# DIGITAL PROCESSING OF DYNAMIC MOIRE IMAGERY AS AN AID IN SCOLIOSIS SCREENING

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## Abstract

Digital image processing is applied as an aid to automatically detect a predetermined standard alignment of free standing human subjects for scoliosis detection by moiré topography. A low cost, portable, real-time system developed for the purpose and consisting of video rate image capture, digitization, digital spatial filter, correlator/convolver and displays is briefly described and some results discussed.

## 1. Introduction

Early detection, diagnosis and monitoring of scoliosis through school screening programs is a valuable contribution to health care. A pilot screening program (Adair, 1977) using experimental moiré equipment (van Wijk, 1980) revealed, among other things, the desirability of standardizing and automating the process in order to remove what has become a data processing bottleneck.

As a particularly useful form of structured light, moiré pattern techniques are especially popular in both industry and medicine (Herron, 1983) because of their value in depicting topography of surfaces in a visually appealing manner and in a form that has potential for single image 3-D analysis with reduced data when compared to stereo methods. Since surface shape measurement is not in common use by clinicians, ways are being sought to standardize and simplify the procedure. Although the generation and acquisition of moiré topograms is deceptively easy, their control and interpretation may not be. Two programs are under way in this area as part of the ongoing work at the National Research Council in photogrammetry applied to medicine. One is the 3-D analysis of moiré topograms by computer for the purpose of classification and quantification. The other is a real-time electronic aid to be used during image capture in order to standardize the relative subject - screening device position and to flag the difference between normal and otherwise. This paper describes the method, apparatus, and some preliminary laboratory results from this real-time electronic aid.

## 2. Digital Processor for Dynamic Moiré

Given a suitable apparatus for casting moiré patterns onto the backs of human subjects (van Wijk, 1980), and a means of calibrating the instrument (Drerup, 1983) a pivotal task in a moiré scoliosis screening venture is to detect a predetermined standard alignment of free standing human subjects to reduce the postprocessing required for extraction of quantitative evaluation data about the topography of each subject's back. This is a dynamic image problem since moiré pattern configuration is highly position sensitive. Given the uncertainty of the screening environment and skin reflectivity any automatic solution should be able to function with poor imagery (i.e. low contrast patterns and patterns exhibiting spatially variant contrast). For this reason it was decided to apply digital image processing techniques in the solution. This would enable conditioning of a range of image degredation sources prior to real-time image matching for detecting a desired standard subject - apparatus orientation. The architecture of a low cost, portable, real-time digital image processing system for the purpose is shown in Fig. 1.

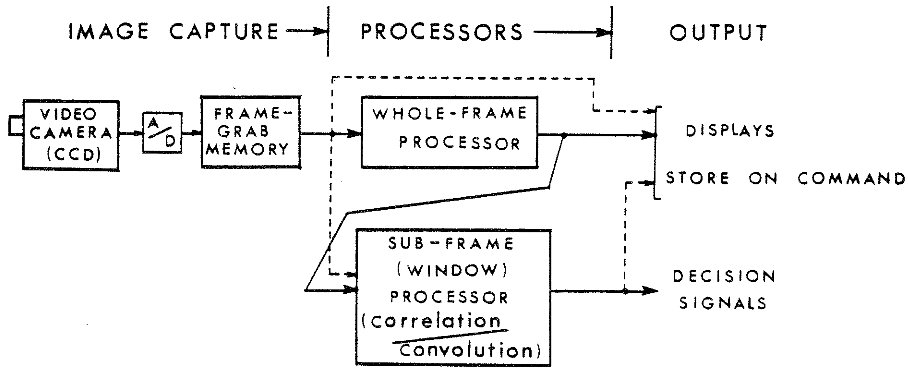



Figure 1: Main elements of the digital electronic aid for moiré scoliosis screening. (A/D - analog to digital converter).

