Implementation of Softcopy Photogrammetric Workstations at the U. S. Geological Survey

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ABSTRACT: The U.S. Geological Survey has provided the Nation with primary quadrangle maps and map products for the last 50 years. The Survey recently completed initial coverage of the conterminous United States and Hawaii at 1:24,000 scale. In Alaska, complete coverage exists at 1:63,360 scale. Effort is underway to build a National Digital Cartographic Data Base (NDCDB) composed of the digital representation of these and other map series. In addition, the Survey plans to meet the demand for more current and complete data through the development and promotion of spatial data standards in cooperation with other Federal, State, local, and private organizations. Plans for a digital revision program call for the extensive use of softcopy monoscopic workstations to serve as the mechanism for revising the planimetric digital data layers. These workstations will be supplemented by analog and analytical photogrammetric workstations to handle hypsography and some amount of feature classification. The advent of a digital orthophotograph production capability, coupled with workstation technology, has directed this trend. The Geological Survey has initiated two research projects to study digital orthophotograph production and revision processes.

INTRODUCTION

THE U.S. GEOLOGICAL SURVEY continues to investigate various approaches to facilitate digital revision of the 1:24,000- and 1:100,000-scale data that reside in the National Digital Cartographic Data Base (NDCDB). The current emphasis is directed toward exploitation of digital orthophotographs (orthophotos) used in monoscopic revision workstations. Digital stereorevision is also being investigated but, at present, is viewed as a supplemental process.

The primary source material being considered for a revision program would come from the National Aerial Photography Program (NAPP). At present research investigations involve both the NAPP and the Satellite Pour l' Observation de la Terre (SPOT)*. The NAPP will be used primarily for the 1:24,000-scale revisions and the SPOT primarily for the 1:100,000-scale and 1:63,360-scale (Alaska) revisions. Other source materials will also be investigated as appropriate.

Production of orthophotos began in 1964. Recently it became feasible to consider the production and use of digital orthophotos as a cost-effective source for revision of planimetric spatial data. There is now a demand for softcopy orthophotos in the mapping community because of the technological advancements in hardware and software that support this type of data. The Survey is addressing this new demand by providing digital orthophotos as both an end product and a revision source.

The advantages of monoscopic revision from a digital orthophoto are smaller image data files, less complex processing requirements, and the availability of many hardware and software platforms that support this type of operation.

Stereorevision is being investigated and is needed to handle the hypsographic revisions. In addition, stereorevision provides an aid in feature classification which can reduce the need for the more costly field classification procedures. As the technology advances in the areas of data storage and processing, softcopy stereorevision could be considered as the primary operational scenario.

Several pilot production efforts are underway to evaluate and determine optimal approaches for digital revision. Initial research investigations have focused on monoscopic revision. Future investigations will be directed toward monoscopic revision on other platforms, image processing to enhance feature extraction, softcopy aerotriangulation, autocorrelation to produce digital elevation models, and softcopy stereorevision.

BACKGROUND

The National Mapping Program is the responsibility of the U.S. Geological Survey. A brief chronology of accomplishments, programmatic requirements, and program objectives follows:

- For 40 to 50 years the Survey has concentrated on producing 1:24,000-scale topographic maps (1:63,360-scale in Alaska).
- In 1979, the Survey received Federal appropriations to initiate the Digital Cartography Program, which in turn gave birth to the NDCDB.
- In 1990, the Survey completed first time coverage of the United States at 1:24,000-scale (1:63,360 in Alaska).
- In 1990, a report was prepared by the Mapping Science Committee, National Academy of Science, at the request of the Director of the Geological Survey (Mapping Science Committee, 1990). Recommendation 5, concerning data base structure and operations, reads:

  > The committee recommends that the National Mapping Division establish plans for and begin prototyping a national spatial data base, which would be an enhancement of the National Digital Cartographic Data Base and would be feature oriented ....

