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DEVELOPMENT OF A FIELD PORTABLE BI-CHANNEL REAL TIME HYBRID IMAGE PROCESSING SYSTEM

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ABSTRACT

A bichannel, portable, low cost, hybrid processor capable of interactive real-time image processing for use in the field or laboratory is described. Major features of the Programmable Video Processor (PVP) such as operation as a remote pre-processor controlled by a host image processing computer facility or manual operation as a stand-alone processor, digitally programmed operating mode control and internal image statistic generation are discussed. Finally, selected applications in which the PVP has proven useful are outlined.

INTRODUCTION

The development of a field portable image processing system is a partial result of image processing research being conducted at Rensselaer Polytechnic Institute. Under sponsorship of the Office of Naval Research, this research, in cooperation with Dr. Bernard Vonnegut, Senior Research Scientist, State University of New York at Albany, has been concerned with the real time field study of geophysical maritime and atmospheric processes. To help accomplish the research goals, a versatile field portable image processing and enhancement system was developed.

The present processing unit (PVP-1) was designed and constructed by Messrs. Corby and Sims. It has the distinguishing features of two channel processing and programmable operation. Certain auxiliary units used with the system, i.e., power supply, baseband modulator, and R. F. modulator were developed by other research assistants at R.P.I. The system is truly field portable as exemplified in some of the applications for which it has been utilized. It can be run using an automotive battery or aircraft power and can use a conventional color home receiver for display in the field using the modulator.

In contrast to other commercially available, large and more costly labora-systems, which will be compared in the paper, this processor functionally accomplishes the majority of spatial processing and enhancements performed by the others, but additionally can perform real time dual channel spectral and temporal processing and enhancement as well in field conditions. Its cost varies from 1/3 to 1/10 the cost of laboratory systems. However, this processor has been in fact often used in cooperation with large laboratory systems and not in competition with them. It provides a new dimension for real time analysis which can be subsequently analyzed in the laboratory in more detail using it or other laboratory based systems.

The problems which prompted the design of this unique processor all have to do with the evaluation of an image as input data in real time in the field. Most physical processes of initial interest to us (cloud micro-physics, maritime and weather processes, etc.) could not be probed directly for the data of interest. Some indirect measure of the internal process under study must be remotely acquired. After interpretation, inference about the desired process is made. Data for these initial problems we sought to measure were visual, i.e. the data was in the form of a time varying spatial image. It is known that the human visual/brain system more easily grasps data in a pictorial or graphical format rather than as raw data. This fact is another impetus for image enhancement/processing work. Since there

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is more data present in the input image than is necessary for the decision we seek, effective enhancement, redundancy removal and filtering techniques are indeed necessary. This conversion from uniform emphasis in the input image to an enhanced, emphasized and reduced output in the output image is the task the processor performs.

The data base is in the form of time-varying, two-dimensional images. These are described by a luminance function $f(x,y;t,\lambda)$. The image may be monochrome or may have different luminance properties at varying wavelengths λ. Three broad areas of image processing are: Spatial, Spectral, and Temporal. Spatial processing is concerned with $f(x,y;t,\lambda)$ only as a function of position (x,y). Spectral processing and Temporal processing are concerned additionally with wavelength, λ, and time, t, respectively.

However, image processing is not limited to data which originally appears in an image or spatial format. Transformations can be made on one-dimensional signals $v(t)$, to define a picture function f. This technique has been used effectively on such non-pictorial data as voice and the sound of a heartbeat. In these cases, the time-varying Fourier transform $F(v(t);t)$ has been used to generate two-dimensional plots known as voiceprints and phonocardiograms, respectively.

These processing operations can be done a) on-line or off-line, b) in real or scaled (machine) time and c) batch mode or interactively. The types of problems of interest here demanded operation in a real-time on-line environment due to the now repetitive, time varying nature of the weather phenomenon we initially studied. Some applications such as x-ray enhancement and enhancement work on photographs demanded interactive ability. Lack of rapid, easy interaction would significantly decrease the potential gains with as flexible a system as the PVP. Thus the problems under study particularly demanded an on-line, interactive real-time hardware processor.