It contains three feed-forward steps in the information flow: image capture, processing and output. The rationale for this system and technical details are to be found elsewhere (Real, 1982, 83, 84). Briefly, a solid state charge coupled device (CCD) 380x488 pixel video camera is mounted on the moiré apparatus (van Wijk, 1980) in a position close to, or normally occupied by, the optical camera presently used for image acquisition. The video camera-processor combination has these advantages over the use of an optical camera:

(1) Real-time image adjustment with feedback to the operator.
(2) Immediate storage and playback.
(3) Immediately visible enhancement of poor images.
(4) Automatic repeatability of subject-apparatus orientation to speed-up and simplify the screening and subsequent processing procedures.
(5) The possibility exists to automatically signal the presence of normal subjects and perhaps exclude the need for storing their patterns.
(6) The data from the metrically stable CCD camera is digitized and can be stored, either processed or unprocessed, on a computer compatible medium.

The disadvantages of this approach on the other hand are the system cost and the relatively lower resolution, for a given field, of the video camera compared to optical systems.

The image capture portion consists of a CCD video camera, high speed analog to digital converter and digital "frame-grab" memory. Processing is in two parts; whole-frame digital image conditioning and a high speed image matching processor for a window or patch of the whole frame. This branch permits more computation intensive operations to be completed on part of the frame at the same time the whole frame processing is complete. In this application the sub-frame processor follows the whole frame processor, since the latter is used to precondition poor imagery prior to image matching.

The frame processor is used to remap grey scale distribution within the acquired image. The algorithm implemented in hardware is a 3x3 pixel spatial filter (known as a convolution filter (Real, 1982)), with programmable coefficients. In an electronic image transfer photogrammetric application this transformation often takes the form of enhancing fine detail in an image for better visibility. In this moiré application a pair of such filters are used to:

(1) Improve contrast of faint moiré patterns.
(2) Equalize contrast.
(3)Reduce screen (carrier) noise.
(4) Generate thinner contours.
(5) Compress grey scale. The moiré modulation can be compressed into a near-binary image without the attendant loss of information that would accompany a level slicing or threshold operation.

By judicious choice of coefficients, these operations are achieved to a useful degree simultaneously by using a filter pair.

One approach to subject-apparatus orientation is to accept as a "standard" alignment moiré pattern symmetry at the buttocks. For this trial the sub-frame processor, Fig. 1, was configured as a left-right image matching unit in the form of a correlator/convolver. Left-right image matching by this technique for symmetry detection is demonstrated by use of simple images in Fig. 2. The short traces in Figs. 2(a,b) are autocorrelations of a ring in a 120x120 pixel window. The long traces are convolutions of the image (i.e. matching the image shown with its shifted left-right transposition). The position of the convolution peak varies with the relative position of the image in the window. The cusp has the same shape and magnitude as the autocorrelation because of the perfect left-right symmetry of this pattern.

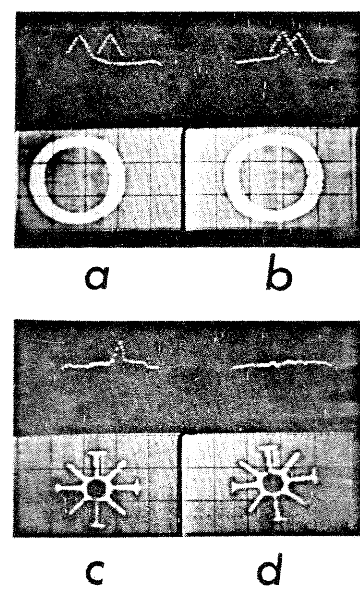



Figure 2:

(a) A ring is autocorrelated (short trace) and convolved (long trace) along the major x-axis. Since the ring is symmetrical, the correlation/convolution peaks are identical.
(b) Repeat of (a) with the ring shifted in x.
(c) Convolution only in x of a pattern.
(d) Repeat of (c) with the pattern rotated. Since most of the left-right symmetry is lost, no distinct convolution peak is generated.

