Digital Mapping and Digital Image Processing

... concerned with the development of math strategies associated with the problem of correlating digitized gray-shade data obtained from the common area of two overlapping photos.

INTRODUCTION

We briefly describe our efforts in two related areas, namely, digital photogrammetry and digital image processing. The similarity between the two is that both involve the manipulation of digitized, gray-shade data. They are separate problems in that they differ in their objectives; that is, digital photogrammetry implies working with gray-shade data from stereopairs of records such as a photograph with a map for map revision purposes. Here there would be much digital image processing performed on the photograph prior to correlating these records with each other. This is another facet of our work.

Additional clarification is necessary for discussing digital photogrammetry as opposed to digital mapping. Our definition of digital photogrammetry includes only that
processing for whatever purpose and that very fundamental questions can be better answered in this type environment.

**Digital Image Processing**

**DICOMED System**

The DICOMED image processing system was procured as a relatively low-cost means of entering into the scientific discipline of digital image processing. This hardware system is commercially available. It is flexible, reliable, and of sufficient accuracy and resolution to accomplish much research in software techniques for handling and manipulating digitized, gray-shade data. The hardware is a means of gathering and displaying results whereas the problem-solving aspects are relegated to the development of unique, efficient and oftentimes complex mathematical processes. These two ingredients, the hardware and the software, are currently separate items, but they will soon be brought together into a very versatile, interactive system.

Currently, the hardware is off-line; that is, the digitized photographic data are put on magnetic tape and carried to a computer for subsequent processing. However, the system comes equipped with programmable hardware which will allow us to implement an interactive capability as soon as we take delivery of our control computer system. This will allow an analyst additional flexibility in performing various sophisticated mathematical operations on selected portions of a photograph.

The system consists of five basic components, namely, an image digitizer, image display storage tube, 7- and 9-track tape units, black-and-white and color printing unit and a coordinate entry unit which allows selective scanning, including a single spot. Therefore, the system provides both raster scans and random-point scanning. Each unit has approximately 17 different commands which can be activated once the system is interfaced with a computer.

To afford the reader an idea of hardware capability, we describe, in general, three of the five basic components, namely, the digitizer, tape units, and display. Information on all components of the DICOMED system is readily available from the company itself.

The digitizer offers a choice of scanning speeds and scanning resolutions. For example, a maximum of 2048 by 2048 points can be scanned in 2.5 minutes, or in a maximum of 1.5 hours where the integrate time for spot is 1280 microseconds. The higher quality afforded by the slower scan capability is visible on the display screen. At the other extreme, scanning at a resolution of 256 by 256 points is accomplished in 4.3 seconds and in 87 seconds at the slow speed. The output from all scanning variations can be at either 64 (6 bits) or 256 (8 bits) gray levels, and the effective spot size at the film plane is approximately 25 micrometers. There are numerous other functional versatilities (which are not discussed here) associated with this piece of equipment.

The Image Display unit is a directly viewed image display which constructs visual images from digital information. The dark-trace storage-type cathode ray tube used eliminates the need for periodic refreshing and results in a completely stable presentation. It constructs either single or multiple images and uses either a raster scan or random position format. A command structure is provided which allows the image display to be operated either manually or under program control. It constructs images with a resolution of up to 2048 points per axis where each point assumes one of 64 possible intensity levels.

The tape unit portion of the system is capable of operating in one of five modes: Bypass, Write, Read, Read-after-Write, or Computer. The Bypass mode allows direct operation between Digitizer and Display thereby bypassing the tape transport. The Read mode allows reading from tape onto the display whereas the Write mode allows recording on tape from the digitizer. In the Read-after-Write mode, data are recorded on tape from the digitizer and 25 milliseconds later the data are read from the tape and transmitted to the Image Display. The tape unit, as with the other components, can be interfaced with a computer thereby allowing approximately 17 different commands to be activated between computer and tape unit.

