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G. R. Allen
Control Data Corporation

L. O. Bonrud
Control Data Corporation

J. J. Cosgrove
Control Data Corporation

R. M. Stone
Control Data Corporation

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THE DESIGN AND USE OF SPECIAL PURPOSE PROCESSORS

FOR THE MACHINE PROCESSING OF

REMOTELY SENSED DATA

G. R. Allen, L. O. Bonrud,
J. J. Cosgrove and R. M. Stone

Research Division, Control Data Corporation, Minneapolis, Mn. ;
Digital Image Systems Division, Control Data Corporation,
Minneapolis, Mn. ; Control Data Corporation, Houston,
Texas ; Control Data Corporation, Houston , Texas

ABSTRACT

The processing of the expected volumes of remotely sensed data will overburden the available computer resources. One solution to the problem is the use of special purpose processors. This paper describes two such processors which are suitable for processing remotely sensed data. Also, examples of the use of the processors on specific problems encountered in remotely sensed data are described.

INTRODUCTION

The acquisition, processing and use of remotely sensed data is now evolving from a research to a production activity. Thus, the volume of data to be processed will increase several fold. For example, it has been estimated that data rates of the order of 10^{14} - 10^{16} bits per year can be expected in the near future. A data rate of 10^{14} bits per year is equivalent to covering the surface of the earth every eighteen days in six spectral regions with a 200 foot digital sample step. The digital processing of this volume of data will generate a large computer requirement. For example, the processing of an ERTS image of 16×10^{6} resolution elements on large scale general purpose computers using the "LARSYS CLASSIFY" (Purdue, 1970) algorithm (4 channels, 10 classes) will require on the order of several hours of processing time.

This paper addresses the problem of reducing the above requirements through the use and design of special purpose processors. Several special purpose devices have been proposed in the past for processing image data, the most ambitious being the ILLIAC III (Ramsey, 1968). However, special purpose devices (Kendall, 1971) have been used in several other areas such as seismic data and side looking radar processing.

The data volume problem occurred in the seismic data processing industry when the recording techniques changed from analog to digital. Digital recording allowed the use of more sophisticated processing techniques which in turn lead to the design and use of several types of special purpose processors. All of these processors were connected to large computer mainframes and either used their own memories or shared mainframe memories. The early devices were hard-wired to perform multiply-add type operations. The devices have now advanced to such an extent as to be capable of performing a variety of tasks such as FFT, vector operations, weighting, filtering, etc. The latest versions of these devices are also programmable and can

execute multiply-add operations on the order of 75 nanoseconds per operation.

The requirement for real-time change detection with side looking radar (SLR) imagery has led to the development of special purpose digital processors capable of performing image matching, correlation, complex spatial transformations, photonomalization, computation of tonal difference images, feature oriented processing and image enhancement. Again, the first processors were hard-wired, but recent developments have led to the development of micro-programmable processors.

This paper describes two special processors which have been developed for the processing of remotely sensed data. Examples of the use of these processors will include, the automatic registration of ERTS multispectral scanner data, change detection and the classification of agricultural resources.

SPECIAL PROCESSORS

Special purpose processors have been developed to increase the efficiency of data handling where certain calculations are performed repetitiously. Such processors are very advantageous when large volumes of data must be processed, particularly when this data can be conveniently organized in array form. One such processor is the Matrix Algorithm Processor (MAP) which was originally developed to solve seismic problems. Another is the Flexible Processor (FP) which was specifically developed for digital image processing.

MATRIX ALGORITHM PROCESSOR (MAP III)

Earlier models of the Matrix Algorithm Processor were developed for seismic applications. The MAP III processor, which is currently being developed, is a microprogrammable device for the high speed processing of arrays. Since the device is programmable, the number of algorithms that can be executed is unlimited and any new algorithms can easily be incorporated. This provides the further advantage that the MAP III can be interfaced to various computers with minimum design changes. Its design features are summarized in the following:

- External Memory (24-256K)
- Programmable
- Floating Point (32-bits)
- Divide
- Square Root
- Multiply-Add
- I/O Processor
- Random Storage Addressing
- Relative Addressing
- Macro Instructions
- Looping of Macro Instructions
- Interrupt of Macro Loops

The MAP III processor (Figure 1) consists of four functional units:

- the host computer interface
- data storage
- arithmetic units
- control unit

The host computer interface consists of a data channel interface for transfer of control information and data with a second data source from a direct memory access if it is available with the host system. The assembly/disassembly and conversion of data from fixed or floating point to the floating point format internal to the MAP III arithmetic units is contained within this section. Also, a control panel and data input device are provided for off-line diagnostic capability.

The data storage section consists of three memories with separate control to allow

simultaneous access to each memory. Memories A and B are both expandable from 8K to 96K while memory C is expandable from 8K to 64K. The memories store a 32-bit word plus parity. Each memory has universal access to the data bussing structure to allow completely flexible use of each memory in the processing of matrix arithmetic problems.

The following arithmetic functions are provided for the calculation of the 32 bit floating point data:

- Multiply
- Divide
- Add/Subtract
- Square Root

The arithmetic units receive input data from the two operand buses I and II or from the other arithmetic units, as shown, with the result placed on the result bus for further manipulation or to be stored in memory. The arithmetic section can be expanded to allow for up to four multiply, two divide, four add/subtract, and two square root units.

The control unit is a microprogrammable device capable of manipulating the host computer interface, data storage and arithmetic section of MAP III. The control memory will be constructed of semi-conductor ROM I/C's. This will allow the host computer to modify the micro-instruction sequence of the control unit, thus allowing flexibility for future algorithm developments. The control unit will also have the capability to scan through a macro instruction list to allow the same operations on different data arrays.

The MAP III can operate at the following speeds:

- In the multiply unit, the product is available 150 nanoseconds after the operands are clocked into the unit (when multiple multiply units are used the multiply time is equal to 150 nanoseconds divided by the number of units).
- In the add/subtract unit, the sum/difference is available 150 nanoseconds after the operands are clocked into the unit.
- In the divide unit, the quotient is available 1200 nanoseconds after the operands are clocked into the unit.
- In the square root unit, the square root is available 1800 nanoseconds after the operand is clocked into the unit.

The MAP III is programmed using a microcode assembler which generates microcode instruction routines through the specification of mnemonic instruction word fields and their corresponding values. Symbolic addressing is allowed. The use of an assembler allows the microprogrammer to specify values for various fields within a word. Symbolic addressing allows the insertion of new instruction words into the middle of an existing program without having to modify the address fields for existing instructions that reference instructions which are moved upwards by the insertion.