- In a paper entitled "USGS National Mapping Division: Preparing for the Twenty-First Century" (Starr, 1990), the following points are made with respect to data management:

  > Of paramount importance will be the ability to keep the NDCDB as current as possible. The 10-year revision cycle of maintaining currency of paper map products is not acceptable in the information environment. The objective would be to develop an up-to-date NDCDB that would be feature oriented and readily accessible by various means.

These points illustrate that the Survey is in transition from being a producer of paper maps to a producer and distributor of digital spatial data. The digital spatial data collected from the map are planned to reflect a feature-oriented implementation in the next generation of the NDCDB. Providing accurate base category information is still a prime objective; however, data

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currency and relative accuracy has become a more dominant concern in today's fast-paced environment.

While photogrammetry has proved to be an economical method for topographic mapping, remote sensing has proved itself to be an effective tool for resource management. Conventional frame aerial photography used in photogrammetry can be characterized as low altitude, analog, and capable of providing stereoscopic viewing while satellite imagery is generally very high altitude, digital, and monoscopic. However, photogrammetry and remote sensing are merging. Aerial photography is being digitized at the same time that stereoscopic-satellite images are being used for mapping applications. As photogrammetry becomes more digital and the resolution of satellite images improves, the tools developed in each respective discipline can be applied to the other. Both technologies can be an effective means to detect manmade or natural changes on the ground on a cyclic basis for map revision purposes.

The first motivational factor behind the digital revision strategy is the growing use of the orthophoto as an economical means of having up-to-date map coverage. The orthophoto served as a substitute for the 7.5-minute, 1:24,000-scale line map until once-over coverage of the conterminous United States was completed. The emerging problem is how to maintain the 7.5-minute series with limited resources and how to provide up-to-date maps to users. There is a growing need for national base map coverage at larger scales. Traditional techniques cannot meet the demands for timeliness, currency, and accuracy from the user. The orthophoto can be a viable solution to the revision problem, as well as fulfill the need for larger scale (for example, 1:10,000 and 1:12,000) base maps.

Digital mapping systems have been under development since the 1970s (Ramirez, 1991). Initially, the systems were mainframe-based and were designed by in-house expertise. Database concepts were nonexistent, and nearly all software was application dependent. In the next stage of development, digital mapping systems were created on minicomputers and were characterized by unstructured formats and internal proprietary formats. These systems were closed systems or "black boxes." The mode of production was to generate hard-copy proof-plots offline. The next stage brought computer-assisted design (CAD), workstation-based systems. These systems had graphics displays that provided online graphics for reviewing and editing digitized data. Though the internal formats remained proprietary, the programmer's interface routines were provided for software development. Translators to the most common formats were typical, and database technology began to emerge in digital mapping systems.

Current mapping systems are generally workstation environments and PC-based. The use of affordable personal computers in digital mapping systems demonstrates the continuing maturity of computer technology. The potential of Geographic Information System (GIS) technology is accepted as a critical part of the digital mapping system. The graphic displays are both raster and vector, which makes possible the use of an orthophoto as a background. This capability provides a geometrically accurate base for map revision and GIS applications. Data standards have become an important issue to the user, and there are more commercial CAD packages to choose from. Object-oriented database management systems are now available for digital mapping systems, and extendable models are being designed for spatial data handling.

SOURCE MATERIAL

Current aerial photographs are the primary elements needed for using photogrammetric methods in mapping. National coverage is essential for a consistent map series, though cyclic updates are needed to maintain a current data source. The NAPP provides national photographic coverage to the general public. The objectives of the NAPP are to complete conterminous coverage of the United States and to develop a complete database before the end of 1992.

The NAPP photography is flown on a 5-year cycle on the basis of cooperative funding from State and Federal agencies. The program can be the basis for map revision, as well as a tool for resource management and Earth science research. Stereoscopic coverage allows digital elevation models (DEM) to be generated with correlation techniques. The NAPP will provide the source photographs for a national orthophoto program. Table 1 outlines the NAPP specifications.