This brief summary of only three of the DICOMED components has been presented primarily to reflect the versatility of the system. When the system is interfaced with our computer, which in turn will be capable of tasking our digital image processing software system, we believe that we will have a versatile tool for conducting research in digital image processing with applications in photo and radar interpretation, perspective scene generation, line-of-sight problems, creating a learning process for pattern recognition, simulating various types of hardware, etc.

**Software-Digital Image Processing**

The development of a flexible software system for digital image processing is in operation at USAETL. The system is called Digital Image Manipulation and Enhancement Sys-
tem (DIMES) and was developed for USAETL by the Computer Sciences Corporation (CSC). Application routines are modular and are called for execution through a free-form user-oriented source language similar to image processing languages in use at the Jet Propulsion Laboratory, Goddard Space Flight Center, and Rome Air Development Center on other computers. It cannot be stressed too strongly that the system is user-oriented. Users are not burdened by data handling problems and complex mathematical developments.

The extreme flexibility of the digital method in image processing makes a wide variety of linear and non-linear processes possible. Some of these uses are:

- Picture generation
- Intensity manipulation
- Geometric manipulation
- Spatial frequency operations
- Analysis
- Multipicture analysis
- Emphasize details
- Sharpen the picture
- Modify tonal range
- Aid picture interpretation
- Remove anomalies
- Detect differences between pictures.

Two scenarios of typical applications are given here. For example, one problem might involve improving the visibility of features in a photographic image. This might include the steps:

1. Read the image into direct access storage from the tape produced by the image scanner.
2. Generate a histogram of gray-level distributions.
3. Stretch the contrast for the range of gray levels which contained most of the image information.
4. Use Fourier transform techniques to generate a digital filter, appropriate to the optical transfer and noise characteristics of the camera system, for reducing image blur.
5. Perform the digital filtering by convolution.
6. Add a descriptive alphanumeric text to the image.
7. Write the image back to tape in a format acceptable to the image display or recording device.

A second problem might involve the registration of an image with a base map or reference image. The steps for achieving this include:

1. Select prominent features which can be identified in both the problem image and the reference image.
2. Determine the precise position of each feature in the problem image relative to the reference image by means of digital correlation over the neighborhood of the feature.
3. Compute coefficients for a suitable linear or non-linear geometric transformation which will bring the selected features in the problem image into registration with the reference image.
4. Perform the geometric transformation.
5. If a composite is being constructed, average together the overlapping image areas.

To execute problems similar to those outlined above, the analyst simply writes a group of command verbs, each followed by fields and subfields, which provide more specific information about the image. Several samples of these commands are:

- RESERVE: Allocate space for a new image on tape or disk.
- FIND: Locate an existing image on tape or disk.
- PARAMS: Name a parameter set for use by multiple tasks.

The basic manipulation and enhancement routines required to conduct the sequence of events outlined above may consist of user-oriented verbs such as:

- HISTO: Compute a histogram of intensity values for a specified image segment and display it graphically on the line printer.
- CONTRAST: Perform a position-independent contrast conversion using a user-specified linear, piecewise-linear, or nonlinear relation between the old intensity values and the new.
- MOSAIC: Form a mosaic by inserting pieces from two or more input images into the output image.
- FFT: Perform a one or two-dimensional fast Fourier transform or its inverse on a data set in floating point format.
- FILTGEN: Compute a frequency-space or convolution (image-space) filter corresponding to a user-specified modulation transfer function.

As examples of other applications, pattern recognition and feature recognition may be facilitated by contrast manipulation to accentuate density thresholds, convolution filtering to detect lines and edges, and generation of phase, amplitude and logarithmic amplitude maps for the two-dimensional frequency spectrum of the image. In addition, comparison of images taken in different spectral bands or at different times may be facilitated by computing intensity differences, and photometric corrections for nonuniform response of video-type cameras may be applied using position-dependent contrast correction.

