A SYSTEM FOR DIGITAL PROCESSING OF DYNAMIC IMAGERY

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Abstract

A portable, low cost, digital image processing system for applications directed toward solutions in filmless, in-situ photogrammetry of dynamic processes is under development. The system, consisting of video rate photoelectronic image capture and digitization, digital spatial filters, correlator/convolver and displays, is described and some results representative of its capability presented.

1. Introduction

Measurement, interpretation, classification and control from imagery is experiencing a revolution propelled by advances in semiconductor technology. The bandwidth of signals which can be digitally processed is now extending some operations into the realm of real-time on images of TV frame size (IEEE, 1981; Lee, 1982). Although this precludes high resolution large format images, there is growing scope for application of digital image processing techniques directly to certain close range applications where filmless, in-situ, real-time operations and control prevail, as might be expected to be encountered in the medical and manufacturing environment.

Although optical techniques are conceptually more attractive for 2-D operations, digital transformation of images proved through the years to be an exceptionally versatile, precise and robust technique. Its main disadvantage, slowness, is gradually eroding as a consequence of exceptional advances in semiconductor technology. Compelling reasons for processing images digitally in photogrammetric applications are to augment human vision, measurement and classification tasks without fatigue, data transformation and extraction, and fast, accurate recall from previously stored data for comparison or matching. Development within our laboratory is aimed at embodying certain existing digital image-processing techniques into low-cost, real-time units utilizing readily available components for routine use in experiments and apparatus employing electronic image transfer. A description of the hardware comprising an experimental unit as it currently stands is followed by some examples of its capability.

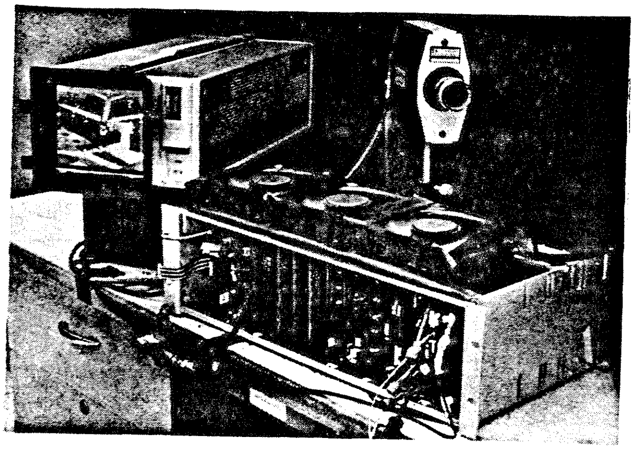
2. Fast Digital Image Processor

An experimental digital image processor, Fig. 1(a), is developed to the extent that it performs video rate photoelectronic image capture, digitization and storage, fast spatial filtering, correlation, convolution, image mixing, matching, addition, subtraction and display. Other desirable features associated with large image processors may become incorporated in time as semiconductor technology evolves.

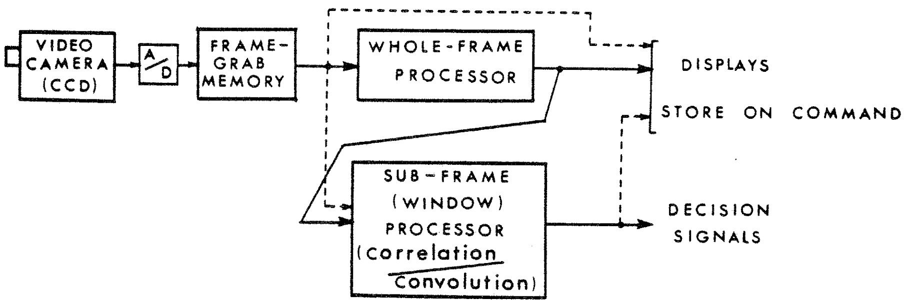
System architecture, indicated in Fig. 1(b), features an input or image capture section and an output section between which is a fast processor. One part of this processor transforms an entire video frame while the branch performs more computation intensive operations on a sub-frame portion (window) of the whole frame, either in parallel or in series with the whole frame unit.

Fig. 1

(a) Experimental digital processing system showing CCD camera, electronics and output monitor.



(b) Main sections of Fig. 1(a).