DIGITAL ORTHOPHOTO PRODUCTION

A prototype digital orthophoto production system is described and includes the digitizing, storage, and computing hardware needed to accomplish the differential rectification of scanned aerial photographs. A diagram illustrating proposed function and process flow is provided as Figure 1.

SCANNING NAPP PHOTOGRAPHS

Generally, scanning resolution depends on the intended use of the orthophoto. For softcopy digital orthophotos, a 50-mi-

TABLE 1. NAPP SPECIFICATIONS

Flight height	20,000 feet
Flight-line direction	North-south
Scale	1:40,000
Focal length	6 inch
Format	9 by 9 inch centered on quarter-quad
Number of cameras	One
Film type	Color infrared (CIR)/black and white (B&W)
Originals	CIR-Processed to positives B&W-Processed to negatives
Forward overlap	60 percent
Sidelap	30 to 50 percent
Exposures to cover one 7.5-minute quadrangle with stereophotography	Ten
Vegetation status	Depends on requirements
Sun angle	30° minimum
Cloud cover and haze	None

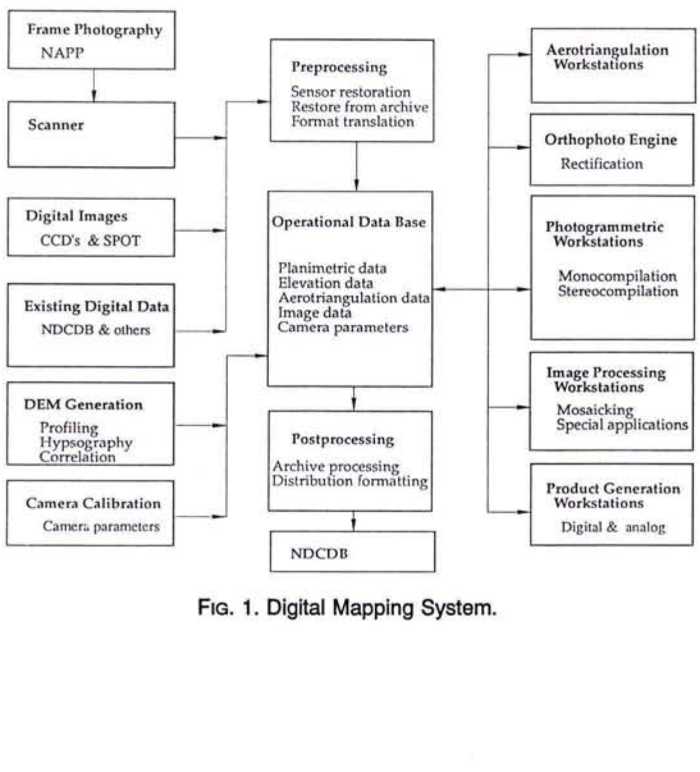

FIG. 1. Digital Mapping System.

crometre picture element (pixel) produces an acceptable image product for many applications. This pixel size produces a rectified image with nearly 3,800 samples by 3,100 lines or a data set of roughly 13 megabytes (Mbytes). A 25-micrometre image quadruples the amount of storage required. When generating hardcopy, a 25-micrometre spot size is desirable because each pixel in the orthophoto is enlarged from photographic scale to final orthophoto scale. The higher resolution maintains better image quality. Scanning times depend on the aperture used, the speed of the scanner, and the number of passes required to digitize the desired colors.

Digital Inputs

The following data are needed to produce a digital orthophoto:

- Ground control—easting, northing, and elevations in a plane coordinate system.
- A rectangular DEM.
- Photo coordinates of the ground control.
- Camera calibration parameters.
- A file of gray-scale values from the digitized aerial photograph.
- Line and sample numbers of the fiducial marks in the digitized aerial photograph file.