With this brief and nontechnical descrip-
tion of DIMES, it is intuitively evident that a great deal of mathematics and data handling is being performed through the use of simple verbs specified by the user. It is this aspect of DIMES which should lead to expanded applications of digital image processing for experimental purposes and which should eventually find its way into production environments.

As stated earlier, we shall have DIMES available through our DIONED system which will be interfaced with a control computer. This computer in turn will communicate with the CDC 6600 computer at 50,000 bits per second transfer rate.

**Digital Photogrammetry**

Our efforts in digital photogrammetry are primarily concerned with the development of mathematical strategies associated with the problem of correlating digitized gray-shade data obtained from the common area of two overlapping photographs. The key words are development of mathematical strategies, thereby implying more than simply adopting one of several well-known equations, such as the linear correlation coefficient equation, to determine whether correlation of conjugate imagery occurs. Our feeling is that the strategies to be developed for total automation are still futuristic and that they have a better chance of evolving in a somewhat general purpose environment as opposed to outright development of special purpose hardware. That this is essentially the case, we point out that numerous questions still arise with current, specialized stereo-compilization equipment even though it has been in production for a number of years.

The data we have been working with thus far comes from an unrectified, stereopair of photographs taken over the Arizona and Fort Sill areas. Approximately 30 different scenes have been digitized using the USAELT microdensitometer. The photographs are at the scale of 1:47,000, and the 30 scenes fall roughly into eight categories:

- Urban area
- Small furrows
- Dark fields
- Drainage patterns
- Mountainous regions
- Flat terrain
- Orchards
- Forests

**SOFTWARE**

All of our software is being written for the CDC 6600 computer. We are using the digital data management capabilities of our DIMES package and all routines written thus far will be converted to modules of DIMES. This will give us added flexibility in manipulating the digital data.

Software is being written in-house to test essentially one concept but embodying several correlation measures. The concept is called the Infiltration Process and it, in turn, uses a Mixed Coordinate scheme. These terms will be defined shortly. It is made clear that testing a concept does not imply that we would eventually recommend it as the best way to do digital photogrammetry. We realize immediately that a large computer memory may be necessary to implement this concept and that it may not be cost-effective until such time that high-speed, mass memories become commercially available. Possibly, with greater consideration given to data organization, this may not be a stringent requirement. This becomes part of our systems analysis. On the other hand, it does offer the possibility of total automation and we find that numerous mathematical strategies evolve which would be tested regardless of the concept.

**INfiltration and Mixed Coordinate Scheme**

Usually the independent coordinates of a stereopair are selected on one image in a prescribed way, say along raster lines, and the dependent coordinates on the stereomate are then calculated. The mixed coordinate scheme defines a coordinate on each image as the independent pair and the two remaining coordinates, one on each image, are then calculated. This approach allows for a significant decrease in interpolation for gray levels over the usual approach.

The matching process generates a matched point, say point $P$, from a neighboring matched point, say point $\Phi$. Let $JXA\Phi$, $Y\Phi$, $X\Phi$ and $IYB\Phi$ be the image coordinates of point $\Phi$ on images $A$ and $B$. $JX\Phi$ and $IY\Phi$ are the independent coordinates and $Y\Phi$ and $X\Phi$ are the derived dependent coordinates. The independent coordinates of point $P$ are defined to be:

- $JXBP = JXA\Phi + \Delta X$
- $IYBP = IYB\Phi + \Delta Y$

where $\Delta X$ and $\Delta Y$ are defined incremental changes. The essential idea in the infiltration process is that $\Delta X$ and $\Delta Y$ are chosen so that the matching proceeds along paths that show the greatest promise for successful correlation. If $\Delta X$ and $\Delta Y$ are sufficiently small, then the dependent coordinates of $P$ are estimated from the prediction equations,

- $YAP' = Y\Phi + RAX + S\Delta Y$
- $XBP' = X\Phi + T\Delta X + U\Delta Y$. 