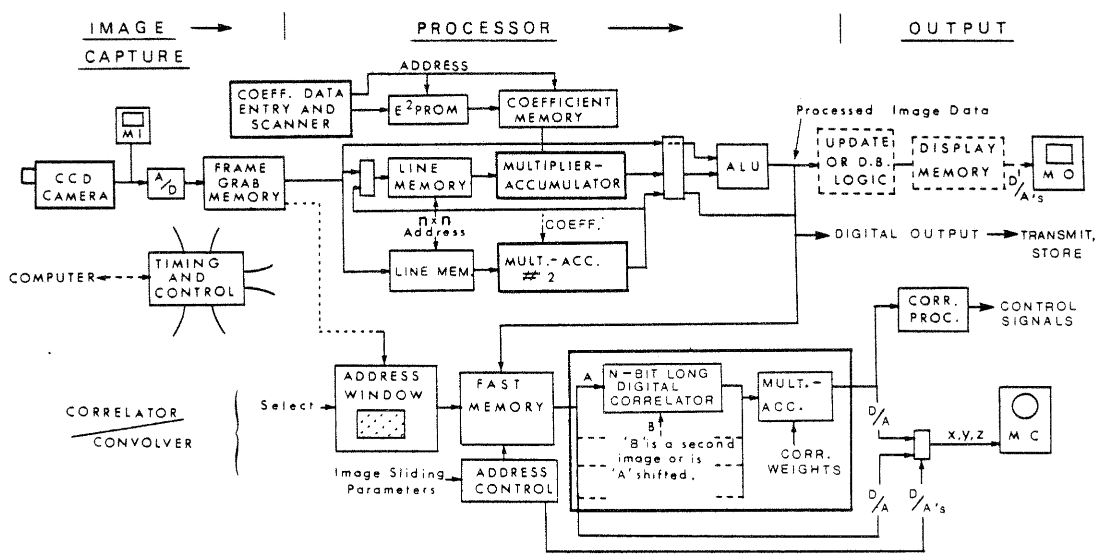


Fig. 2 Electronic functions of the system, Fig. 1.

A/D, D/A analog to digital converter and reverse; Ml-input monitor, MO-output monitor, MC-correlator monitor, ALU arithmetic logic unit. Update or double buffer (D.B.) logic and display memory are not in Fig. 1. n x n is implemented as 3 x 3 ; N as 64 (see text). MO may be a standard TV monitor or X, Y raster - driven display for nonstandard frame sizes and rates, depending upon the application.

Key system elements, shown in Fig. 2, are:

2.1. Image Capture:

A 380 x 488 pixel CCD camera operating at a 7.16MH_z clock rate is input to an 8 bit 20MH_z flash converter (Real, 1983). Standard 4MH_z DRAM chips are used for storing the digitized image data at video rate. The output from this memory may be displayed directly upon a monitor after passing the data through a D/A converter.

2.2. Fast Processor:

This is an evolving sub system which presently consists of three identifiable parts; the spatial filter, dynamic filter coefficient delivery circuits and a correlator/convolver.

(i) Spatial Operator:

The quest for a two dimensional spatial operator which performs useful transformations rapidly with modest means has lead to processing by a nearest neighbour operator in the form of a convolution filter (Real, 1983). For economy, speed and sensitivity to high spatial frequencies, the implementation, Fig. 2, is in the form of a pair of 9 point filters in a 3 x 3 configuration. They can be operated serially as independent filters or as a single pipelined unit at twice the throughput rate. If a 3 x 3 block of pixels (with i, j as the central element) is selected for the convolution filter, then each emerging pixel is modified by its nearest neighbour as a finite convolution:

$$g(x,y) = \sum_{i=-1}^{1} \sum_{j=-1}^{1} f(x+i,\ y+j)\ h(i,\ j) \qquad (1)$$

Excluding scaling and normalization, nine multiplications and eight additions or subtractions are necessary for each pixel emerging from one 3x3 convolution filter. An image is therefore processed spatially and digitally by combining the digitized image data with a programmable m x n array point spread function. It is in general a non-linear operator the kernel of which has its elements individually set to any signed integer in order to achieve a desired result. The filter stages are implemented with 100 ns. 8x8 multiplier/accumulator arrays. A line memory and high speed data transfer register feeds digitized image data to one register of the filter input while the other receives the properly timed coefficient values. Subsampling and time integration by frame feedback are options not indicated in Fig. 2.

