and the time available to transfer targets.

The data reported here were based upon what was judged to be representative samples of imagery from remote sensors and upon "experienced" operators. Even so, the data should be interpreted in light of several considerations. Point location accuracy is certainly related to the amount of detail available in the mission as well as the data base imagery. The amount of detail in the SLAR and IR imagery depends not only upon the kinds and numbers of natural and cultural features but upon the settings(gain, dynamic range) of these equipments. In addition, location accuracies may be improved by having operators make repeated indirect transfers, using different combinations and numbers of control points, and select those points that produce the smallest residual. Furthermore, additional training of the operators may improve location accuracy. Another important consideration is the way in which the school solution of the targets is derived. When the school solution is established independently of true ground control, as it was in the present study, there is the possibility of error in establishing the true position of some points. This may occur because of possible identification problems: one cannot be certain always that an image selected in the SLAR or IR record and the one selected in the data base photograph are from the same object. Because of this potential difficulty, obviously the school solution should be based upon true ground control whenever possible. In summary, then, the results reported here depend in part upon the scene imaged, the sensor settings, operator experience and procedures, and the way in which the true positions of the points to be transferred were established.

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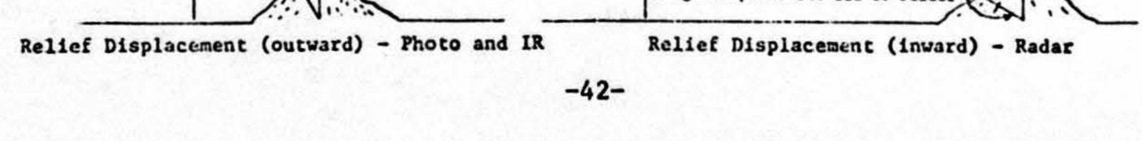

Relief Displacement (outward) - Photo and IR   Relief Displacement (inward) - Radar

CONCLUSIONS

Based on the results of this study and related experience it is concluded that:

- The optical-mechanical rectifying or scaling equipment evaluated was found to be far less useful than an analytical transformation.
- Electronic image manipulation methods are impractical for meeting the point transfer requirements associated with APPS operations.
- Indirect as well as direct transfer techniques are needed by the APPS operator for transferring points from a variety of records from remote reconnaissance sensors.
- Point transfers can be made with useful accuracy to a photo data base from radar and infrared reconnaissance imagery having a wide range of scales and ground resolutions.
- Point transfers can be made with acceptable accuracy from a static TV display of vertical photography to a photo data base.

RECOMMENDATIONS

It is recommended that:

- An indirect point transfer subsystem be developed fully, including equipment modifications, and be made available to APPS operators.
- In future tests, true ground coordinates be established for all points of interest.
- Further studies be made with television mission imagery including simulated, real-time dynamic imagery.
- Techniques for transferring points in mountainous terrain be developed.

APPENDIX A

ANALYTICAL PHOTOGRAMMETRIC POSITIONING SYSTEM (APPS)

The Analytical Photogrammetric Positioning System (APPS) is a point positioning system developed at the US Army Engineer Topographic Laboratories (USAETL), Fort Belvoir, Virginia. The APPS has evolved as a solution to the problem of determining X, Y, Z coordinates of points of interest anywhere in or forward of a Corps-size area in a matter of minutes.

Photogrammetric theory and techniques have been combined with the capabilities of a desk top programmable calculator to provide for utilization of the analytical methods of determining position, unlike the more classical analog methods found in photogrammetric map compilation instruments. The problem is treated as an intersection problem for which universally accepted solution techniques are available. Numerical data are accepted for certain known parameters and measured photo coordinates are treated as the observed parameters, thereby solving for the unknown X, Y, Z coordinates of a point.

There are two parts to the APPS; (1) a Data Base (DB) consisting of mapping quality aerial photography and its associated numerical data, and (2) an assemblage of mensuration and data processing equipment with associated software.

The DB is the key element of the APPS. It is rigorously prepared as part of the normal mapping process and only then extracted from that process for application to the APPS. The DB is mathematically adjusted by an analytical procedure known as aerial block triangulation which is based upon the method of least squares. Given two points of known horizontal positions (X,Y) and three points of known elevation (Z), one can determine the six orientation parameters of a photograph, whether dealing with one overlapping pair of photographs or overlapping coverage of entire countries. Use is made of redundant control data whenever possible to reduce accumulation of small uncorrected systematic errors and random errors. The adjustment is held to ground control.