These equations are used to generate the predicted coordinates of the matching points, $YAP'$ and $XBP'$, which are then compared with the observed coordinates, $Y\Phi$ and $X\Phi$. If the predictions are within a specified tolerance, the matching is considered successful and the coordinates are accepted. Otherwise, the search is continued along the same path or another path is chosen and the process is repeated.

This approach allows for a significant decrease in interpolation for gray levels over the usual approach.
R and S are the partial derivatives of YAP with respect to the independent X-coordinate and with respect to the independent Y-coordinate, respectively. T and U are similarly defined. The partial derivatives are estimated from previously matched points at and around point \( \Phi \). The prediction equations are derived by Taylor expansion after assuming the existence of a functional relationship between the dependent coordinates and the independent coordinates. The prediction equations can easily be enlarged to include second- or higher-order terms.

The predicted coordinates are refined by generating a correlation function at and around \((YAP',XBP')\) and then defining the coordinates associated with the peak correlation as \((YAP,XBP)\). The value of the peak correlation and the shape of the correlation function are used to evaluate the quality of the match.

**RESULTS**

The results shown in Tables 1, 2 and 3 pertain to an urban scene taken from the Phoenix model. Input included the exterior orientation of each photograph. The spot spacing is 12.5 \( \mu \text{m} \) and the spot diameter is 25.0 \( \mu \text{m} \). In the matching process, seven arrays were generated in the direction of major parallax, i.e., the array centers were selected along the computed epipolar line. The array sizes were \((7 \times 7)\), the spacing within arrays was two spots, and the central array was located at the predicted match point. Seven arrays were also generated in the Y-direction. Note that the central array of the major parallax set is identical to the central array of the Y-set. Two correlation functions were generated by correlating the central array of each set with the seven arrays of the other set. The correlation measure is the well-known linear correlation coefficient.

The process began at the center of the scene \((JXA\Phi = IYB\Phi = 0)\) where four matched points were generated by a TOHOLD routine. The infiltration technique proceeds from the four points and progresses through the scene by attempting to match those points with even independent coordinates. That is

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|ΔX| and |ΔY| are 0 or 25 μm depending on the infiltration path. The tabulated results pick up after the process has matched, or attempted to match, 1761 points. Therefore, elevations at approximately 1000 points in this scene can be computed using these data where the spacing of the points are 25 μm or less; that is, every 4 feet at the scale of the photography.

CP and CQ are the values of the second derivatives of the correlation functions with respect to X (major parallax direction) and Y, respectively. CΦNF is a function of CP, CQ, and the peak correlation in the X-direction. If CΦNF > 0 the match is regarded as successful; if CΦNF ≤ 0 the match is regarded as a failure. PK and QK are the computed shifts along the major parallax and Y directions, respectively. As the orientation parameters are known, the Y shift is constrained to ±0.01 where the sign is determined from the Y correlation function. PX and PY are parallax values. They are the differences between the independent coordinates and the derived dependent coordinates. The column headings of the correlation values pertain to the shift of the corresponding array center from the central array. In this particular example a shift of one unit pertains to 25 μm.

The infiltration process employs a restart feature if the process fails. In the restart mode the process leaves the troublesome area and begins anew in an area determined by the process. For example, if the infiltration process produces 21 failures in a row, the process goes into the restart mode. It turns out that trial 1762 was the 21st failure in a row. (Trial 1742 was the first in this particular sequence.) Note that trial 1763 takes place at a considerable distance from trial 1762. Unfortunately trial 1763 produced another failure (CΦNF = −.025); however, trial 1764 was a successful match (CΦNF = .389). The next three trials were successes, but note that point Φ and P of the last trial are the same as trial 1767. This is because the infiltration process will attempt a new match at the same point with refined values of R, S, T and U if |PK| is greater than a given test value. In this example, the test value was 0.25; the confidence improved (.147 to .317) but the shift got larger. This indicates that the process is running into a sharp elevation change. Note that the peak correlation improved.