The photo coordinates and corresponding ground coordinates can be obtained from normal aerotriangulation procedures. The DEM must be rectangular and cover the pass points and the quadrangle corners. Currently, DEM data are generated by profiling on stereoplotters, digitizing contour data from existing topographic maps using vector and raster techniques, or as a by-product of orthophoto generation on the Gestalt Photomapper.

Computer Processing

The software first computes the parameters to transform the scanned photograph data to the camera system. Secondly, the software performs a space resection of the scanned photograph using available ground control and the corresponding photo coordinates. Differential rectification to remove relief displacement is made on a cell-by-cell basis. A cell (30 by 30 metres) is bounded by four adjacent elevations from the DEM data. Each cell is subdivided into ground resolution distance represented by the pixel size. The four elevation posts are used in a linear interpolation of elevations for each subdivision. The proper gray-scale value from the scanned data is selected for each subdivision using nearest neighbor, bilinear, or cubic convolution resampling.

Digital Outputs

Digital outputs take three forms:

- Digitized aerial photograph.
- Digital orthophoto.
- Hard-copy produced from the digital orthophoto.

A raw image is an aerial photograph that was digitized without processing or image manipulation. The digital orthophoto is differentially rectified so that each pixel is referenced to its proper ground position. The hard-copy orthophoto can be produced by continuous tone plotting of the digital orthophoto file with a film writer. For mosaicking, the orthophoto is digitally processed to remove join lines between the mosaicked images. The mosaicking software can join simple rectangles or complex polygons to form one complete image. The join lines are removed by a simple ramp perpendicular to the join lines.

Production Times

For a digital orthophoto based on a NAPP photograph, production times are as follows:

Technical planning	1.1 hours
Aerotriangulation	5.5
DEM production	3.5
Digital orthophoto	2.0
Hard-copy finishing	8.7
Total	20.8 hours

Data Storage

Storage of data before and after rectification is on 9-track magnetic tape or on disk. A 25-micrometre digital orthophoto file is approximately 60 Mbytes for each photograph. Storage of orthophotos for the conterminous United States would require at least 120,000 tapes. The same data could be stored on 2,700 8-mm digital audio tapes.

Hardware Requirements for Minimum Digital Production Levels

Hardware requirements for digital orthophoto production include a scanning microdensitometer for digital image scanning and a computer to differentially rectify the digitized photograph. An operational database for archiving digitized data after scanning and rectification is also needed to effectively manage the large volume of data.

Scanner

A single-pass scanner is required to achieve a reasonable production capability. These scanners can digitize one black-and-white (B&W); or three red, green, blue (RGB); or four B&W and RGB bands in a single pass over the photograph. Charge-coupled device (CCD) flatbed scanners with optically joined images are faster than drum scanners; however, they tend to be more expensive. The Survey currently uses an Optronics ColorGetter 4100SP for its prototype production system.

Computer

A dedicated very high-speed computer is also required. Approximately 8 Mbytes of memory is now used for production of one orthophoto band. Minimum disk capacities should be 650 Mbytes to contain one RGB or several B&W orthophotos on the disk system at one time. To decrease processing time, software should be parallelized. Image processing software optimized for parallel execution must also be available for image enhancement and digital mosaicking. The computer used by the Survey is a Stardent GS3000 graphics supercomputer.

PILOT PRODUCTION PROJECTS

Project Descriptions and Objectives

Both the Rocky Mountain Mapping Center (RMMC) (Lestinsky, 1990) and the Mid-Continent Mapping Center (MCMC) (Fuller, 1990) of the Geological Survey have research projects that implement soft-copy monoscopic revision with Intergraph workstations. The objectives are to determine source material requirements, evaluate the hardware and software platforms available in-house, and develop preliminary system requirements and workflow procedures. A comparative analysis of the two projects follows.