The DB photograph requires no special processing such as rectification. It is annotated with orientation points called index points and with check points. Its associated numerical data includes interior and exterior orientation parameters, photo coordinates of the index points, and geocentric coordinates of the check points. APPS equipment calibration parameters are also incorporated in the numerical data.

The other portion of the APPS, the hardware, is primarily an assemblage of commercial, off-the-shelf items that will accept the DB and perform the necessary measurements and computations for X, Y, Z coordinates. The current package represents first generation components. Modifications and add-ons have been envisioned to increase the flexibility of the system.

There are five major component items of equipment to include: (1) a modified Zeiss Stereotope,[1] (2) an operator control box, (3) an interface unit, (4) a Hewlett-Packard[1](HP) 9810A programmable calculator,[1] and (5) an HP cassette memory.[1] See Figure A1.

The Stereotope provides the capability for stereoscopic viewing and parallax measurement by the X, Y and X-parallax motions it possesses. To extract these measurements, a Bendix X, Y digitized data grid[1] is installed under the Stereotope baseplate and a signal cursor is connected to the moveable photocarriage. Also, a shaft angle encoder is connected to the X-parallax motion drive.

The operator control box provides a simple means of selecting a particular operation for the APPS to perform, i.e., zero the baseplate data grid datum, or index the DB stereomodel, etc.

The interface unit converts cursor signals to the HP language and subsequently HP language to a desired output language.

The HP 9810A programmable calculator and the HP cassette memory function together. The memory holds the software programming and DB files on tape covering a Corps size area for sequential access by the calculator. The calculator uses the program and one numerical DB file at a time together with the input from the Stereotope through the interface to compute the X, Y, Z coordinates of a point.

In practice, the operator uses a photo index overlay to determine which DB stereo pair of photographs to place on the Stereotope. He inserts the magnetic tape cassette containing the program and DB numerical data files for that model into the cassette memory. He then activates the cassette memory to load the program by use of a magnetic card. The card also contains the Stereotope calibration parameters mentioned earlier. He then calls in the DB file for the model being used by keyboard commands. Each photo of the model is oriented independently using the index points mentioned earlier. The photo coordinates of four index points are measured and a transformation computation made to relate the measured photo coordinates to the adjusted photo coordinates. The operator then observes and measures a check point, this time in stereo, to ascertain that he correctly oriented the model. He must agree with the known coordinates of the check point within established tolerances before he can proceed. Once he is signalled to proceed he then observes the point of interest, measures and computes the X, Y, Z coordinates of the point and obtains a printout on paper tape of the UTM Zone, Easting, Northing and elevation in meters.

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[1]Commerical or trade names are given only in the interest of precision in reporting experimental procedures. Use of the names does not constitute official endorsement by the Army or by the U.S. Army Research Institute for the Behavorial and Social Sciences.