Algorithms can also be programmed as macro instructions which are collections of micro-instructions. With this capability it is possible to string together sets of macro instructions.

FLEXIBLE PROCESSOR

The Flexible Processor was developed for a large digital change detection system for concurrent processing of four channels of side-looking radar (SLR) imagery. Its name is derived from its capability to be micro-programmed to solve a variety of array processing problems, such as sub-region matching, correlation, spatial transformation, photonormalization, photoequalization, difference image generation, and image enhancement. It will find application in many image processing applications.

The flexible Processor is a special purpose computing unit which features high computation performance and input-output capabilities as required for SLR image processing. The logic organization and control mechanisms allow a range of computation, register file, microcontrol,

I/O, and memory capability to be configured for specialized applications without disturbing the basic mechanical and electrical wiring construction. The Flexible Processor (FP) is particularly effective in applications which require a high data throughput. The I/O structure is very flexible and allows serial and parallel arrangements of FP's to work together on the processing problem.

The unit features arithmetic logic capable of a 0.125 microsecond addition of 16-bit or 32-bit operands, a 0.250 microsecond fixed point multiply of 8-bit bytes, and a 1.25 microsecond fixed point multiply of 16-bit operands. The I/O structure provides for high speed file buffered transfers and for slower bus-oriented register biffered transfers. The FP is microprogrammable and uses random access semiconductor memory up to 1024 words of 48 bits each for microprogram control. A dual internal data bus system is used to match data transfer speed to the speed of arithmetic logic. Two 16-bit data buses route operands between the memory, computation and microprogram control memory units as shown in Figure 2. The main features of the FP are summarized below:

- Microprogrammable - random access microcontrol memory
- 32-bit or 16-bit word lengths
- Array hardware multiplier
- 16 level hardware priority interrupt mechanism - 4 mask registers
- Conditional instruction execution - 4 condition and 4 mask registers
- Specialized logic for square root and divide
- 8 mHz file buffered word transfer rate - 16 word x 32 bit unput file buffer
- 2 mHz register - buffered transfer rates
- Dual 16-bit internal data bus system
- 0.125 microsecond clock cycle
- 0.125 microsecond 16-bit or 32-bit addition; 0.250 microsecond byte multiplication; 1.25 microsecond 16-bit multiplication
- Register file capacity up to 4160 bytes in several configurations of speed and size
- Hardware network for conditional microinstruction execution

Four separate balanced partyline transmission channels are available (Figure 2). Each 32-bit channel can initiate and receive register-buffered transfers. A scanning system allows several FP's on a partyline to communicate with each other and with peripheral devices. Each of the four partyline interfaces can communicate compatibly with other equipment. For maintenance purposes a forced transfer capability on the partyline is provided which allows an external device (or another FP) to force data into and out of an FP without the FP having any prearranged programming.

For high speed data transmission (8 mHz) from one Flexible Processor to another, a 32-bit output channel is provided which interfaces on balanced lines with 16 x 32 bit register files in receiving FP's the 32-bit channel is composed of two 16-bit channels which have independent control mechanisms. The input register file of an FP can be written into only by another FP, not by itself. The receiving FP can READ its input file at the same time the sending FP WRITES the file and can be connected to this high speed output channel.

The Flexible Processor is controlled by microinstructions held in a read/write 48 bit semiconductor memory which is expandable from 256 words to 1024 words. A new instruction can be executed every 125 n secs; i.e. at an 8 mHz rate. Four categories of instructions used in the microprogramming are transfer, transfer constant, shift, and I/O.

A 22-bit portion of the 48-bit microinstruction has the same format for each of the four instruction types. These 22 bits select the instruction type and control index register loading and decrementing, multiplier input gating network add/subtract, and logical operations. The other 26 bits are used to control selection of operand source and destination for each of the two data buses, control the shifting registers and control the input/output channels.

IMAGE PROCESSING ALGORITHMS

Image processing algorithms can be broken down into two broad categories, algorithms to perform geometric corrections on the image data and algorithms to perform operations on the image data itself. Examples of the latter are image enhancement involving the redistribution of gray-scale values to effect a different tonal distribution, crop classification based upon gray-scale values, and change detection.

GEOMETRIC DISTORTIONS

Geometric corrections are required to produce an image which accurately represents a preselected projection and which registers point by point with another image of the same scene. The utilization of remotely sensed data typically requires that data values be obtained for the same ground location from a number of images and in different spectral bands. Considering the anticipated work load, it is essential that automatic methods be established for obtaining accurate image registration.

Image registration is complicated by a number of geometrical distortions. Among these problems are scaling, crab and drift, tilt induced displacement, relief displacement, displacement caused by Earth's curvature, and radial lens distortion. Given the required data each of these corrections can be determined directly, but generally sufficient data is not immediately available for all of these factors. Other means must then be applied to eliminate any residual geometrical distortions between images which are to be compared.

The complexity of the geometrical distortions are dependent upon the kind of imagery as well as stability of the photographic platform and ground terrain. For example, roll and yaw in the spacecraft platform will produce a continuously varying tilt displacement in the case of multi-spectral scanner imagery.

For a flying height of 832 kilometers (450 nautical miles) the tilt displacement is about 5 cells at 92 kilometers (50 nautical miles) normal to the flight line when the tilt varies by 1°. (The equivalent ground dimension of one cell is taken to be 76 meters or 250 feet). Many applications will require that two images be registered to within a few cells, and ideally, registration should be to within 1 cell if the data is to be most effectively used. Therefore, it can be concluded that instability of the spacecraft platform can create significant distortions which must be corrected.

When the entire image is exposed simultaneously a single tilt angle applies to the image frame, and the spatial correction is a simple linear function. But the tilt varies from one frame to the next and corrections are needed to register each image with a rectified image.

Elevation induced distortion is often insignificant for satellite imagery, but it can be significant where large changes in ground elevation occur. If a 20% grade should exist over a distance of 3 kilometers (1.6 nautical miles) at a distance of 92 kilometers from the nadir the resulting distortion in the image is 1 cell over a distance of 3.3 millimeters (0.13 inch). Scale = 1:1,000,000 and flying height = 832 kilometers . Thus, for such conditions interpolated spatial transformations should be made on the basis of correlations every 3 millimeters (40 cells) if displacement errors are to be held to 1 image cell. Elevation induced distortions are appreciable in underflight data, and it is important that corrections be made when underflight and overflight data are correlated.