DESIGN GOALS FOR THE PROGRAMABLE VIDEO PROCESSOR

Apart from the features that characterize operation of the PVP-1 system, a few general criteria had to be met regarding design factors. The size of the unit was important. Since the unit was to operate in the field, (airborne operation also was an option) the physical size and weight had to be small. The present processor is 48 cm x 38 cm x 20 cm (19 in.x15 in.x8 in.) and weights approximately 7Kg (15 lbs.).

Since field operation is a key limitation, the unit was designed for low power consumption, about 30 watts, supplied via on-site line voltage or 12 volt battery operation.

Tolerance to temperature extremes and vibration were also allowed for by the conservative design of the various electronic sub-systems. Following is a summary of key operations that the system should be capable of:

a) The system should provide a particular operational configuration either manually on-site or electronically by a remote host computer through an appropriate interface, thus acting as an intelligent remote pre-processor.

b) The device architecture had to provide for <u>independent</u>, <u>simultaneous</u>, <u>multi-channel</u> processing capability. This was necessary since in many cases comparisons between two or more video sources yielded the desired differences (Spatial, Spectral or Temporal) in the images. Often the data of interest is carried by the differences between images of a time-varying process.

c) Due to the large number of combinations of operations that were possible given the multi channel, multi-analyzer structure, the operating controls had to be arranged in a fashion that would facilitate operation by the human operator. Also this method of organization of operating controls had to be general enough so that any desired combination of operations could be commanded as well as allowing for new experimental processor modules and their particular operation codes.

d) As noted before, the processor must operate interacting in real-time. This meant using fast digital special purpose hardware for some tasks such as generating luminance statistics, etc. while using analog hardware for other signal processing operations such as image squaring, division, differentiation, etc., thus resulting in the hybrid nature of the processor.

DESCRIPTION OF SYSTEM

The PVP-1 Programmable Video Processor is designed to accept two video sources, operate upon one or both sources simultaneously and deliver an enhanced result to a color monitor. The enhancements are user selected and programmed operations such as edge enhancement, nonlinear expansion or compression, inversion, color level encoding and windowing.

The bichannel architecture of the PVP-1 makes possible the selection and multiple mode processing of a single input source or operations between the inputs of two different sensors. Thus, two live scenes may be directly compared and enhanced. Using a scan converter as frame storage, the PVP-1 can process signals temporally as well as spatially and spectrally with color encoding used for temporal information display. In this type of processing spatial variations due to the passage of time are to be enhanced. This can take two different forms. The first is the comparison of successive frames with one initial frame; the second, continuous comparison of pairs of frames separated in time by T seconds.

The programmable nature of the processor allows for virtually unlimited expansion of channel processing functions due to the "bus" or parallel style of processing. The key to the PVP-1's flexibility lies in the front panel keyboard, through which the processing parameters, such as source, channel operations and window aperture, are entered.

The PVP can also function, when used in conjunction with a local or remote digital controller, as an image preprocessor in a computer based data compression or feature extraction system. Currently the PVP-1 is interfaced with a Varian 620/i minicomputer with IDI graphics computer with disk based operating system. Provisions are currently being made to enable this flexible graphics computer system to have full operating control over the PVP when operating in the remote mode. The five digit operations code together with four or five digital parameters are transferred through the controller. If, in such a system, a scan converter is used to convert the computer processed image to standard video rates, the PVP can also be used as a postprocessor to analyze or to enhance the computer image output.