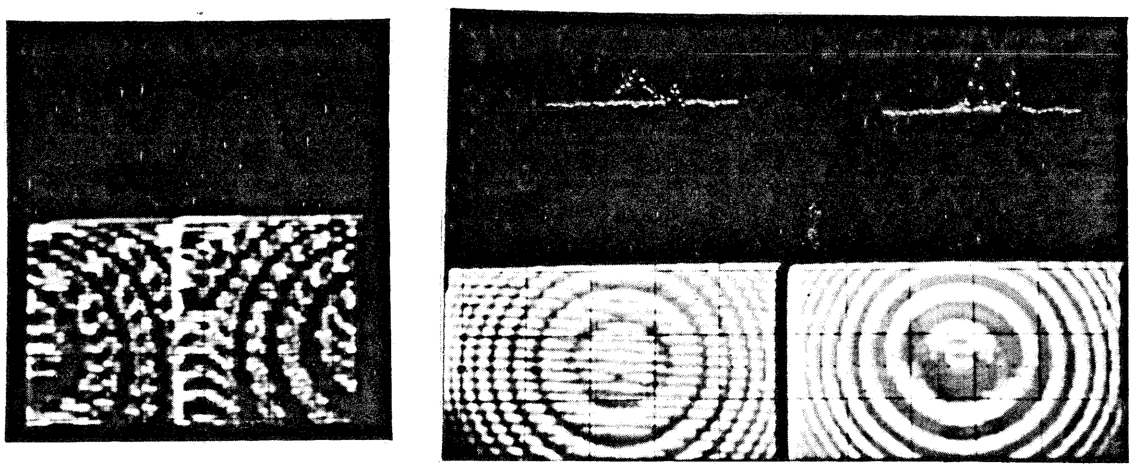
Fig. 2(c) shows the convolution trace for another pattern with left-right symmetry. The cusp generated here is narrower than for the ring because of the finer structure of the image. The convolution trace in Fig. 3(d) is relatively flat once the pattern is rotated since only the central ring of the left-right transposition will match. These simple figures demonstrate the principle to be tried in achieving the stated goals. The autocorrelation is used to signal whether there is useful information within the window, and the longer path length of the convolution reduces the need for left-right centering of the pattern of interest. These operations occur digitally in the sub-frame processor, Fig. 1, are converted to analog, and then combined with the stationary image to the correlator for the purpose of display and visualization (Real, 1984).

The output section consists of one or more decision or control signals and optional digital data transfer, storage and displays. At its simplest, the system, Fig. 1, will simply trigger an optical camera at the appropriate moment. However, since the data is destined for transfer to a computer, it is reasonable to store it in digital form. High capacity, high data rate digital magnetic disc systems are indicated for a mass screening venture, but they are costly. The write/read digital optical disc is an appropriate medium, but these systems are still in an early state of commercial development. A video display, although not essential once set-up geometry is established, would nonetheless be useful for subject position and fringe contrast monitoring from the camera.

## 3. Results

### 3.1. Fine Fringe Rejection

A fixed screen (raster) moiré fringe projection results in moiré contours on an irregular surface which contain the fine structure of the screen as a spatial "carrier". A magnified patch of such an image is shown in Fig. 3(a).



a b c

Figure 3: (a) A magnified patch of moiré pattern showing fine structure or spatial carrier present when using a fixed horizontal screen.
(b) Autocorrelation (short trace) and convolution of symmetrical concentric rings with a slightly tilted spatial carrier. Note the relatively low convolution cusp.
(c) Repeat of (b) with much of the spatial carrier suppressed by defocussing. Convolution peak is almost as large as the autocorrelation peak.

This is quite unsuitable for the proposed correlation implementation. A slightly tilted horizontal fringe or raster is evident in the concentric circular pattern in Fig. 3(b). The left-right convolution of such a raster-free pattern should exhibit the same magnitude as the autocorrelation. The convolution shown as the cusp in the long trace in Fig. 3(b) is clearly below the strength of the autocorrelation. By optically defocussing (integration or low pass spatial filtering) the circular image (Fig. 3(c)) the screen carrier is largely suppressed and the strength of the convolution improves. A degree of electronic smoothing is also possible in place of, or added to, optical defocussing by setting all of the coefficients of the first stage convolution filter to the same positive value.