(ii) Coefficient Delivery:

Rapid coefficient delivery is important in a dynamic or adaptive situation. For example, if the operator of a photogrammetric instrument is dissatisfied with the visibility of the images he sees, coefficient entry from keyboard as a large aerial photo is scanned would be most impractical. A coefficient scanner, Fig. 2, permits an image analyst to run through a library of coefficient sets rapidly while viewing the results. A fast response is important because it is easier to optimize a process by subconscious human feedback when there is no interruption in the task flow. Keyboard entry is available if coefficient sets not prestored are required.

Coefficients to be prestored are programmed into an E^2PROM via keypad. Upon system power-up contents of the E^2PROM are transferred to a high speed RAM for delivery to the multiplier/accumulator. When pipelined, the kernel for the lagging multiplier/accumulator is fetched from the leading one via shift register delay. The coefficient fast memory addresses may be selected randomly or sequentially via a joy stick controlled UP/DOWN counter scanner multiplexed into the RAM addresses.

(iii) Image Matching Correlator/Convolver

The sub frame processor, Fig. 1(b), is configured in the present system as a high speed correlator/convolver for image matching applications. It allows up to a 32k pixel rectangular patch of arbitrary shape and position to be selected from the processed (or unprocessed) image stored in a high speed dedicated RAM and autocorrelated, convolved, or cross correlated with a second image stream by means of a bank of binary correlators, Fig. 2. The correlation implemented is a rough approximation. The time correlation of two functions $f_1(t)$, $f_2(t)$ with time shift (τ):

$$R_{12}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{+T/2} f_1(t)\, f_2\,(t+\tau)\, dt \qquad (2)$$

is approximated by:

$$R_{12}(j) = \sum_{0}^{n/64} \sum_{k=0}^{63} \left[f_1(k)\, f_2(k+j) \right] \qquad (3)$$

where k and j substitute for variables t and τ and n is the number of pixels comprising the sub frame image. The output from the band of four binary correlator units, Fig. 2, is multiplexed into a multiplier/accumulator which serves to assign any prescribed weights and to sum the elemental 64 bit long correlations to obtain the final approximation to the correlation. A threshold register is present within each correlator and the multiplier/accumulator can be preset to any value.

This experimental unit is designed for image sliding along the two major x, y window axes as a test for image matching or left-right or top-bottom pattern symmetry, Fig. 3. (Image sliding can be programmed to take place in any

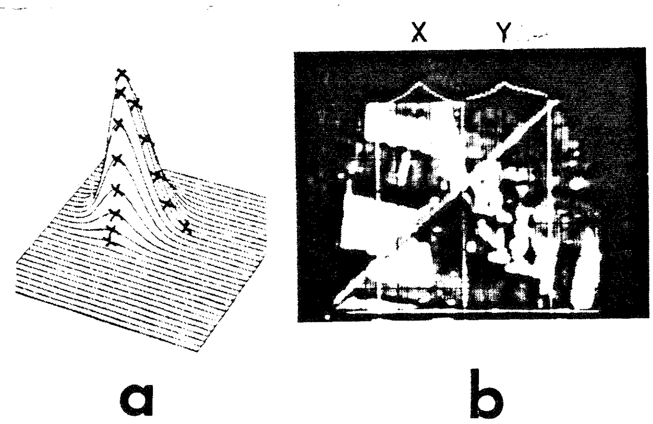


Fig. 3. An image patch is autocorrelated over a ±15 pixel excursion along the major x, y axes of the correlation plane (a) and the converted analog results displayed by the dots in (b).

arbitrary direction if required). As such it is expected that sufficient information can be extracted from these approximations to perform adequately for some applications. The subject image patch is read into the correlator as an "A" stream which is "centered" and a "B" stream which is slid by varying amounts in x or y. The digital "score" for each image patch displacement is stored for further processing. The correlator portion of the processor is in an early stage of development and will undergo change as more powerful correlator chips become available. With signal processing a grey scale image can sometimes be rendered into a binary equivalent, but some information will thereby be lost. For images having large dynamic range with intelligence imbedded near regions of large contrasting shading, it is anticipated that four bit wide correlation of preprocessed images will generally be necessary.