CORRELATION AND SPATIAL TRANSFORMATION

The general approach for deriving a spatial transformation to register two images of the same scene is to determine the coordinates for a number of specific locations in both images and to create an interpolated transformation function satisfying these coordinate values.

For this discussion each image can be considered to be a rectangular array of the gray-scale values at each cell location. The locations of corresponding image points in both images can be determined by placing an M by M window matrix in the independent image matrix and

moving another M by M window over the dependent image until the point of maximum similarity is found. An effective metric for measuring this similarity is the correlation coefficient.

A global map warp over the entire image can be created by a least squares polynominal approximation. A maximum of about 40 degrees of freedom are practical with this method.

Yet another method is to effect a local quadrilateral transformation on four neighboring correlated points with a single analytic function $\emptyset (u, v)$ where

$$u = a + bx + cy + dxy ; \qquad v = e + fx + gy + hxy .$$

Values within the quadrilateral are selected by interpolation or by a nearest neighbor criterion. This method allows for hundreds of degrees of reeedom in the spatial warp.

Global or block processing techniques require large memories and are accordingly expensive. Another technique based upon recursive computation techniques (strip process) was developed in which the imagery is processed continuously with a line at a time from both images being read in simultaneously. A relatively small number of lines from the dependent image are updated in a modest memory, and a corrected scan line is read from this memory to correspond with the current independent scan line. This method has the further advantage that it too provides hundreds of degrees of freedom.

The strip process is utilized in the pipeline digital change detection system which was built for the Air Force, and it is also used in a new change detection system which is under construction. The Flexible Processor as the building block for this new system is capable of solving the numerous processing algorithms. The strip process technique has been applied successfully to a wide variety of side-looking-radar imagery and photographic imagery, as well as to the automatic registration of multispectral scanner imagery from the ERTS-1 satellite (Figures 3, 4).

INFORMATION EXTRACTION

In the process of extracting information from the gray-scale data it is often necessary to perform some kind of image enhancement, e.g., to minimize noise. Image enhancement techniques generally involve filtering of the image in either the space or transform domain. Both of these operations usually require considerable computer effort. However, it is this type of well defined operation that is suited to special processors. In fact, both the MAP III and the Flexible Processors can be configured to perform several of the transform techniques (i.e. Fourier, Walsh, Hadamard, etc.) which are commonly used.

Image detection techniques attempt to extract information from the image. Examples of this are edge detection, crop classification, etc. This type of operation usually requires a systematic scan ot the image and a calculation is done using each pixel. Classification techniques also require ground truth to determine statistical information which is in turn used to classify the image. As in the enhancement process, these techniques usually require considerable calculation. However, since the techniques are serial they are, again, well suited to special processors.

IMAGE PROCESSING EXAMPLES

Special purpose array processors serve the need for reducing the computing load on an existing central computing system. The philosophy behind their development has been to perform the repetitious computations at high speed in the array processor and to use a general purpose computer to supervise the process. Thus the design approach is toward a pipeline system. Aside from this specialized system approach the array processors can be added as peripherals to an existing computer facility and greatly increase the production of that facility. Typical image processing examples suitable for execution in special purpose algorithm processors are discussed in this section.

DIGITAL CHANGE DETECTION

Digital change detection has been successfully applied to side looking radar (SLR) reconnaissance (Lillestrand, 1972; Lam and Hoyt, 1972). In the Air Force system the process consists of simultaneous digitization of a dependent (mission) image and an independent (reference) image, matching, correlation, spatial warping (rectification), photonormalization (transparency rectification), generation of a difference image, and enhancement of the difference image.

The difference image for a SLR image pair will contain a certain quantity of noise in the form of spurious differences or "false alarms" in addition to the desired change events. Under operational conditions reconnaissance flight paths may differ considerably. The false alarm problem is also intensified because of shadow differences and scintillation, i.e., different radar returns from the same feature caused by slightly different aspect angles. Under operational conditions the false alarm rate is typically 20-50%, excluding the effects of small random fluctuations between independent and dependent images. These small random fluctuations caused by noise sources in the acquisition, photo processing and scanning of SLR imagery can be effectively suppressed by the nonlinear enhancement or thresholding techniques described in (Lilliestrand, 1972). The real problem is to develop a means of reducing the false alarm rate for the larger and more systematic false alarms caused by scintillation and shadow differences without reducing the detection rate for legitimate changes.

One is tempted to use the same thresholding technique or some other form of gray-scale processing because of its computational advantages. Gray-scale processing techniques do not utilize information about the spatial distribution of gray-scale or intensity values. These techniques are based solely on the joint distribution or "target classification diagram" (Lillestrand, 1972) of intensity values on the independent and (digitally processed) dependent images. One can exploit the separation between the distributions for legitimate changes and false alarms, then suppress false alarms at minimal expense in terms of the detection rate for legitimate changes. Since these techniques tend to be very simple and require no knowledge of the spatial distribution of gray-scale values, they can be applied on a point-by-point basis as the difference image is generated.

For shadow-induced false alarms there is in general a distinct separation on the target classification diagram and gray-scale techniques are usually successful. Shadow intensity levels vary as a function of the scanning parameters and quality of the imagery, but are typically 0 to 6 or 8 on a six-bit scale. The mean background level on SLR imagery, on the other hand, is typically 14 to 17. Thus, changes usually occur in backgrounds of significantly higher intensity than shadows and a simple thresholding technique (Lillestrand, 1972) and (Lam, 1972) can be effectively used for shadow suppression. The ability to bring two images into precise registration in real time makes digital change detection applicable to a number of image processing problems. Applications which are currently being investigated include the following:

- Change detection of chest radiographs for clinical diagnosis
- Precise registration of multispectral scanner imagery
- Digital change detection for high resolution aerial photography
- Correlation of imagery from different sensors, particularly correlation of SLR with aerial photography
- Cartography, particularly derivation of elevation from stereo photographs .

The versatility of microprogrammable array processors in solving numerous image processing algorithms is illustrated with a particular application of the flexible processor in a digital stereo mapping system (Figure 5). Numerical scanner control, correlation, spatial work, and photonormalization are fundamental to change detection, as well as to mapping. (The numerical scanner control is responsible for utilizing the warp data to read a spatially corrected dependent image). To these are added the functions of computation of elevation, feature extraction, and generation of an orthophotograph.