### 3.2. Poor Image

A fixed screen apparatus is used to cast a moiré fringe upon a manikin, Fig. 4(a). Fig. 4(b) contains the same pattern at a projected light intensity level less than one hundredth of that in (a), resulting in a poor image. The high pass filtered version of (a) is shown in (c). The contours are accentuated and less variable in intensity than in (a). Convolution of a patch from (c) is shown in (d). Convolution of a similar patch directly from (b) yields an essentially flat trace, but if that image is operated upon by

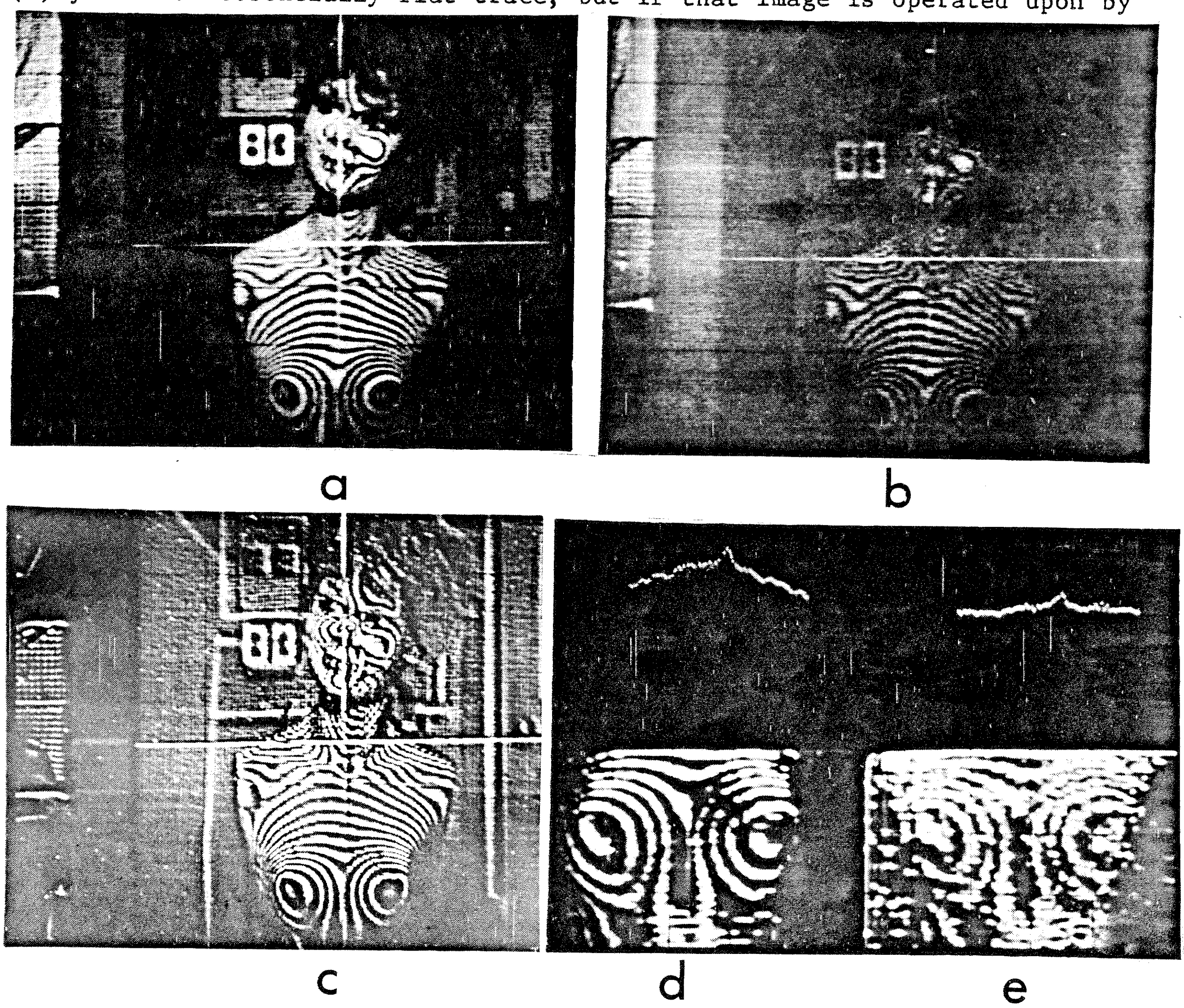



Figure 4: (a) Moiré fringe pattern generated by a fixed screen projector.
(b) Repeat of (a) with light intensity reduced by a factor of one hundred.
(c) Digitally processed version of (a) with convolution kernel