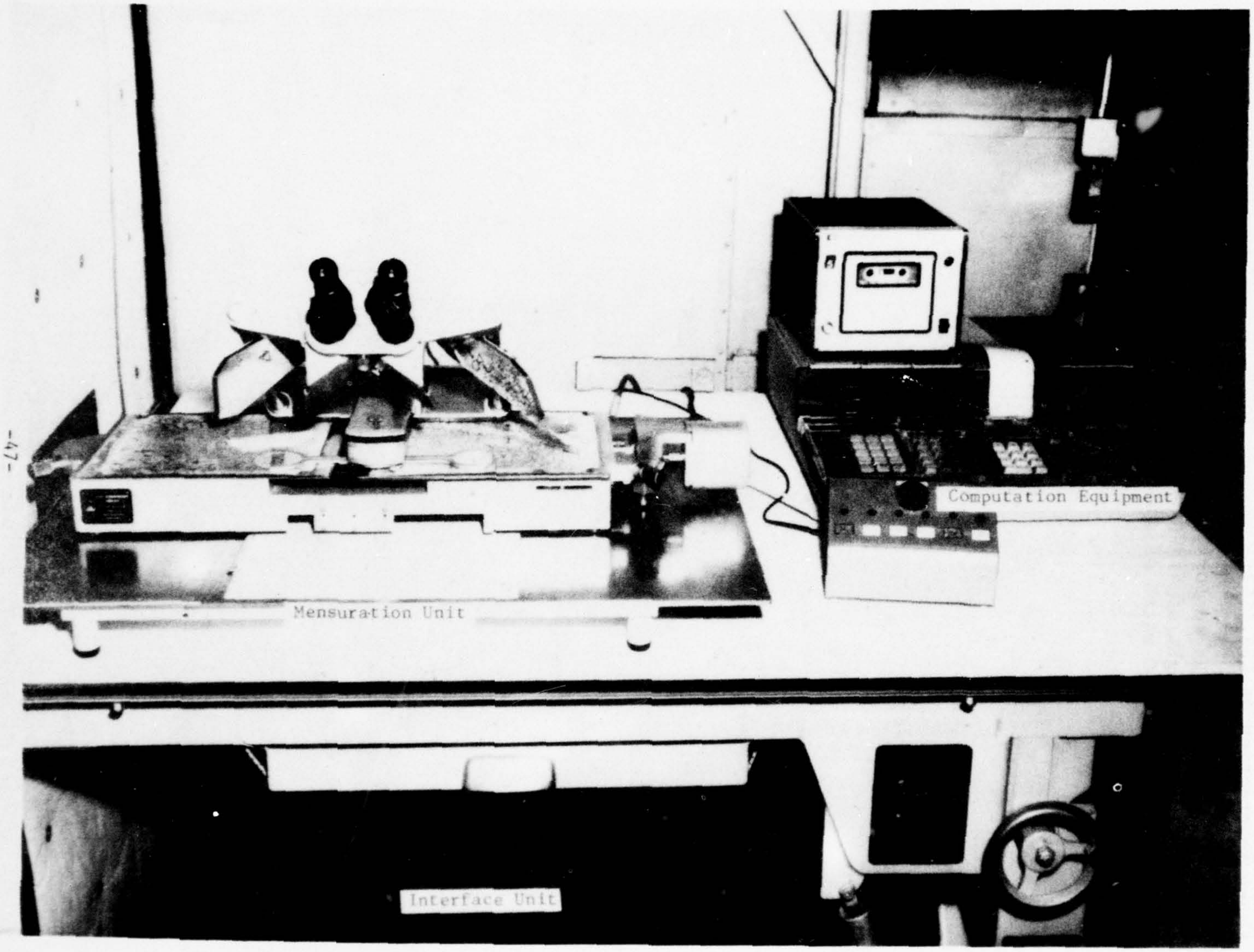


Figure A1.- Analytical Photogrammetric Positioning System (APPS) Equipment

Test results conclude that horizontal position locations determined with the APPS are approximately equivalent to third-order ground surveys. This is readily achieved by personnel having previous training in the interpretation of aerial photographs and additional 16-40 hours instruction on the APPS.

The APPS is packaged for transport in three militarized carrying cases for a total weight of 478 pounds and a volume of 27.42 cubic feet. It requires 600 watts of power at 110v, 60 Hz.

APPENDIX B

INVESTIGATION OF ALTERNATIVE TARGET TRANSFER TECHNIQUES

Three general areas were explored in search of new transfer techniques or equipment:

- Optical-Mechanical Equipment
- Electronic Image Correlation Techniques
- Analytical Transformation Technique

Optical-Mechanical

Several types of instruments fit into this general classification. Most of them are able to change the magnification of one or both photographs but cannot achieve attitude rectification. Four such instruments were examined. The Multi-Sensor Take-Up Table (MSTU) with Bausch and Lomb Variable Stereoscope is a back-lighted glass surface with rail-mounted optics. The optics have the capability to rotate the image and to vary the magnification in each optical train. Magnification ranges are: 3.5X to 15X; 7X to 30X; and 14X to 60X, depending on eyepieces and lens attachment selected.

The Lacey-Luci, commonly used in photographic laboratories and for graphic arts, is a very simple instrument with a photographic image plane moved by crank handles for magnifying or reducing within a ±4-power range. Correlation between mission imagery and data base could be accomplished with this instrument, but the final resolution on the viewing screen was well below useable limits. No rectification for differential attitudes was possible with this instrument, so only near vertical photographic data could be used.