2.3. Displays and Outputs

This portion of Fig. 2 is more conventional, consisting of up to three displays and miscellaneous outputs. The latter include an 8 bit digital output port to transmit images at any rate, and specialized digital and analog control outputs as the application warrants. Displays consist of a monitor for the CCD camera to facilitate focussing, centering, etc; of inputs, and an output display driven by D/A converters from the frame memory or from the processed image output. These are run at various frame rates and resolutions on a Tektronix 608 monitor.

Display specifications depend upon application. For monitoring a process, an x, y, z display run at an arbitrary frame rate will suffice. If measurement within the output image is to be pursued, (i.e. video image transfer in photogrammetric instruments), a non flickering image is essential. A double buffered video display memory (Fig. 2) may be required to minimize visual disturbance when the processing rate is slower than the display refresh rate. This rate depends upon the display screen persistence. The digital data can either be converted to standard TV form of 60 interlaced frames per second on black and white phosphor, or displayed at a 20 to 30 percent higher frame rate on a low persistence, high resolution monitor (e.g. Tektronix 608).

A composite correlation window image and analog display of correlation values is derived from the digital data and displayed on an oscilloscope as a monitor, Fig. 3(b). The 4 bit wide 32K pixel (maximum) windowed image for correlation is multiplexed with the output from the correlator multiplier/accumulator unit. Each dot in the correlation trace Fig. 3(b) is the image matching "score" for the entire M x N pixel window. Dot separation in x is a function of image-image displacement and in y is a function of the relative correlation or image match value after scaling and D/A conversion. The stationary image, Fig. 3(b), which is the "A" input to the correlator, Fig. 2, is refreshed at a high frame rate since it is derived from the independent high speed correlator memory. The refresh rate of the dot sequence in the composite depends upon the total number of frame correlations (dots). For 32K pixels at $20MH_z$ they are formed at the rate of one per 1.6 ms. This display is useful for visualization and observing trends during experiments, as illustrated in the results.

3. Examples of the Experimental Image Processor Capability

3.1. Image Improvement

Digital spatial filtering (Hall, 1979, sec. 4.4), is imminently suited to the task of rapidly altering the photometric character of an image in any desired way. In video transfer systems with the eye as the final transducer, its most common use is to remap grey scale so that detail conveyed on a wide range of background shading is rendered visible on video display units of reduced dynamic range and, in addition, detail amplified for human viewing as demonstrated by the set in Fig. 4 (a-f), and in Fig. 5 a,b. Note the simultaneous emergence of detail in both the bright and dark regions. These examples

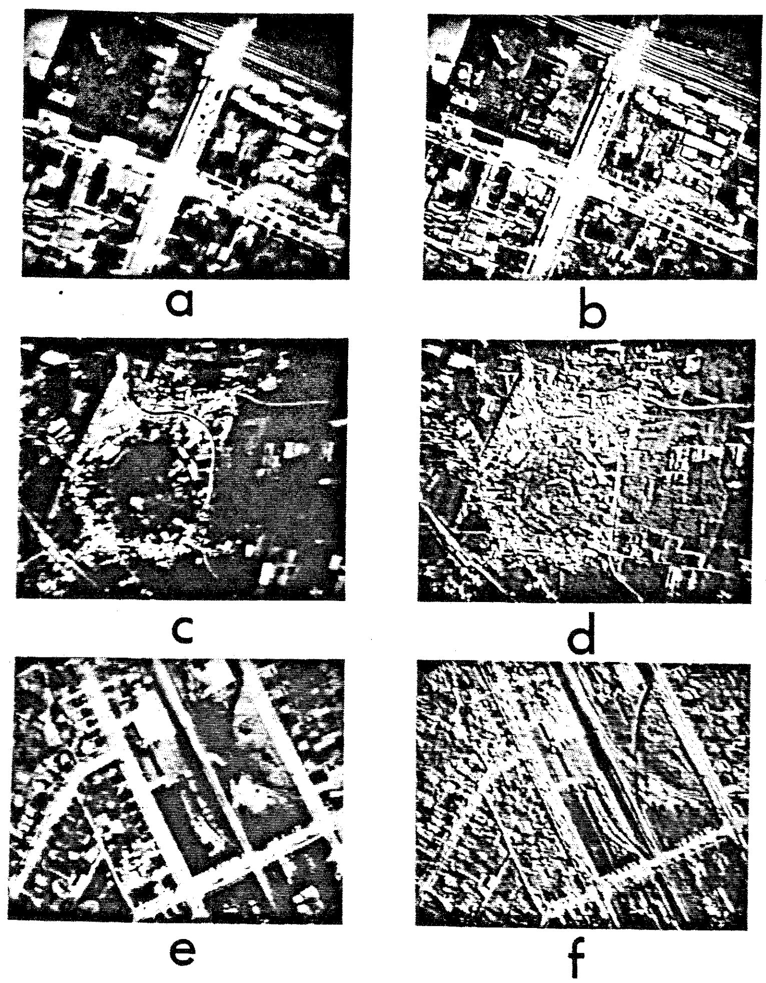


Fig. 4.