FEATURE ORIENTED PROCESSING

The assumption is made in feature oriented processing that the relative properties of

features on the independent and dependent images for legitimate changes are significantly different from those for false alarms. For a scintillarion-induced false alarm the same basic feature is present on both images with only minor differences, e. g. , in mean intensity or contrast. For a legitimate change, on the other hand, features on the independent and dependent.

For successful suppression of scintillation-induced false alarms some information about the spatial distribution of intensity values is necessary. In the feature oriented process intensities on the independent and dependent images are compared over an area surrounding a given change event. The change event is then classified using various statistical tests performed over this area. The most significant test uses the correlation coefficient between the two images. Supplementary tests are then performed on the mean intensity and contrast of both images, on the slope of the regression line and on the standard deviation of the joint distribution normal to the regression line. Tests have been made using SLR test imagery with side oblique photography for ground truth (Henrikson, 1972). The classification error rate was 3 change events in 39 (8%), i. e. , 92% of the change events were correctly classified. Moreover, of the 3 events incorrectly classified, only one was a two-cell event while two were one-cell events. Thus in terms of total area, the classification error was only 4 pixels of 383 or 1%, i. e. , 99% of the change events on an area basis were correctly classified.

CLASSIFICATION

This example will consider the implementation of the "CLASSIFY ALGORITHM" which is used in the LARSYS crop classification method (NASA, 1970). The classification algorithm which is a maximum likelihood processor reduces to finding

$$\underset{h}{\text{Max}} \quad \left[1/2 \ (X - M_h)^T \ K_h^{-1} \ (X - M_h) \right] \quad \text{------(1)}$$

Where
- h = number of classes
- X = observation vector (n channels)
- M_h = mean vector for the hth class
- K_h^{-1} = the inverse covariance matrix for the hth class

Equation (1) can be rearranged to give

$$\underset{h}{\text{Max S}} \quad \sum_{j=1}^{N} \left(\sum_{i=1}^{j} d_i \ a_{ij} \right) d_j \quad \text{------(2)}$$

Where
- n = number of channels
- d_i = i^{th} element of $(X - M_h)$
- a_{ij} = ij^{th} element of K_h^{-1} $(i \neq j)$
- a_{jj} = $1/2$ a_{jj} element of K_h^{-1} $(i = j)$

Now the problem reduces to a filtering problem which is suitable for solution on special purpose algorithm processors. If we let P equal the number of pixel elements to be processed and C the number of classes, then, the total number of multiples equals $1/2$ PC $(n^2 + 3n)$ and, the total number of adds equals $1/2$ PC $(n^2 + 3n)$. Thus, knowing the multiply and add times of the special processors, it is possible to calculate the total time required to classify a given area.

Implementation of Classify Algorithm Using Flexible Processors

The following problem has been considered to demonstrate the capability of the flexible processor. Classify an ERTS image of 16×10^6 pixels using 4 channels and 10 classes in 10 minutes. A flexible processor has the following characteristics:

- 125 nanosecond cycle time
- 3 cycles/addition
- 5 cycles/multiply

Thus if only one processor were used, the total processing time would be

$$T = 8.33 \times 10^{-9} \times P \times C (n^2 + 3n) \text{ minutes}$$
$$= 37.3 \text{ minutes}$$

Now, if the processing were distributed over 10 processors, the time would be reduced to 3.73 minutes, which is well within the required time. Figure 6 shows the hardware configuration using 10 processors plus 1 supervisory processor. The software system will consist of two types of programs: the supervisor and the algorithm processor.

The SUPERVISOR program residing in FP No. 1, the supervisor flexible processor, performs the following functions:

- Control the flow of data between the host computer and the flexible processor subsystem
- Load all constant coefficients (K) into the flexible processor subsystem
- Accomplish the final editing of the (S*) partial likelihood values computed in the line flexible processors
- Write each partial likelihood value (S*) and its class number back to the host computer

- Stimulate and synchronize the line flexible processors for one complete iteration
- Buffer the pixel vectors (X) into the flexible processor subsystem.

The ALGORITHM program, residing in each of the line flexible processors, will perform the following functions under control of the SUPERVISOR program residing in the supervisor flexible processor:

- Fetch each pixel vector (X) from its predecessor flexible processor using the input block file
- Perform the algorithm computations with pixel (X) and all of the constant (class) coefficients residing in that flexible processor
- Edit the partial likelihood values (S*) computed in that flexible-processor
- Post flexible processor status to be monitored by the supervisor flexible processor.

It appears evident that the configuration is quite suitable for the processing of many other image processing algorithms. Most of the image processing algorithms can be reduced to a series of multiply-adds which are capable of execution in such a parallel processing mode as that demonstrated in this configuration.

Matrix Algorithm Processor III (MAP III Implementation

Using the same example as the one above, the MAP III which multiplies and adds at a 150 nanosecond rate (1 multiply-add unit) the ERTS image could be classified in 4.5 minutes, even allowing for 100% program overhead, this would still be well under the 10 minute requirement.

For this application the constants such as the covariance inverse matrix and the mean vectors for each class would be stored in one of the MAP III memories. (Figure 1) The pixel data vector would be read into the other MAP III memory. The mean would be removed to yield the d_j elements. Then the two filtering operations would be performed; the inner filter operation would be performed first with the results being stored in the results memory. These results would then be filtered with the d_j vector to produce S. Then the maximum S would be determined, thus giving the correct class to classify the pixel into. This process would be repeated for every pixel on the image. It should be noted that the constant data would only be read to the MAP III memory initially.

REGISTRATION OF MULTISPECTRAL SCANNER IMAGERY

Multispectral scanner image data gathered by the ERTS-1 satellite over Lake Somerville, Texas (Figure) was automatically registered with the strip process technique. These are quarter frame images from Band 5 and represent an area 46 by 185 kilometers (25 by 100 nautical miles). Each image is composed of 2340 scan lines, each line having 700 elements reproduced in 64 gray-scale values.

The time interval between passes is 90 days, and extensive changes in the ground cover

are evident north of the lake (Figure 3). These changes, as well as the clouds and cloud shadows decrease the correlation considerably. However, it was possible to minimize the effect of clouds and their shadows by applying a threshold to the gray-scale data.