Investigation Parameters

Workstation Configurations

Both projects were conducted with Intergraph's Interview 3240 workstation. (The Survey currently has 40 of these workstations in production centers.) Different software environments were used for each project. The RMMC used Microstation 32 and RETSAM-32 (Survey developed application based on Intergraph's Interactive Graphic Design Software (IGDS)) to handle the vector data and I/RASC for imagery display operations. The MCMC used the Intergraph TIGRIS software that provides for both vector and raster data functionalities. TIGRIS Analyst was used for vector data manipulations and TIGRIS mini-imager provided the image display. TIGRIS mini-imager provided image processing functions that were lacking in the RMMC configuration. The specific hardware and software configurations are outlined in Table 2.

Quadrangle Maps

Both studies used 1:24,000-scale, 7.5-minute maps. The RMMC revised the Mont Belvieu, Texas quadrangle, and the MCMC revised the southwest quarter-quadrangle of Waukegan, Illinois.

Source Material

In addition to the use of different maps, the RMMC had access to field- annotated photographs at 1:18,000 scale. These photographs were used to aid in the feature classification process and to provide a check against the quality of classification when using only the NAPP stereophotographs and the digital orthophoto quadrangle (DOQ) displayed on the monitor. A field operation prior to revision compilation is not planned in the future. The field-annotated photographs were used to view what might be achieved with this type of approach and to validate the feature classification that was achieved with only the NAPP source material. Table 3 outlines the source material used for each project.

File Sizes

One of the main reasons for conducting these projects was to determine if current workstation configurations could handle the large volume of data that would need to be processed in a softcopy revision production program. The DOQ with overedge data is required in the production process and can be used to facilitate feature edge-matching operations for adjacent quadrangles. If image enhancement is applied to the DOQ to enable more successful feature identification and results in one or more image files for any one quadrangle, it is easy to see the need for additional disk storage. Ultimately, local and wide area telecommunications and data archive requirements will need to be addressed prior to any production implementation. Table 4 outlines the file sizes for the original and trimmed DOQ and digital line graph (DLG) files.

Investigation Results

The results are provided in terms of performance for both the hardware (machine processing time) and time to revise (man-hours). In addition, the success of feature classification using a soft-copy monoscopic process was determined.

Processing Times

Tables 5 and 6 outline the recorded processing and man-hour times for selected operations. The processing times in Table 5 apply to quarter-quadrangle data sets and compare I/RASC used by the RMMC with TIGRIS used by the MCMC. In addition, the MCMC used the window and scale function (zoom) in TIGRIS to determine refresh times. The revision times in Table 6 serve as a preliminary indicator for what might be achieved with this process considering that MCMC times reflect revision of the SW quarter-quadrangle for Waukegan and RMMC times reflect revision of the entire quadrangle for Mont Belvieu. The two quadrangles differ in both feature density and regional characteristics with Waukegan urban and Mont Belvieu largely rural. Separate feature category times were not available for the Waukegan test.

Table 2. Workstation Configurations

Hardware:	RMMC/MCMC	Interview 3240 14 MIPS CLIPPER C300 Processor 32 Mb Memory I/O Processor-80386 Disk-156 Mb and 355 Mb Monitor-dual screen, 19 inch 1,184- by 884-pixel resolution 512 display colors
Software:	RMMC	UNIX System V, Release 3.1 with Berkeley extensions I/RASC Microstation 32 RETSAM-32
	MCMC	UNIX System V, Release 3.1 with Berkeley extensions TIGRIS

Table 3. Source Material

Source Material:	RMMC	NAPP quarter-quad centered 20,000-foot flying height Kodak Aerochrome IR 2443
		Digital Line Graph
		DEM (level 2)
		Field annotated photographs (1:18,000-scale)
	MCMC	NAPP quarter-quad centered 20,000-foot flying height Kodak Aerochrome IR 2443
		Digital Line Graph
		DEM (level 2)