The output of the PVP-1 is normally displayed on an ordinary composite video color monitor although an ordinary 525 line, 60 field/sec commercial color television receiver can be used. The correct output is selected by the user by simply plugging the output cable into the proper modulator jack. Each input can be any source which produces or has been converted to a standard 525 line, 60 field/sec NTSC composite video signal. Of course, two video sources need not be used. The same source can be entered into both channels by use of proper programming codes.

Also available for use with the PVP-1 system is a sequential, frame-synchronized, color filter wheel. The filter wheel allows one image to be spectrally prefiltered in real time in different spectral bands with a single camera, eliminating registration problems. The image is prefiltered by two predetermined and optimized filter packages mounted on the rotating disc. Using the intersection mode of processing on the PVP-1, the two sequentially filtered images may be directly compared for common characteristics, and also displayed in two colors, one for each spectral band.

Thus, with the PVP-1 system, three modes of real-time processing are possible: Spectral, Spatial and Temporal. Having all three modes simultaneously available in real-time results in a significant gain in enhancement and processing capability of the system.

Additionally, a luminance distribution analyzer plug-in is available to work with the PVP system. This device generates a histogram approximation to the distribution of grey levels in the line image. This display is generated in real time and can be displayed on an oscilloscope or TV screen. The distribution analyzer allows complex high bandwidth video imagery to be reduced drastically by transforming the original image into its 1st order pdf. It has been shown that important properties of video imagery can be extracted from the first order pdf, which can be transmitted or stored much more easily, due to its drastically reduced bit rate.

An electronic window has been developed for use in the system. This rectangular aperture (with parameters for height, width and postion) spatially pre-filters the input (or output) images, thus allowing processing within the window's area only. Thus higher order pdf's and other image measures can be evaluated. The window is also controllable by the host computer so that adaptive tracking schemes (using the PVP internal statistical generators) are possible. These are currently being investigated.

DETAILS OF OPERATION

The System consists of the following units: PVP-1 Programmable Video Processor, Television Camera, Color Monitor, Power Supply and Color Modulator.

The Programmable Video Processor (PVP) pictured in Figure 1, is the central unit of the system. The following description refers to Fig. 2. Video information from two synchronized sources, called source A and source B, are attached to the rear apron BNC connectors.

Using the keyboard on the front panel, a five digit "operations code" (OPCODE) is entered by the user. The format is shown in Table 1. Basically, two sources are selected together with an operation on each source. The processing channels are completely independent, allowing for over 1000 distinct combinations of sources and processing operations. The operations implemented in the present model are unity gain, logarithmic amplification and two different derivatives. The outputs of both channels are arithmetically or logically operated upon. The current choice of combining operations includes addition, subtraction, multiplication, division, and logical intersection. The result, of the general form f(A)*g(B)(where * signifies a joint operation), is then passed through an electronic, user programmed, window or aperturing circuit.

As a simple example, using a common source, by differentiation selected in one channel, unity gain in the other, and addition as the operation, real time crispening can be performed. A wide variety of operations and examples will be shown as part of the paper presentation, as well as those showing spatial, spectral and temporal processing.

The window's dimensions and location are entered via the keyboard (numerical data) and front panel data routing switches (X, ΔX, Y, ΔY). The window affects only the quantized, color encoded image. A white, rectangular frame, corresponding to the window, may be superimposed on the background image.

The user can vary the level of the background analog image and the bias and amplitude of the pseudo-color encoded mage. Also, the colors into which the display is encoded are operator selectable by the color matrix pins. Thus the operator has complete control over all items connected with the final display of the processed, color enhanced image.

Two additional features can be used to extract image information. The CURSOR, selected by a front panel switch, allows for the display of a graph of the image luminance along a vertical line. If the image is thought of as a three dimensional surface with the horizontal scan along the X axis, vertical scan along the Y axis, and luminance along the Z axis, the cursor can be thought of as a "cross section" of the brightness surface. This is displayed as a straight vertical line denoting position in the XY plane, together with a graph of the brightness along the line. The user selects the position of this "cutting plane" with a front panel control.