A tonal difference image was created by subtracting each dependent image gray-scale value from the corresponding independent image value (Figure 3). Changes are emphasized by digitally increasing the contrast of the middle tones in this difference image. Clouds, on the other hand, are de-emphasized as explained above. It is possible to recover the cloud changes either by storing the threshold data or by applying the derived spatial transformation to the original dependent data, with which a difference image can be created to represent all changes. Such selective processing is very useful.

Despite the clouds and other extensive changes the process (which began at the top or north end) maintained registration generally within one cell. This is demonstrated by superimposing the spatial gradient of the independent image upon the warped dependent image (Figure 4 - magnified section).

Spatial distances along the flight path are consistent to within 2 image elements, indicating very uniform velocity and little pitch and yaw. There was, however, an additional translation of 26 elements in the image data files, but this was readily corrected with the automatic processing. Warp vector components normal to the flight direction were not as consistent, varying from 2 to 21 elements in length. Such displacements are considered significant when remote sensing signatures are constructed.

PHOTONORMALIZATION WITH THE FLEXIBLE PROCESSOR

The photonormalization process adjusts the gray-scale values of the dependent image so that its tonal values match the independent image. This is done to eliminate from the tonal difference image those changes which would occur due to differences in illumination and processing variables. Typically the required corrections are generated from computations of the average value and standard deviation of gray-scale values. These corrections are made continuously over the entire image area as the warp is applied.

This example demonstrates the use of the Flexible Processor in implementing the photonormalization function.

The calculation is, $A_N = A \times C + D$

Where
A = gray-scale value of dependent pixel
C = contrast correction factor
D = density correction factor
A_N = gray-scale value of the normalized dependent pixel

In the correlator the calculations needed to produce new C and D factors are performed by logic sections other than the photonormalization section. The photonormalization logic section implements the above equation and then proceeds with change detection and image enhancement functions. The Flexible Processor was programmed to match the operations carried our by the photonormalization logic section of the Change Detection Correlator.

Photonormalization Program
Gray-scale correction occurs early in the photonormalization program at step 9 (Figure 7). The adjusted dependent and independent pixel values are then subtracted to form the difference. The difference operand is compared with thresholds, DHT and DLT (from flow chart), to determine whether or not a real change is present. The pixel magnitudes are also compared with a threshold, DST which is used to suppress shadows from being labeled as changes. If none of the thresholds are exceeded, the output will be one of three background modes: independent, dependent, or tonal difference image.

It is desirable, as in the case of the tonal difference image, which is generally flat and has very little contrast, to expand the range of its gray-scale values. This is accomplished by

(K) and adding (M). An option controlled by the operator allows either the output or its complement to be displayed.

The Flexible Processor executes the photonormalization at the rate of one pixel in 3.625 microseconds.

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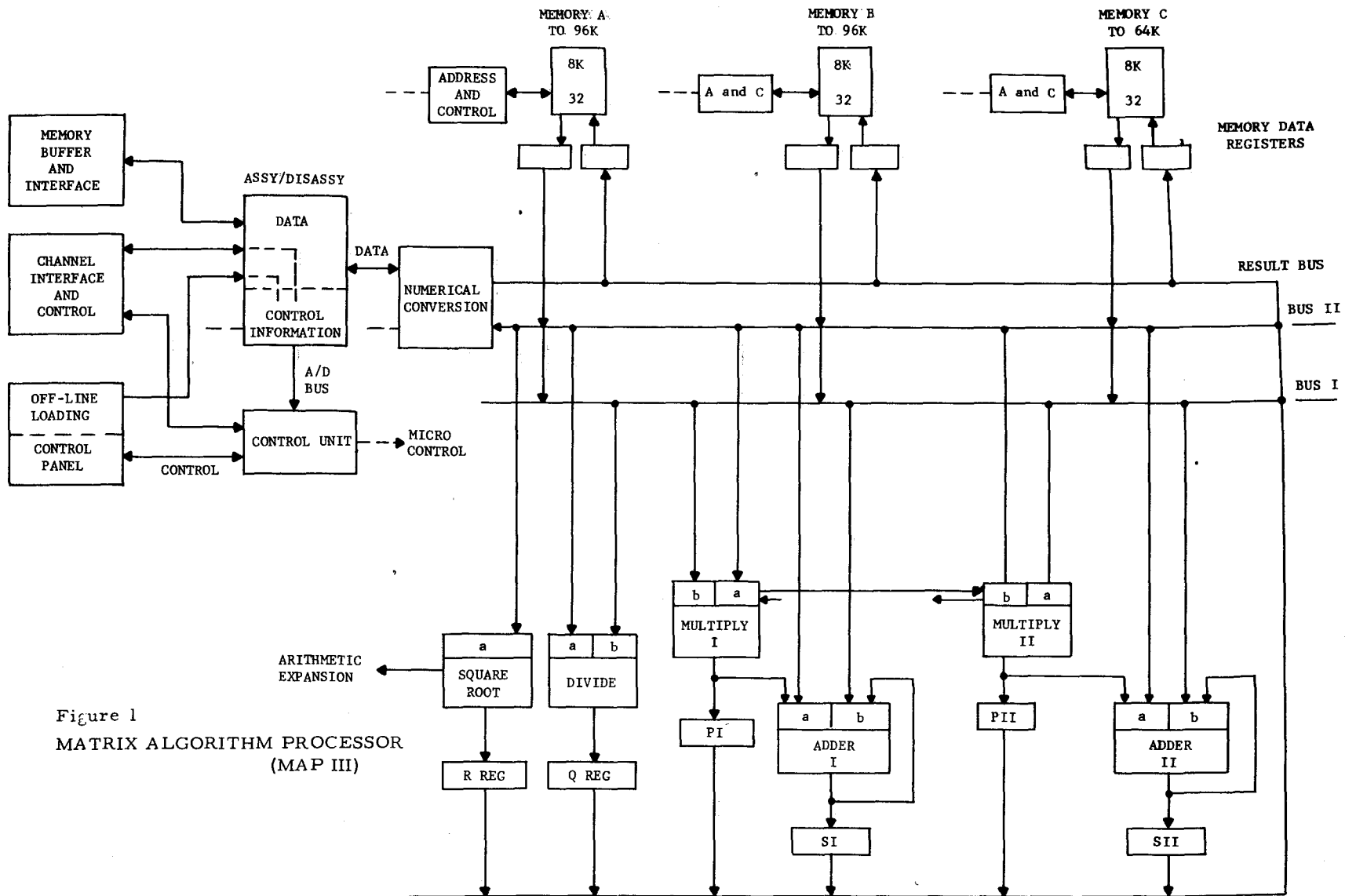
Figure 1