A set of aerial images, (a, c, e), enhanced for higher visibility of detail; (b, d, f), with some detail lost in the printing process. A magnified patch of moiré pattern (g) is low pass filtered for spatial carrer suppression (h). Relative 3 x 3 coefficients (Real, 1983) from top to bottom on the right are:

b

$$\begin{bmatrix} -2 & -2 & -2 \\ -2 & 3 & -2 \\ -2 & -2 & -2 \end{bmatrix}$$

d

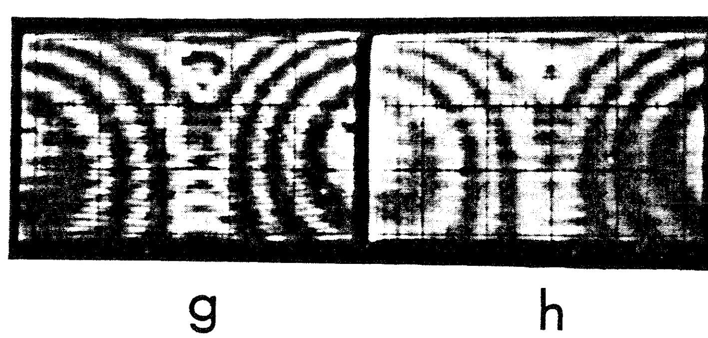
$$\begin{bmatrix} 0 & -5 & 0 \\ -5 & 1 & -5 \\ 0 & -5 & 0 \end{bmatrix}$$

f

$$\begin{bmatrix} 2 & -4 & 2 \\ -4 & 1 & -4 \\ 2 & -4 & 2 \end{bmatrix}$$

h

$$\begin{bmatrix} 3 & 3 & 3 \\ 3 & 3 & 3 \\ 3 & 3 & 3 \end{bmatrix}$$



illustrate high pass spatial filtering. Low pass spatial filtering is usually employed for some forms of noise rejection. Fig. 4(g) is part of a magnified patch of moiré pattern exhibiting some horizontally oriented "noise" which results from the grating carrier frequency. Setting the filter coefficients to positive values, Fig. 4(h), is analogous to defocussing the image, thereby suppressing this carrier to some degree.

3.2. Special Effects

A host of unusual mappings of grey scale from the original are possible to create special displays or grossly exaggerate sets of features to render them more immediately obvious to the viewer. Fig. 5(c) is a simple example of this, employing digital image contrast reversal with simultaneous edge sharpening.

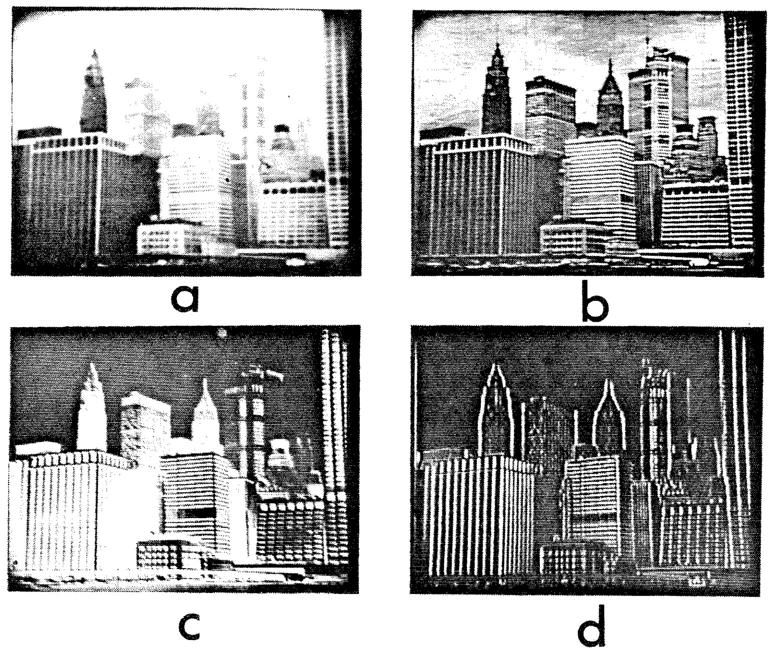


Fig. 5.