Another feature is the AREA MEASUREMENT circuit. This measures quantitatively the percentage of the screen covered by any one of the four levels which generate the quantized, color encoded sense. Internal circuitry computes the percentage coverage of the level of interest when "AREA MEASURE" is pressed. The resultant count on the counter indicates the amount of coverage by that particular grey level. Alternatively, measurement can be initiated by software command of the host remote computer, and data read out via the interface.

Additional features of the PVP-1 are variable height calibration bars which can be inset on the color screen, thus enabling a permanent record to be made, photographically, of the settings of the various slicing or quantizing levels; and the histogram generator which can operate on either the total image or a portion of the image defined by the electronic window.

While any 525 line, standard format, video or IR camera with composite video of approximately 1.0 volt peak to peak will work, the present system uses high quality, high resolution COHU series 2810 camera. It is a completely self contained unit with provision for external sync. It has a one inch vidicon image tube with 525 line 2:1 interlace scan and 900 line resolution. An automatic light range circuit compensates for variations in light over a range from .2 ft-candles to 1000 ft.-candles. A TIVICON tube is also often used with the system.

The monitor used is a Setchell-Carlson 9MC14 19" color monitor which has been modified for direct access to the color amplifiers. The monitor has 300 line color resolution. Controls on the front panel which function in the RBG mode of operation are contrast, brightness, and function selector. Tint and color controls are functional only when using the baseband modulated output from the system.

The power supply is completely self-contained and totally protected. It delivers +5 volts at 4 amps, ±6 volts at .5 amps, and ±15 volts at .5 amps.

The color modulator accepts the red-blue-green output signals of the PVP-1 along with analog background information and combines them into a standard baseband composite color video signal. Also, this baseband signal is modulated by an RF carrier so that the output of the system can be viewed on channel 3 of a standard broadcast color receiver. System synchronization signals for the cameras, monitors and the PVP-1 are supplied by the modulator.

PROGRAMMING THE PVP-1

MANUAL FUNCTION SELECTION

Seven frequently used functions - A, B, B/A, A-B, $\bar{A}$, dif A_1, and dif A_2- can be selected from the function selector switch on the instrument front panel. The function selector switch can be set to any of the seven preselected functions without resetting the operations register.

Description of Preselected Functions

A - Unity gain display of the signal from input A.

B - Unity gain display of the signal from input B.

B/A - This is the ratio of input B to input A scaled by a factor of 10. The important applications of this function include spectral and temporal processing where B is either in a different spectral range from A or is the signal A delayed in time. Alternatively, B-A or log (B/A) may be used for these types of processing.

B-A - This is the difference between A and B. B-A gives a lower contrast image than B/A, but it will not saturate where A is at the black level.

$\bar{A}$ - This is the additive inverse of A. This function often improves the visibility of subtle features in dark surroundings such as on X-ray plates.

DIF A_1 - This is the A input differentiated left to right along the horizontal direction. DIF A_1 is proportional both to the change of amplitude and to the rate of this change, so that a sharp edge between black and white will appear brightest.

DIF A_2 - This is the same as DIF A_1 except that it is even more sensitive to very rapid changes in the image. DIF A_1 and DIF A_2 are used to extract vertical edges in an image. Additionally they can be used to enhance other high frequency information known as "fine texture".

FUNCTION PROGRAMMING (VIA COMPUTER I/O INTERFACE OR MANUAL MODE ENTRY)

The digital programming feature of the video processor extends the number of available video functions to well over 1000. The desired code is entered on the keyboard and the "ENTER" button is pressed.