MATRIX ALGORITHM PROCESSOR
(MAP III)

INPUT FILE 16 words x 32 bits

32

PARTY LINE CHANNELS

32 → AQ 3
32 → AQ 2
32 → AQ 1
32 → AQ 0

SMALL FILE 16 words x 32 bits

HIGH SPEED BUFFERED CHANNEL

32 →

LARGE FILE 1024 w x 32 bits

PRIORITY INTERRUPT NETWORK

CONDITIONAL INSTRUCTION NETWORK

ARITH-METIC LOGIC UNIT 32 bits

MICROMEMORY CONTROL NETWORK 1024 w x 48 b

16   16

MULTI-PLIER

16 bit results
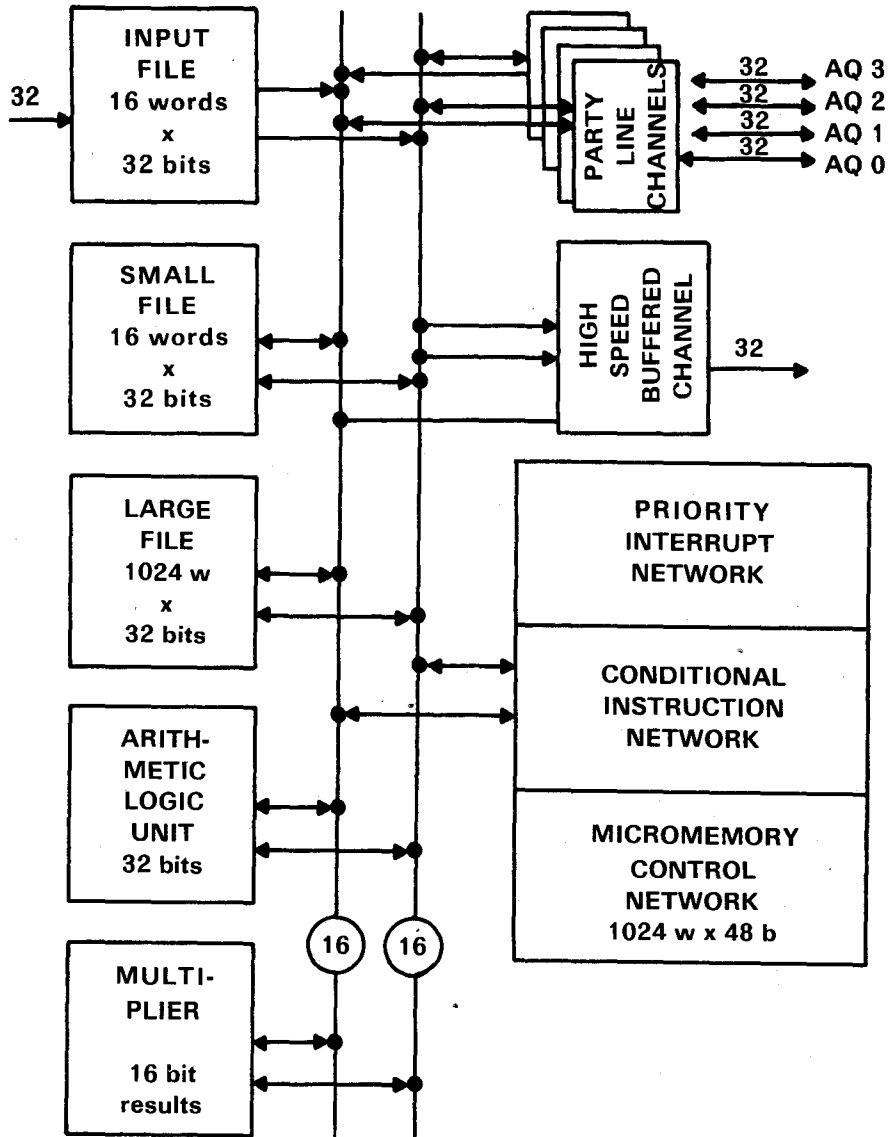
D2013

Figure 2

FLEXIBLE PROCESSOR

1A-37
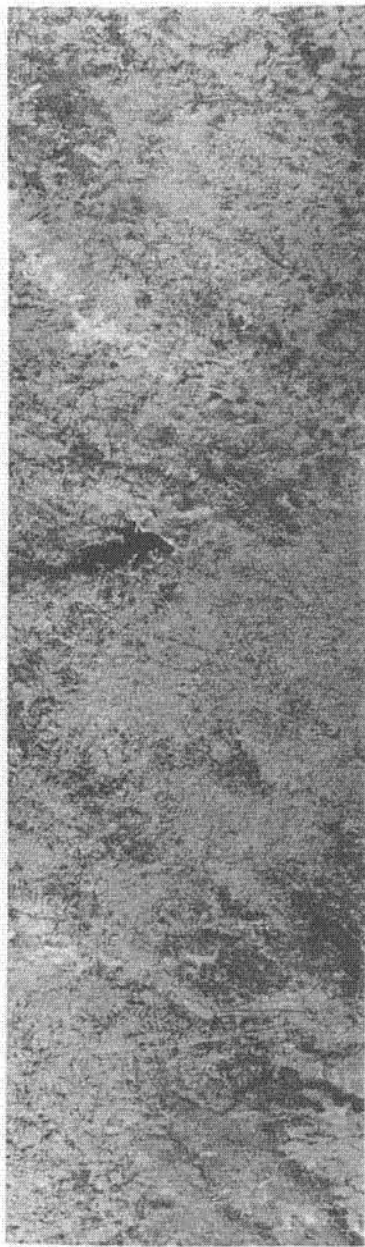
Figure 3
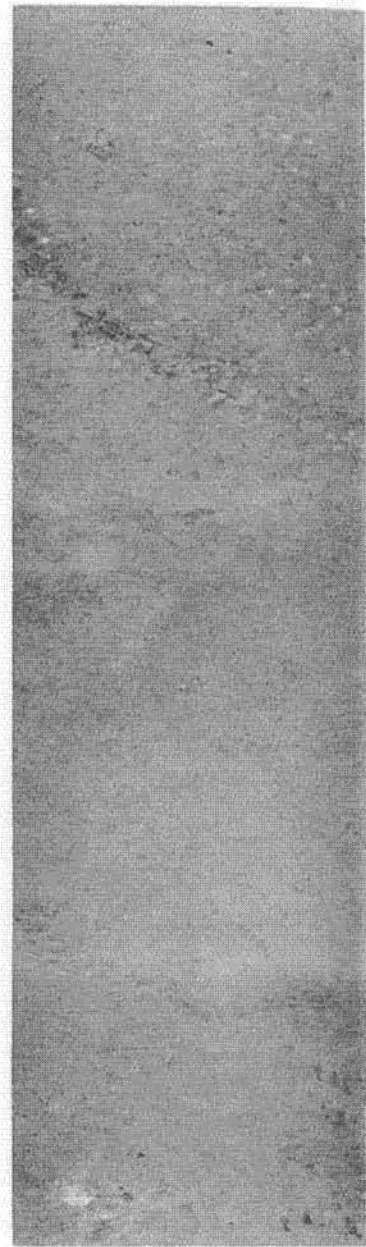
AUTOMATIC REGISTRATION OF MULTISPECTRAL SCANNER IMAGERY
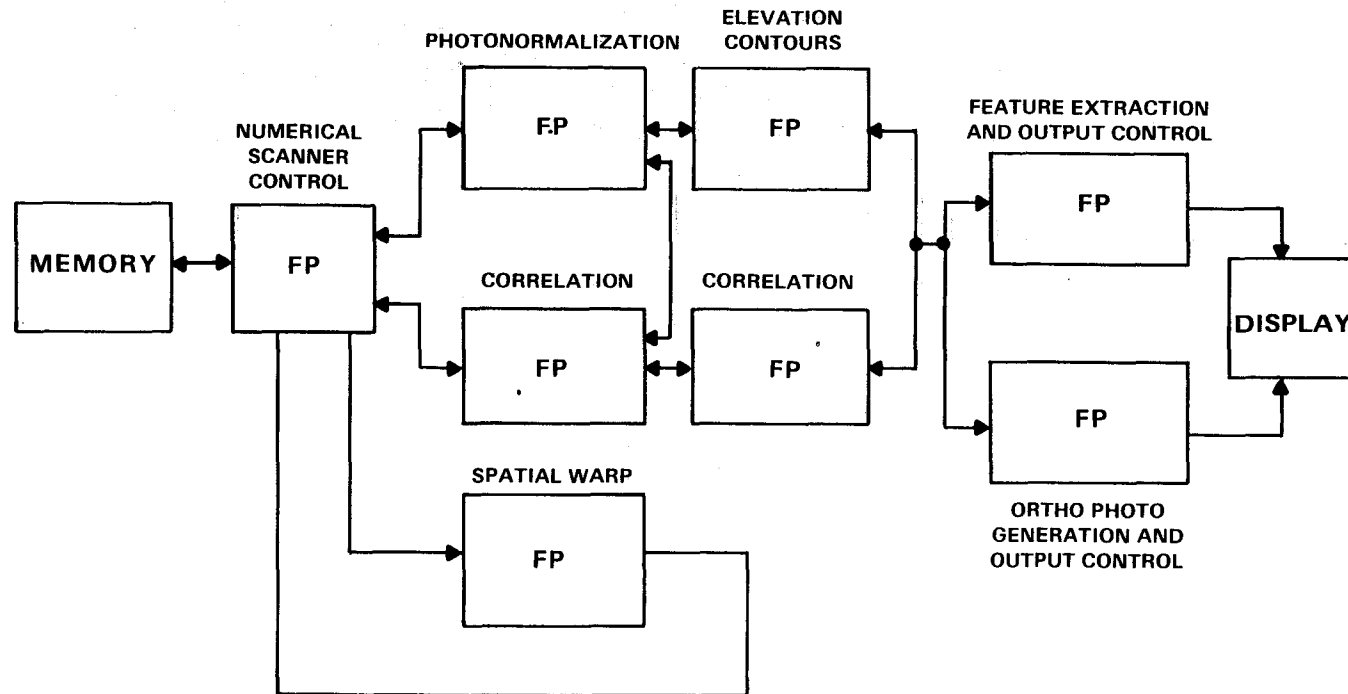a) Independent Image, b) Dependent Image, c) Difference (Emphasized)