The original (a) is processed for high visibility of detail (b), contrast reversal with edge exaggeration (c) and partial edge detection (d). Coefficients:

$$(b)\ \begin{bmatrix} 8 & -8 & 8 \\ -8 & 4 & -8 \\ 8 & -8 & 8 \end{bmatrix} \qquad (d)\ \begin{bmatrix} 0 & 14 & 0 \\ -15 & 0 & -14 \\ 0 & -14 & 0 \end{bmatrix}$$

(c) = (b) with ALU, Fig. 2, set for inversion.

3.3. Image Reduction

Fig. 5(d) illustrates conversion of a grey scale image into a set of edges. Such image reduction is useful when further computation intensive tasks are anticipated in order to facilitate subsequent operations such as image matching or image search.

3.4. Change Detection

Change detection is an important operation in dynamic processes and medical diagnostics. The arithmetic logic unit of Fig. 2 permits single point operations on images such as mixing and differencing. An example of the latter, Fig. 6, depicts automatic change detection between two half frames of an altered scene. The residual image in (b) shows that the marker pen was removed and the position of the goose neck lamp support altered.

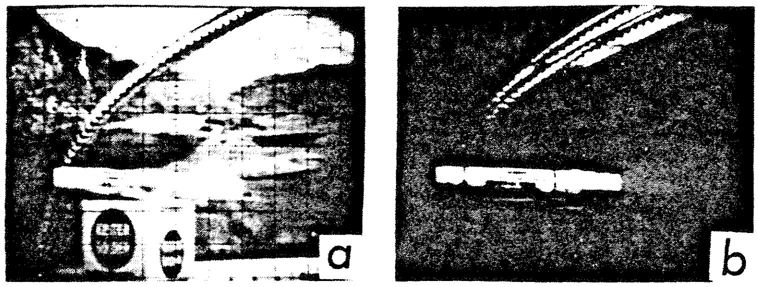


Fig. 6.

An example of image differencing. The marker pen was removed and the lamp support moved - the difference from (a) was automatically detected and imaged in (b).

3.5. Dynamic Filter Coefficients

A feature of the system described is being able to rapidly scan through a prestored library of filter coefficient sets so that a human operator may adjust the perceived image to his liking. Fig. 7 depicts a selection of three images from such a set along with the original. Figs 7(b), (c) and (d) illustrate the effects of increasingly higher frequency spatial filtering.

3.6. Image Matching with Correlator/Convolver

The correlation branch, Fig. 2, is being applied to a project related to the routine screening and detection of scoliosis by moiré topography (Adair, 1977). Additional laboratory results of this effort are to be found elsewhere (Real and Fujimoto, 1984; Real 1984). One of the problems is to detect when a time variable moiré pattern has attained a certain degree of symmetry. By way of illustration of simultaneous digital image conditioning and correlation, Fig. 8(a) shows part of a frame of a moiré pattern which is varying because of relative motion between the moiré projector and the subject, in this case part of a manikin. A deliberately noisy image has been generated with non stationary "snow" occluding parts of the scene. The best improvement of signal to noise ratio can be gained by frame integration, implemented by adding successive frames in digital memory. However since this is a dynamic problem, time does not permit this action. A spatial approach, rather than time, is indicated by employing spatial averaging techniques for noise reduction. The simplest one, used to condition a signal prior to correlation, is obtained by setting the coefficients in the convolution filters, Fig. 2, to positive values for tandem low pass filtering. This result is windowed and left-right convolved, Fig. 8(b). This composite image display shows the stationary 4 bit image forming the "A" input to the correlator, Fig. 2, while the trace is comprised of 64 dots, each representing the convolution mate of expression (3). The best left-right match of this time variant image occurs when the singular cusp in the convolution trace reaches its maximum. In the absence of symmetry, the trace exhibits no such cusp.

4. Conclusion

The current lack of general purpose digital signal processing computer modules which are fast enough for real-time digital image processing compels its implementation using specialized components in unique system architectures. The system described is an experimental front-end digital image processor designed to begin the extension of photogrammetric application into the sphere of immediate, filmless, in-situ analyses of dynamic processes.