Description of Programming Code

Each digit of the operations register has a specific meaning as follows:

Digits #1 & #2
These digits select the inputs to channels 1 and 2, respectively, according to the following code:

0 - input A
1 - input B
2 - a preselected constant
3 - zero (ground)
4 - input A times a constant selected by the "GAIN 1" pot
5 - input B times a constant selected by the "GAIN 2" pot

Digits #3 & #4
These digits select the individual operations or inputs to channels #1 and #2 respectively, according to the following code:

0 - unity gain linear amplifier
1 - logarithmic companding
2 - "dif 1" differentiation
3 - "dif 2" differentiation

Note that the functions of digits #1-#4 operate on no more than one input at a time.

Digit #5
This digit selects the operations which combines the output of the two channels according to the code:

0 - addition: $X + Y$
1 - subtraction: $Y - X$
2 - multiplication: $X \cdot Y$
3 - division: Y/X
4 - logical intersection $X \cap Y$

The operation of logical intersection is described in appendix A.

The seven preselected functions are a subset of the programmable functions equivalent to the following codes:

A	:	03000
B	:	13000
B/A	:	01003
B-A	:	01001
$\bar{A}$	:	02001
dif A_1	:	03200
dif A_2	:	03300

PROGRAMMING TECHNIQUES

Single channel operations are programmed by setting digit #1 or #2 to "2" or "3" and using the addition or subtraction operations (digit #5 equal "0" or "1"). For example, A can be represented by 03000, 30000, or 30001.-log B can be represented by 13101.

Dual channel operations can be performed on one source (in this case A) by entering either "0" or "4" into first two digits. Such operations are often quite useful. The crispening operation of A + k DIF A_2 (04030) is an example.

Operations on two inputs are performed by entering either "0" or "4" into the first digit and either "1" or "5" into the second (or vice-versa). Subtraction and division have the effect of comparing two images by taking their difference or quotient. Addition superimposes the images, while multiplication correlates them. Logical intersection permits the simultaneous viewing of features of both inputs.

SOME COMMONLY USED OPERATIONS

04030 "Crispening"

This operation, by adding a variable amount of edge information to the original image, "crispens" the edges and also brings out the texture of objects. As the gain control on channel 2 is increased, the crispening is strengthened.

04030 Logarithmic Companding

This nonlinear operation amplifies the darker portions of the image more than the lighter portions, making darker features more easily discernable. By varying the target voltage on the camera, the relative amplification in the lowlight and highlight areas may be changed.

44011 "Solarization"

By subtracting k_1 A from k_2 log A, highlights may be inverted, while lowlights are transmitted normally. This is shown in Fig. 4. By properly adjusting k_1 and k_2, a particular grey level in A may be made to appear brightest on the display.

SELECTED APPLICATIONS

The image processing work at R.P.I. has been applied successfully to numerous practical problems documented in [1] and [2], which will also be reviewed in this paper.

From its conception in 1971, the evolution of the PVP has been paralleled at every stage of development by applications to important research problems. These applications have served as impetus for expansion and modification of system functions. The original stimulus for development of the PVP was the investigation of a cloud phenomenon known as "crown flash" and the enhancement of lightning phenomena. Crown flash, described by Gall et. al. (1971), is a sudden brightening sometimes observed near the top of a cumulonimbus cloud concurrent with a lightning discharge. Vonnegut (1965) suggests the following explanation for the crown flash phenomenon. Above the melting band, a cloud is composed chiefly of ice crystals, often in the form of hexagonal platelets, needles, or columns. Normally, the atmosphere has a slight negative charge with respect to the earth. In this "fair weather" electrostatic field, the orientation of the ice crystals is governed chiefly by gravity and aerodynamic forces within the cloud mass. During a storm, charge begins to separate within the cloud. Strong updrafts in the center of the cloud bring positively charged water droplets to the turret of the cloud. Under the influence of the electrostatic field thus formed, the ice crystals accept an induced dipole moment. This effect has been demonstrated experimentally in a Schafer cold box (Vonnegut, 1965). As the field increases in magnitude, the ice crystals slowly tend toward an orientation in which the axis of the dipole moment is aligned with the electric field. Field strength is generally strongest when a lightning discharge is imminent. When the discharge occurs, the flow of currents tends to relax the fields in the cloud rapidly, with the subsequent drastic realignment of the ice crystals. A change in the luminance distribution over the cloud occurs as the ice crystals, acting as tiny mirrors, change their angle of reflectance of incident sunlight. An observer at the proper angle will perceive the effect as a flash of light.