Table 4. File Sizes

File type	Digital orthophoto quadrangle (megabytes) Overedge	Trimmed
25-micrometre, B&W quarter-quadrangle	85	55
50-micrometre, B&W quarter-quadrangle	21	13
50-micrometre, CIR quarter-quadrangle	64	39
Quadrangle	DLG	
Mont Belvieu, Texas full quadrangle all categories (except hypsography)	2 (IGDS)	
Waukegan, Illinois full quadrangle all categories (except hypsography)	13 (TIGRIS)	

Table 5. Processing Times

RMMC-I/RASC	Processing times 50-micrometre B&W	25-micrometre B&W
Convert DOQ into continuous tone (COT)	2:30	11:00
Load COT into IGDS	0:10	0:23
Refresh screen (full image & DLG)	0:10	0:28
MCMC-TIGRIS	50-micrometre B&W	25-micrometre B&W
Convert DOQ into COT	1:20	6:22
Refresh screen		
image/DLG/1:18,000	0:40	–
image/DLG/1:9,000	0:15	–
image/DLG/1:4,500	0:05	–

TABLE 6. MAN-HOURS

Feature Categories	Man-hours to revise	
	Mont Belvieu	Waukegan*
Roads and trails	40	–
Railroads	4	–
Miscellaneous transportation	9	–
Hydrography	24	–
Surface cover	17	–
Survey control	3	–
Manmade features	70	–
Hypsography	17	–
TOTAL	184	160

*SW quarter-quadrangle

Feature Classification

Feature classification accuracy includes the correct identification of features and the collection of a complete set of features considered to be map worthy. Both projects addressed the viability of performing these two functions with 1-metre and 2-metre resolution imagery. The following conclusions were reached:

- Given current disk storage and memory constraints, the 2-metre imagery was used to collect most features. There was, however, sufficient improvement in feature recognition from the 1-metre resolution data to justify the acquisition of additional disk and memory to collect these data from the NAPP for monoscopic revision.
- The quality of NAPP photographs is critical to the feature identification process. Photographs used as a source for DOQ production are currently three generations away from original NAPP source material with a large variance of image quality. Investigation into the production of DOQs from an earlier generation of NAPP photographs is warranted.
- A hardcopy NAPP stereopair and a pocket stereoscope were used to classify the features and determine map worthiness. The monoscopic image did not provide sufficient information to perform this function. Feature delineation was possible from the monoscopic image but required the use of the stereopair as a guide.
- The addition of selected features (levees) and of hypsography, where extensive change has occurred, is not possible with this process.
- In areas of tall vegetation, it was extremely difficult to identify and delineate features. Careful use of the stereopair was required for intermittent drains and manmade structures in these areas. Monoscopic digital revision is more viable in areas where tall vegetation is not a predominant feature.
- Image enhancement was performed on the DOQ to evaluate the potential for feature identification. Image enhancement as a preprocess to monoscopic revision could increase the viability of this process. Manmade features represented the most difficult category to collect from the DOQ and might benefit from certain image processing techniques.

Table 7 was extracted from the study on the Waukegan quarter-quadrangle that used 2-metre imagery and provides more specific results. The revision of the Mont Belvieu quadrangle took advantage of field annotated photographs at 1:18,000 scale to validate and quantify the feature classification results. Table 8 represents the results of selected areas from the Mont Belvieu quadrangle.