Figure 4

GRADIENT OF INDEPENDENT IMAGE SUPERIMPOSED ON DEPENDENT IMAGE

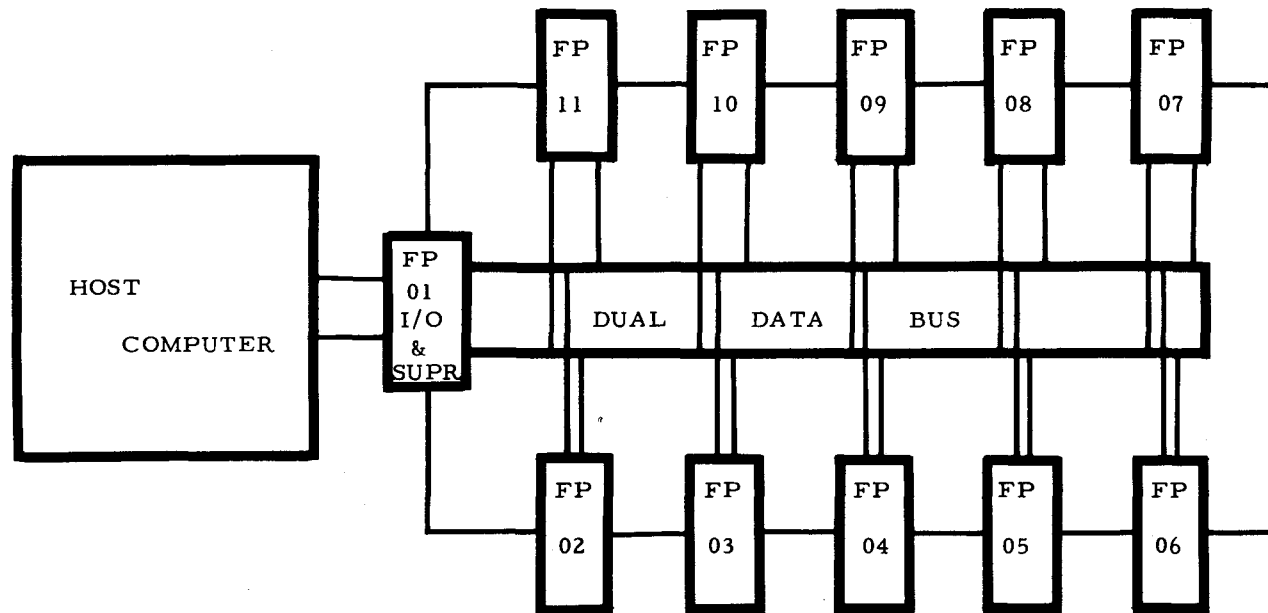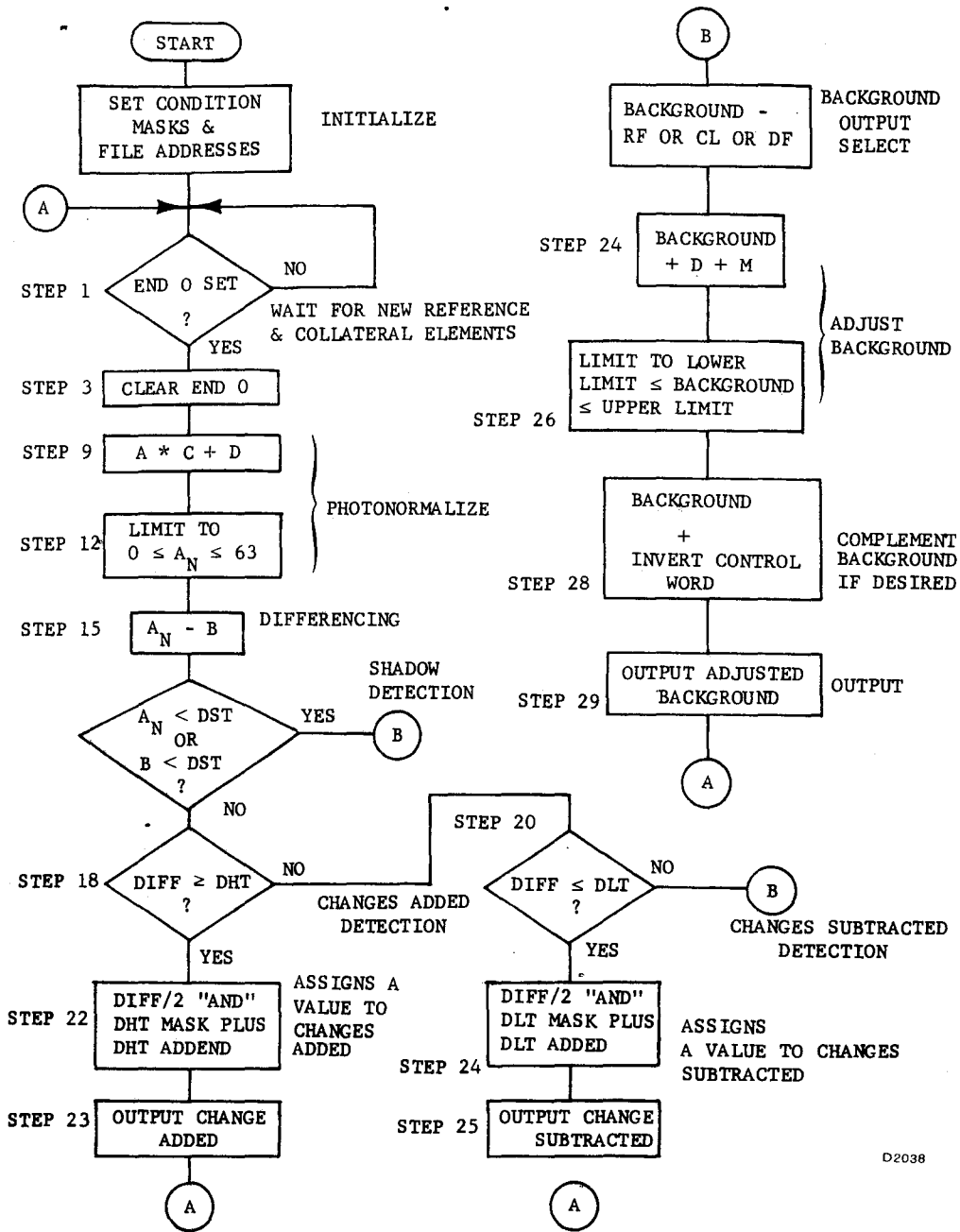D2016

Figure 5
FLEXIBLE PROCESSOR IN A SYSTEM CONFIGURATION

Figure 6   Preliminary F P Configuration for Classification

START

SET CONDITION
MASKS &
FILE ADDRESSES   INITIALIZE

(A) ──────▶◀──────

STEP 1   END 0 SET ?   NO
          WAIT FOR NEW REFERENCE
          & COLLATERAL ELEMENTS
          YES

STEP 3   CLEAR END 0

STEP 9 $A * C + D$

STEP 12   LIMIT TO
          $0 \leq A_N \leq 63$ PHOTONORMALIZE

STEP 15 $A_N - B$ DIFFERENCING

          $A_N < DST$
          OR
          $B < DST$?   YES   (B)   SHADOW DETECTION
          NO

STEP 18   DIFF $\geq$ DHT ?   NO
          YES
                              CHANGES ADDED DETECTION

STEP 22   DIFF/2 "AND"
          DHT MASK PLUS
          DHT ADDEND   ASSIGNS A VALUE TO CHANGES ADDED

STEP 23   OUTPUT CHANGE
          ADDED

          (A)

STEP 20   DIFF $\leq$ DLT ?   NO   (B)   CHANGES SUBTRACTED DETECTION
          YES

STEP 24   DIFF/2 "AND"
          DLT MASK PLUS
          DLT ADDED   ASSIGNS A VALUE TO CHANGES SUBTRACTED

STEP 25   OUTPUT CHANGE
          SUBTRACTED

          (A)

(B)

BACKGROUND -
RF OR CL OR DF   BACKGROUND OUTPUT SELECT

STEP 24   BACKGROUND
          + D + M

STEP 26   LIMIT TO LOWER
          LIMIT $\leq$ BACKGROUND
          $\leq$ UPPER LIMIT   ADJUST BACKGROUND

STEP 28   BACKGROUND
          +
          INVERT CONTROL
          WORD   COMPLEMENT BACKGROUND IF DESIRED

STEP 29   OUTPUT ADJUSTED
          BACKGROUND   OUTPUT

          (A)

D2038

Figure 7

PHOTONORMALIZATION FLOW CHART