During the summers of 1972, 1973 and 1974, the system was set up at the field facilities of the New Mexico Institute of Mining and Technology in Socorro by Dr. Bernard Vonnegut of the Department of Atmospheric Sciences, State University of New York at Albany, and the authors. Each summer, during three weeks of eight hours a day continuous operation at the ground stations in the Rio Grande Valley, no operational difficulties were encountered with the PVP. Data was recorded in the form of 16mm motion pictures taken from the color display. Color enhancement was also applied to the study of time resolved lightning spectra and time lapse 16mm movies during the course of these studies.

In the coming months, the PVP system will be applied to the study of maritime processes. Already multi-spectral aerial photographs of the Mississippi Delta have been analyzed in a laboratory situation. The average reflectance of a water surface can be correlated with its turbidity, while textural properties, easily enhanced by the PVP, are a direct measure of wave motion and turbulence. Pictorial data collected and preprocessed by an airborne version of the PVP system will be analyzed to determine a set of parameters for describing sea state (e.g., mean distance between wave crests, height of waves, per cent coverage of whitecaps, etc.). A program is being developed for the R.P.I. Interactive Graphics/Image Processing Facility (host computer) which will model a set of textures as a random field (two-dimensional random process) with variable parameters. The collected data will be used with this program to provide a general analysis of sea surface conditions.

Other applications have included the enhancement and analysis of medical and industrial X-rays. Differentiation of dental X-rays has been found to highlight major features such as cavities, fillings, and the root canal which are not easily recognized in the original X-ray. Software is being developed for the IGIPS system for further analysis of these and other medical X-rays. In particular, chest X-rays are being examined to calculate heart capacity and the position of the valves. A preliminary investigation of industrial X-rays shows that the PVP can be used to locate defects in materials and to measure their severity and area affected.

SUMMARY

The PVP system has been proven effective both as an on-line field portable independent unit and as a satellite preprocessor for a larger computing facility. Applications to meteorological processes have proved successful and in the future analysis will be extended to maritime and other areas of interest. In each application, the modular construction of the device has provided the flexibility necessary for the particular problem at hand.

REFERENCES

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2. N.R. Corby and E.M. Sims, "Image Processing: Research at R.P.I.", Rensselaer Engineer, April, 1974.
3. B. Vonnegut, "Orientation of Ice Crystals in the Electric Field of a Thunderstorm," Weather, Vol. 20, pp. 310-312, 1965.

Note:
A patent is currently being applied for by the Department of the Navy for the above system.

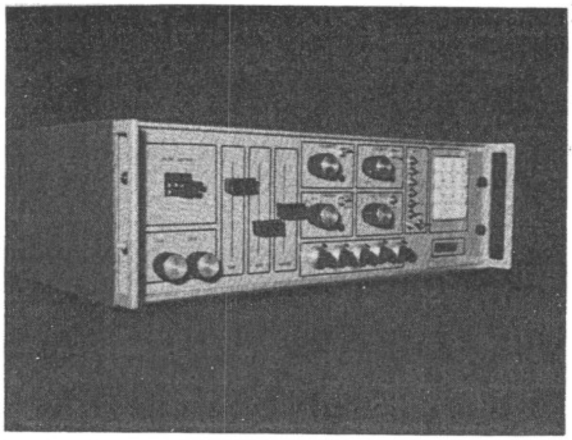

Figure 1 - Programmable Video Processor (PVP-1)