TABLE 7. FEATURE CAPTURE AND CLASSIFICATION FOR WAUKEGAN, ILLINOIS, QUARTER-QUADRANGLE

Overlay	Features	Extraction Potential
Railroads	Major lines	Good positioning, but not number of tracks
	Spurs in light industry	Difficult to impossible to capture
Pipelines/ Transmission	Transmission towers	Impossible to capture
	Pipelines	Only if a scar is visible in timber
Roads and Trails	Class 1, 2, 3	Easy in developed areas with engineered roads, classify with ancillary material
	Class 3 highly urban	Very bright signature, difficult in a few select situations
	Class 3, 4 in trees	Must stereoscope
	Class 5	Difficult to impossible to classify
Hydrography	Large ponds	Generally easy, some dense timber and rooftop confusion
	Small ponds	When collecting DLG data, many 60-foot ponds could be missed
	Single line drains	Natural drains in timber difficult to follow
Manmade	Large buildings	Easy, although several black rooftops appeared as ponds and parking lots
	Small houses	Difficult to capture in trees
Vegetative	Large timber stands	Generally easy, although some appeared as wet areas or large water bodies
	Scattered	Difficult in deciduous with leaf-off
Nonvegetative	Sand	Very bright signature, easy to identify in the data set by proximity to water
	Others	No other in data set

FUTURE RESEARCH

SOFTCOPY AEROTRIANGULATION

Conventional aerotriangulation processes to establish mapping control are proven and effective. However, traditional aerotriangulation uses of hardcopy image source makes the interface to a digital revision process cumbersome requiring the development of digital methods of control extension. To revise a digital data set on a workstation requires digital input that is derived from imagery. Aerial photographs will have to be digitized: however, imagery from airborne scanners may also be used in the future. Control can then be derived with the proper type of viewing system, a very fast computer, and large peripheral data storage devices.

The mathematics and some of the processes of conventional aerotriangulation can be used to accomplish digital aerotriangulation. In general, the methods of softcopy aerotriangulation parallel conventional procedures. A sketch of the way it could be accomplished follows:

Planning

Aerial photograph contact prints would be used for the planning. Location of ground control, pass points, and tie points would be circled on the photographs and diagramed. Working along the flight line, pass points and control would be circled and diagramed. Tie points between flight lines would then be circled on the respective adjacent photographs and diagramed. This process would continue until the entire block of photo-

TABLE 8. FEATURE CAPTURE AND CLASSIFICATION FOR THE MONT BELVIEU, TEXAS, QUADRANGLE

Collected with annotated photography	Results with no annotation
New small subdivision (NE)	
6 roads (class 1 and 3)	same
1 pond, 2 ditches	missed pond
1 pipeline	saw scar
39 buildings	missed 4 buildings/misclassified 5 buildings
New subdivision in rural area (SE)	
22 roads (class 1 and 3)	added 2 extra roads
2 ditches	added extra ditch and extra small pond
103 buildings	missed 1 building/collected 4 extra buildings
1 water well	missed
1 water tank	missed
Small section of former downtown Mont Belvieu (NE)	
17 roads (class 1, 3 and 4)	collected 4 extra roads
1 ditch	same
1 pipeline	saw scar
29 buildings	missed 14 buildings/added 7 extra buildings/for many of the buildings in this area it was difficult to ascertain what was or was not a building; some were abandoned, surrounding contrast was very poor for others
10 tanks	missed all tanks
Small section with tree cover (NE)	
8 roads (class 3 and 4)	missed 1 road/added 2 extra roads
7 ponds	missed 4 ponds
13 buildings	only saw 1 clearly contrast was very poor in this area
4 large tanks	same
9 railroad sidings	only saw 3 clearly
Part of Chevron Chemical Plant (NE)	
41 roads (class 3 and 4)	missed 3 roads/misclassified 3 roads
16 ponds	missed 4 ponds
52 railroad sidings	could not see most of them clearly enough to properly digitize
68 tanks	missed 21 (the smaller ones)
35 buildings	missed 9 and was not sure of classification or extent of some of the others, contrast was also poor in this area

graphs was planned and diagramed. While the planning and diagraming is in process, the diapositives would be scanned on the scanning microdensitometer.

Point Marking and Measuring

Marking of the control, pass points, and tie points on the digital image would take place in the workstation. Using the planning diagram and delineated photographs, the digitized photographs for each flight and adjacent flights would be loaded into the graphics workstation. Each pass point would be digitally located and measured at the same time. Workstation softcopy would retain point numbers and measured line and sample coordinates for the aerotriangulation points and fiducials on each photograph.