With these results, we see that the digital photogrammetric approach gives us information on the quality of a match as a byproduct of the operation. This kind of information will be available to operators of future digital systems and should be of tremendous value in producing quality products for which information on the degree of goodness is available at each step. By the same token, at the input end of the operation, operators will be able to specify various parameters designating the quality required as output. These input parameters will be developed as part of our effort, also.

**Hardware: Associative Array Processor**

Special efforts have been made to investigate current digital technology and its development for processing data in parallel. Probably the best known of the parallel processors is the ILLIAC IV computer which is now installed and operating at NASA's Ames Research Center, Moffet Field, California. However, during the development of this computer, industry began implementation of this type digital technology into much more special-purpose parallel processors, thereby reducing costs significantly. As time passes, we read more and more about these special, digital parallel processors being used in place of so-called analog systems. One reason for their popularity is that they offer a degree of flexibility not afforded by other types systems in that they are programmable. We believe that the degree of programmability is directly related to their cost. In any event, among numerous other reasons which are beyond the scope of this paper, the programmable aspects of these processors offers the opportunity to change strategies without significantly changing hardware. This was a recognized fact by personnel at the Goodyear Aerospace Corporation (GAC), Akron, Ohio, a number of years ago which in turn led to their development of GAC's Associative Array Processor (AAP)^4, called STARAN, and is now commercially available.

Let this brief and very general discussion of parallel processors indicate our interest in their potential for processing photogrammetric, digitized gray-shade data. As a result, we developed an idealistic scenario which could be supplied to several manufacturers so that they could provide timing estimates based on exactly the same ground rules. This scenario is:

- **20-μm spot size.**
- **40-square-inches of stereo area.**
- Assume digitized, gray-shade data is readily available, i.e., idealistic high-speed mass memory system (no data transfer rates involved).
- Arrays are 11 × 11.
- Move the array throughout the 40-square-inch area.
- Assume a match at each move.
There are approximately $56 \times 10^6$ moves or matches.

No computational short cuts.

Evaluate timing estimates for the absolute difference algorithm between two arrays (Algorithm 2 in Table 4).

Personnel in the Computer Sciences Laboratory, USAETL, developed the timing estimates for the CDC 6600 computer using the minor cycle times of this machine, i.e., 200 nano-seconds for an add. The results of this timing game are given in Table 5, comparing the CDC 6600 with GAC's S-1000, STARAN, which is a four-array processor. Not only is the aforementioned algorithm evaluated, but several others, also.

As stated earlier, this scenario was evaluated by other parties using their special purpose signal processors. Let it suffice to say that there were slight differences in the estimates among these special processors but large differences if compared to the CDC

### Table 4. ETL Correlation Algorithm Examples.

<table>
<thead>
<tr>
<th>Algorithm No.</th>
<th>Equation</th>
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</thead>
<tbody>
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<td>1</td>
<td>$\sigma_1 = \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} Y_{ij}$</td>
</tr>
<tr>
<td>2</td>
<td>$\sigma_2 = \sum_{i=1}^{n} \sum_{j=1}^{n} \text{ABS}(X_{ij} - Y_{ij})$</td>
</tr>
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<td>3</td>
<td>$\sigma_3 = \sum_{i=1}^{n} \sum_{j=1}^{n} \left( X_{ij} - Y_{ij} \right)^2$</td>
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<tr>
<td>4</td>
<td>$\sigma_4 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} Y_{ij} - \left( \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} \right) \left( \sum_{i=1}^{n} \sum_{j=1}^{n} Y_{ij} \right)}{n^2 - 1}$</td>
</tr>
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<td>5</td>
<td>$\sigma_5 = \left[ \left( \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij}^2 \right) \left( \sum_{i=1}^{n} \sum_{j=1}^{n} Y_{ij}^2 \right) \right]^{1/2}$</td>
</tr>
<tr>
<td>6</td>
<td>$\sigma_6 = \frac{\sigma_{xy}}{\left( \sigma_{xx} \sigma_{yy} \right)^{1/2}}$</td>
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</tbody>
</table>

where:

$$\sigma_{xy} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} Y_{ij} - \left( \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} \right) \left( \sum_{i=1}^{n} \sum_{j=1}^{n} Y_{ij} \right)}{n^2 - 1}$$

$$\sigma_{xx} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij}^2 - \left( \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} \right)^2}{n^2 - 1}$$

$$\sigma_{yy} = \sum_{i=1}^{n} \sum_{j=1}^{n} Y_{ij}^2 - \left( \sum_{i=1}^{n} \sum_{j=1}^{n} Y_{ij} \right)^2$$