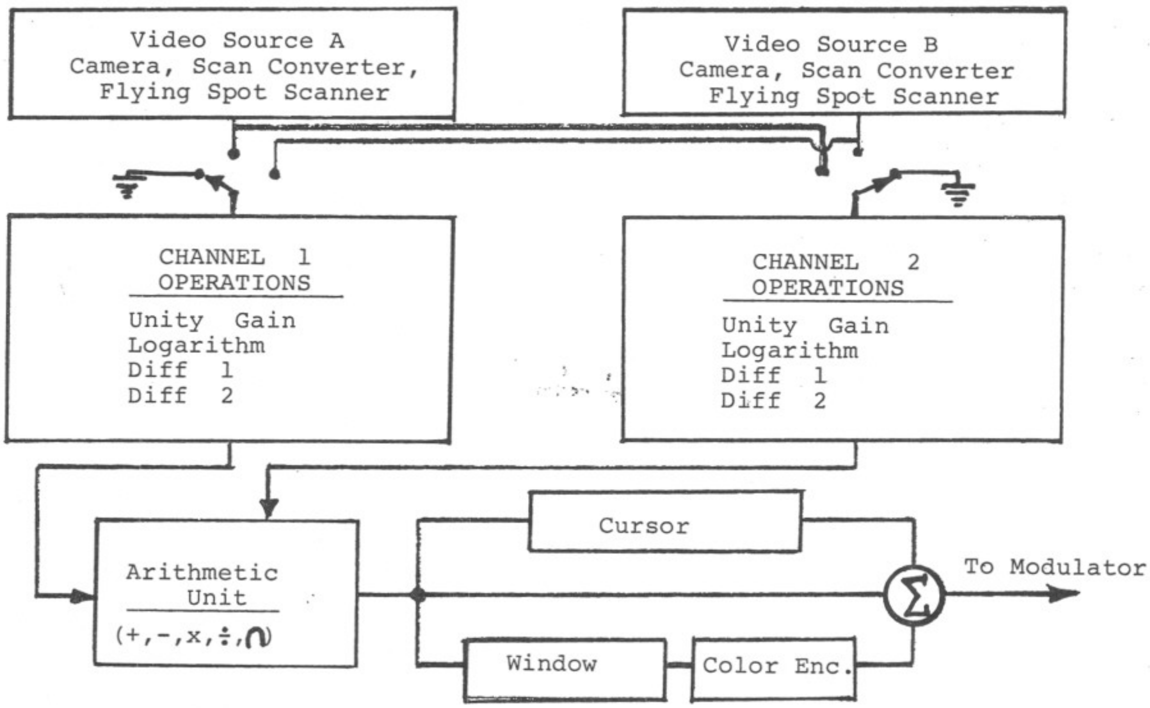

Figure 2 System Signal Flow Diagram (PVP)

1	2	3	4	5

Digit #1 - selects video source for channel 1
Digit #2 - selects video source for channel 2
Digit #3 - selects the processing operation to be performed by channel 1
Digit #4 - selects the processing operation to be performed by channel 2
Digit #5 - selects the cross channel post processing operation to be done

	SOURCE CODES		CHANNEL FUNCTION CODES		OUTPUT CODE
0	A	A	Unity Gain	Unity Gain	+
1	B	B	Log (.)	Log (.)	-
2	D.C. Constant	D.C. Constant	Diff 1 (.)	Diff 1 (.)	x
3	Ground	Ground	Diff 2 (.)	Diff 2 (.)	÷
4	k_1* A	k_2* A	*	*	∩
5	k_1* B	k_2* B	*	*	*
6	*	*	*	*	*
7	*	*	*	*	*
8	*	*	*	*	*
9	*	*	*	*	*

(*= unspecified at present, $0 \leq k_1 \leq 2$, $0 \leq k_2 \leq 2$, ∩ = intersection)

(Table 1 - Description of Operation Code Structure)