Block Adjustment

The measured data from the graphics workstation would be formatted for input to any one of the block adjustment programs presently in use in the Geological Survey. The storage devices mentioned previously would also be capable of storing the scanned photographs and all measured line and sample numbers. A workstation with stereo capability would be required. It would need a fairly large random access memory with very large peripheral storage devices and the software capability to scroll the stored image from the disk at a rapid rate. Softcopy aerotriangulation is presently at the same stage of development that the digital orthophoto was at several years ago. At that time computers were not large or fast enough to process the digital orthophoto data. Relatively inexpensive computers are now available to process digitized photographs. Small inexpensive workstations with large memories, however, are not yet available.

AUTOCORRELATION—DEMS

Profiling with stereoplotters and converting digitized contour data are the current manual methods for generating DEMs. The Gestalt Photomapper also simultaneously generates both orthophotos and DEMs. Future production requirements for digital orthophoto revision and the age of current hardware are forcing the Survey to investigate new systems for DEM generation. Price-performance ratio for computer hardware and the trend toward softcopy make systems that use autocorrelation techniques a viable next-generation replacement for current production systems.

The U.S. Army Engineering Topographic Laboratories (ETL) has been assisting the Survey in evaluating their autocorrelation system for generating DEMs for the NDCDB. A project is underway to test the system in a production mode to determine accuracy and efficiency. The ETL system, developed by Ray Norvelle (Norvelle, 1990), looks very promising.

SOFTCOPY STEREOREVISION

The Geological Survey and Defense Mapping Agency are investigating softcopy stereorevision technology through a cooperative research project with Purdue University. The math model for SPOT developed by Dr. Edward Mikhail has been installed at several sites for production testing and further research. Current work in this research project is addressing frame photography and soft-copy aerotriangulation.

The Survey has also investigated such systems as the HAI system by Helava Associates and the Digital Stereo Photogrammetric Workstation used by ETL. Other state-of-the-art systems are emerging, and the Survey will undoubtedly procure softcopy stereorevision systems in the future.

CONCLUSIONS

By the year 2000, the Survey plans to have a significant percentage of digital spatial data available from what is now contained in approximately 57,000 maps. Research is underway to provide more current spatial data with the use of digital imagery.

The Geological Survey's initial movement toward a softcopy environment was the implementation of monoscopic revision workstations using digital orthophotos. However, the aerotriangulation and DEM generation portions of the current photogrammetric mapping process are still a manual operation. Correlation techniques are being tested using a Silicon Graphics IRIS 4D workstation and will be implemented into production in the near future. A new digital photogrammetric workstation is being procured for the aerotriangulation and stereocompilation tasks. The implementation of these workstations will provide a complete photogrammetric functionality to test the concept of a digital mapping system.

REFERENCES

Fuller, T.J., 1990. *Investigation of Monoscopic Digital Line Graph Revision/Feature Extraction Capabilities of the Stand-Alone Edit Station with TI-GRIS Platform using Digital Orthophotos*, U.S. Geological Survey, Mid-Continent Mapping Center unpublished report, 57 p.

Lestinsky, H., 1990. *Monoscopic Extraction Pilot Project*, U.S. Geological Survey, Rocky Mountain Mapping Center unpublished report, 21 p.

Mapping Science Committee, Board on Earth Sciences and Resources, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, 1990. *Spatial Data Needs: The Future of the National Mapping Program.*

Norvelle, F.R., 1990. *Digital Photogrammetric Compilation Package*, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

Ramirez, J. Raul, 1991. Computer-Aided Mapping Systems: The Next Generation, *Photogrammetric Engineering & Remote Sensing*, Vol. 57, No. 1, pp. 85–88.

Starr, L.E., 1990. USGS National Mapping Division: Preparing for the twenty-first century: *Proceedings of GIS/LIS '90*, Anaheim, California, Vol. 2, pp. 872–881.