Note: $n=11$
TABLE 5. COMPARISON OF STARAN S-1000 AND
CDC 6600 COMPUTATION TIMES ESTIMATES

<table>
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<tr>
<th>Algorithm No.</th>
<th>STARAN S-1000</th>
<th>CDC 6600</th>
<th>Time Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.488 hrs.</td>
<td>4.04 hrs.</td>
<td>8.3</td>
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<tr>
<td>2</td>
<td>0.257 hrs.</td>
<td>4.66 hrs.</td>
<td>18.1</td>
</tr>
<tr>
<td>3</td>
<td>0.519 hrs.</td>
<td>12.0 hrs.</td>
<td>23.2</td>
</tr>
<tr>
<td>4</td>
<td>0.892 hrs.</td>
<td>5.9 hrs.</td>
<td>6.6</td>
</tr>
<tr>
<td>5</td>
<td>1.47 hrs.</td>
<td>12.0 hrs.</td>
<td>8.1</td>
</tr>
<tr>
<td>6</td>
<td>1.87 hrs.</td>
<td>15.84 hrs.</td>
<td>8.5</td>
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6600, as is the situation between the CDC 6600 and STARAN. It is very difficult to get a normalized set of values between various parallel processors because they can be configured to the problem.

CONCLUSIONS

We have presented some aspects of our current research in two broad areas, namely, Digital Image Processing and Digital Photogrammetry. Some results of our digital photogrammetric effort was presented primarily to indicate the degree of flexibility that we have in operating in a somewhat general-purpose environment without being strapped with special-purpose hardware. This is especially evident if one considers that we are currently independent of a scanning system. Many specific features of our software for correlating digitized gray-shade data have been omitted simply because we have the capability to add, change, and delete strategies. We have availed ourselves of this flexibility many times and we expect that we will continue to do so. However, we see already that the information obtained from our digital approach will prove invaluable in making judgments concerning the quality of the end product in future systems.

Our efforts in Digital Image Processing have proven to be worthwhile from the point of view that we have already produced simulated PPI radar scenes starting with an aerial photograph. In generating these scenes, extensive use was made of the DIMES software, especially the digital filtering capabilities. Other applications thus far include taking a photograph, digitizing it, and then generate various perspective views of the scene. Views can be made from inside or outside of the data base while simultaneously handling the hidden terrain problem; that is, there are no false representations of terrain after manipulating the data base. We expect that this capability will be useful in radar-scene generation where a proper perspective of objects will give a radar analyst a better chance of assigning proper reflectance values. Also, the process can be used for placement of various perspectives of a portion of the terrain in the border of special map products. The basic philosophy in these efforts is that the photograph itself is the data base, or mass storage device, so to speak, and we must devise efficient means of exploiting this fact.

Not overlooking the fact that we must quickly and efficiently handle digitized gray-shade data, we have investigated recent developments in digital signal processors, array processors, associative array processors, or parallel processors, however closely these processors resemble each other in digital logic, as the means of performing tasks for which they are best suited as opposed to the serial computer. In general, we are interested in maintaining flexibility by being able to program these special processors simply because requirements change.

Finally, we expect that we shall soon have a Digital Photogrammetric Simulation System (DPSS) in which we shall be independent of scanners or any other special-purpose equipment. This will give us an unprecedented opportunity to develop parameters which control the quality of the final product, and will be as variable as one wishes it to become.

REFERENCES