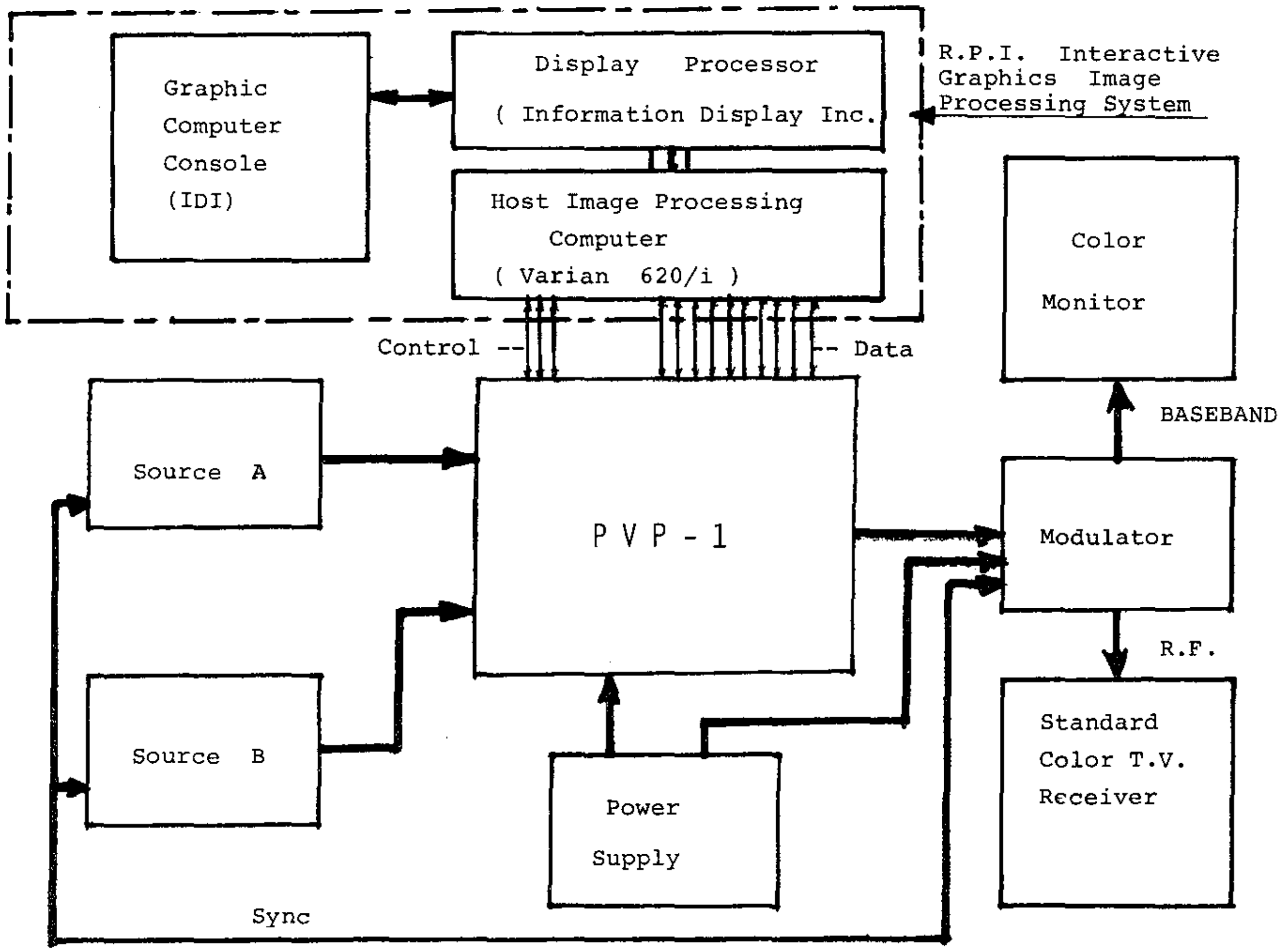

Figure 3 PVP-IGIPS System Block Diagram