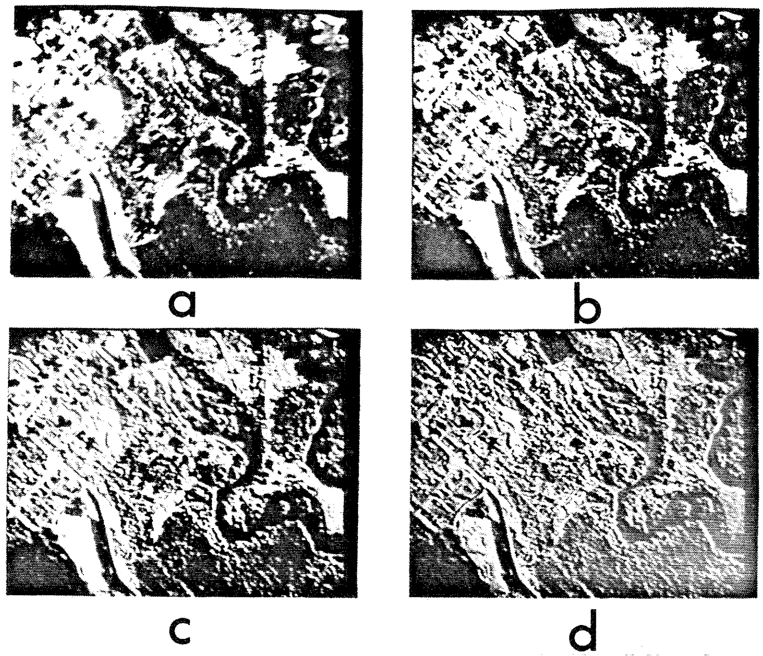


Fig. 7.

Original (a) is processed by increasingly high-pass digital spatial filters in (b), (c) and (d).
Relative coefficients respectively of (b), (c) and (d)

$$\begin{bmatrix} 0 & -4 & 0 \\ -4 & 4 & -4 \\ 0 & -4 & 0 \end{bmatrix} \qquad \begin{bmatrix} 4 & -6 & 4 \\ -6 & 3 & -6 \\ 4 & -6 & 4 \end{bmatrix} \qquad \begin{bmatrix} 4 & -4 & 4 \\ -4 & 2 & -4 \\ 4 & -4 & 4 \end{bmatrix}$$

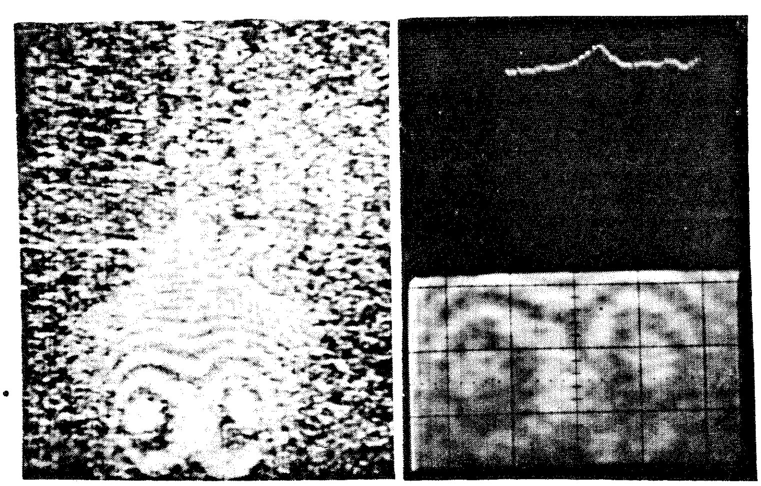
b c d

Fig. 8.

Noisy moiré image (a) is low pass filtered for noise reduction then a windowed portion (b) convolved for left-right image symmetry evaluation indicated by the singular cusp in the convolution trace in (b).

Filter coefficients (b) :

$$\begin{bmatrix} 15 & 15 & 15 \\ 15 & 15 & 15 \\ 15 & 15 & 15 \end{bmatrix} \cdot \begin{bmatrix} 6 & 7 & 6 \\ 7 & 0 & 7 \\ 6 & 7 & 6 \end{bmatrix}$$



a b

5. Acknowledgement

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