The B&L Zoom Transfer Scope (ZTS) is a table-top instrument used to superimpose images from two different graphics. One graphic (SLAR, IR, or photo imagery) is placed in the 9" x 9" plate holder and the other (data base) is placed on the table under the ZTS. Zoom magnification, continuous from 1X through 14X, provides rapid, accurate matching of mission imagery scale to data base scale. An anamorphic lens system enables the instrument to compensate for some of the geometric anomalies in an image. A dial control selects the direction and a lever controls the enlargement ratio (stretch) from 1:1 to 1:2. The instrument provides the means for rotating the image from the plate holder through 360°, as an aid to the operator in making the critical final adjustment. After the two images are superimposed, a point of interest appearing on the image in the plate holder can be transferred to the data base by use of a Snap Marker or a simple marking device.

The ZTS is capable of making geometric and scale changes so one photo image will correlate with another photo image of the same area if the relative attitude between the two images is not too great. For small areas, SLAR and IR images also can be restituted into a photo data base. A crude correlation could be made between the mission and data base imagery, but the correlation was not sufficiently accurate. Usually there was a great difference in the ground resolutions of the two images and the sharper image dominated the scene so much that a correlation to a few mils was usually difficult, if not impossible. It became even more difficult when non-photographic images were used. Furthermore the correlation process was very time consuming.

The Bausch and Lomb Micro-Mark is a precision point transfer instrument with independent variable magnification for each eyepiece. It provides optical rotation through 360°. After two images are correlated stereoscopically, or are superimposed, the point of interest is marked on each image by a heated die. Using this instrument with a variety of image types and scales proved to be unsatisfactory for the same reasons found with the ZTS plus the fact that it has no restituting capabilities. Precise transferring of points between two photo images can be performed with this instrument if the differences between the scales and attitudes of the two photographs are not too large.

Electronic Image Correlation Techniques

Electronic image correlation techniques have frequently been used in the past in photogrammetric instruments to automate the process of point transfer and to remove parallax in stereo models. Most of the successful applications have been in instruments designed to operate with similar imagery: i.e., photo to photo, SLAR to SLAR, IR to IR, etc. In addition, most of these instruments have a limited accommodation range for scale variations.

In the general case, one would like to automatically match any type of imagery with any other and at all scales. Such an ambitious undertaking is probably impractical; however, it might be instructive to make some estimates as to how far this idea might be carried. First, one should realize that matching SLAR to photo, or IR to photo, or SLAR to IR, is probably impractical because of the excessive costs of such an instrument. The problems that occur are due not only to geometry but also to the fact that the different sensors image the same scene in different ways. This fact is why the different sensors are useful but is also precisely what would defeat any but the most sophisticated automatic matching instrument. For example, a contrast change from dark to light in an IR record might not show up at all in a photo, and might show up as the opposite phase in a SLAR record. Therefore, if one wishes to automatically match mission imagery with a data base, it would probably be feasible only when the mission and data base records are from the same type of sensor.

Assuming the data base is composed of vertical, frame photography, estimates should be made of the range of scale variations and the image distortion that might require accommodation in an automatic image correlator type instrument. Absolute estimates cannot be made because for certain conditions of terrain slope and camera tilt the terrain is not imaged at all, and so the required range of compensation becomes infinite. One must assume certain conditions in the data base photography (scale, terrain slope) and certain reasonable accommodation ranges in the correlator, and then determine the limiting cases for the reconnaissance coverage (A similar approach should be used for the SLAR-to-SLAR and IR-to-IR matching).

Assuming the data base is composed of vertical, frame photography of the standard 6" focal length, 9" x 9" format, there will be local scale variations due to terrain slope. These variations are a function of the terrain slope angle and the angle off the camera optical axis. For example, a 30° terrain slope at the edge of the format will produce a local scale factor approximately two times smaller than the average scale factor.

The reconnaissance photography to be matched with the data base will probably have a different average scale factor, and if the photography is oblique or panoramic it will have local scale variations. These scale variations, due to the camera axis being non-vertical, can be quite extreme for large angles off vertical. In the limit at the horizon, the scale is obviously infinitely small. Thus, if the correlator has a finite scale accommodation range, the sweep angle of panoramic photography or the inclination angle of oblique photography must be restricted to certain angles from the vertical to stay within this range. Panoramic photography, for example, exhibits a 2:1 scale change from nadir to 45° sweep angle. Thus, the total scale accommodation range will have to be apportioned in a way to handle the average scale difference between the data base photo and reconnaissance photography, and also the scale variations within each of the two photos.

To arrive at some reasonable estimate of the scale accommodation range of a correlator, consideration must be given to the practical limits of the components and circuits that may be used. The correlation process itself is dependent on resolution and contrast in each of the two areas to be matched. In other words, one could have infinite resolution, but if there were no contrast changes in the area under consideration, the process would fail. From past experience and tests it is reasonable to believe that a correlator will produce a reliable output when scanning an area as small as 20 x 20 resolution elements in the photo having the lower resolution. In the case under discussion this is probably the data base photo. The corresponding scan on the reconnaissance photo would probably have more resolution elements due to the generally better resolution and larger scale of this type imagery.

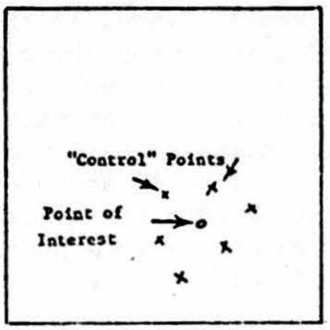
Scanning of the photos to convert the density changes into electrical signals can be accomplished by several techniques. But those that perform at high speed and reasonable cost, such as flying spot scanners and image dissectors, are generally limited by a spot-to-diameter ratio of about 1/1000. If it is assumed that the spot diameter is matched to the resolution element of the data base imagery, then there would be a 50 to 1 scale accommodation range for the reconnaissance imagery. If a factor of 2 is allowed for the slope induced scale

variations and for the camera tilt, then about a 12:1 average scale variation could be accommodated.

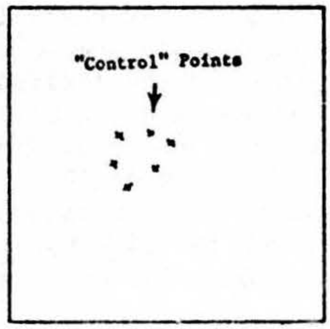
Transferring points by automatic electronic image correlation does not hold immediate promise for the variety of sensor record and exposure conditions that must be considered.

Analytical Transformation

The only approach that seems to hold any promise for a variety of reconnaissance sensors is an analytical transformation of points from one record to corresponding points on the other record. The procedure is as follows. Select 4 to 6 points ("control" points) surrounding the point of interest in the mission imagery. These points must be features identifiable in both the mission and data base imagery. Place the



Mission Image



Data Base Image

mission photograph in a comparator and measure the image coordinates of the control points and the point of interest. Place the data base photograph in the comparator and measure the coordinates of the fiducials and the corresponding control points. Using a five-, six- or eight-parameter transformation program, transform the control points and the point of interest into the coordinate system of the data base.

When control points can be found reasonably close to the point of interest, the transformation can be made to about the same accuracy that the control points can be identified and measured.

One of the attractive features of this approach is that analytical transformations can be used with all types of mission imagery, such as vertical and oblique frame photography, panoramic photography, infrared imagery and side-looking radar imagery.

Further Considerations

Points can be transferred stereoscopically with high accuracy if two images have similar ground resolutions. But if the ground resolutions of the two images are quite different, it is difficult to form a stereo model and the transfer accuracy suffers. Often two images of the same area, even with the same type sensor, are taken from approximately the same X, Y ground coordinate but at different altitudes so there is no significant parallax. The two images can be matched but a stereo model will not be formed, so transfer accuracy will deteriorate. Matching images from unlike sensors (for example, photo and radar) or matching two records differing significantly in ground resolutions is time consuming and the results are usually disappointing. If one desires to make such matches to get a stereo model, the best way to do so is to mark three or more points on one record (near the area of interest) and to mark the corresponding points on the other record. Scaling and rectifying one record to the other can now be done with much greater speed and accuracy (assuming the equipment is able to accommodate the attitude and scale differences). But because corresponding points must be selected to perform a good match, it seems more appropriate to measure the coordinates of the points and use the coordinates to perform an analytical transformation.

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