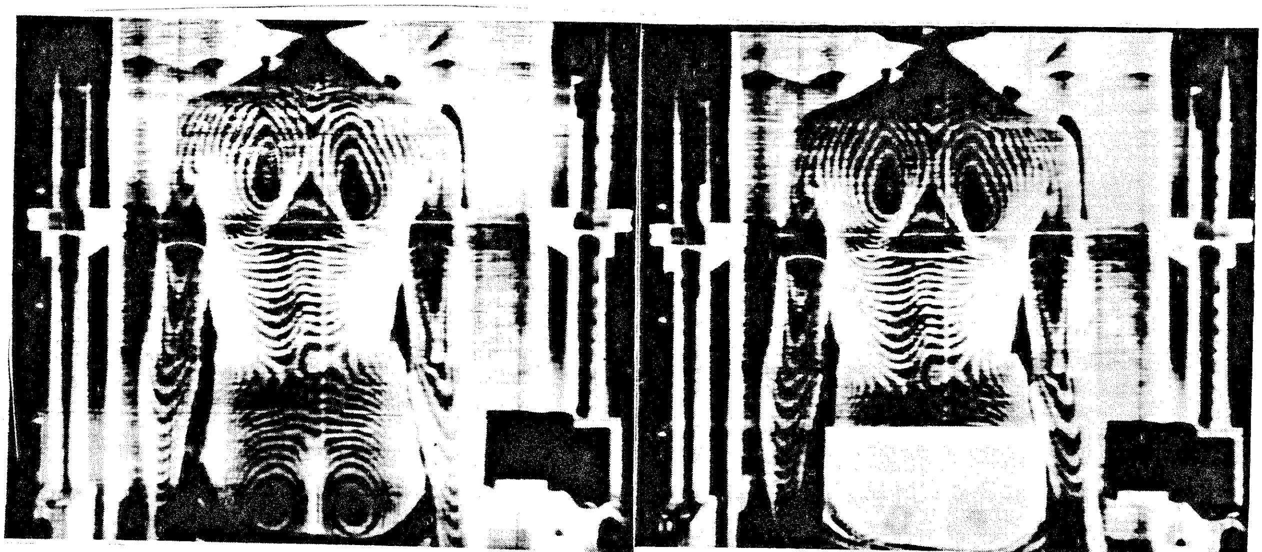
$$\begin{bmatrix} 0 & -7 & 0 \\ 0 & 6 & -7 \\ 0 & -7 & 0 \end{bmatrix} \quad \text{(see Real 82, 83)}$$

(d) Convolution of patch of (c)
(e) Convolution of equivalent patch from (b) after operating on (b) by the same kernel as in (c).

the same kernel as in (c), then a small convolution peak does emerge, as seen in Fig. 4(e). In practice the human form will not exhibit perfect symmetry, as also evident on the manikin, hence the convolution peak representing the best match of an approximate or nearly symmetric condition will be less than the corresponding autocorrelation peak. Such approximate left-right matching is exhibited in Fig. 4(d).

### 3.3. Automatic Determination of a Standard Position by Left-Right Symmetry

A moiré topogram of a subject standing in the desired position is shown in Fig. 5(a). The experimental standard position is that where the moiré pattern on the buttocks region exhibits symmetry, or at an least an approximation thereto, (since most subjects will not be exactly symmetrical in any part of the anatomy) where the fringe orders are in the same phase. The dynamic range of a video display is unable to reproduce the entire depth of grey scale or shading, hence parts of Fig. 5(a) appear both over and underexposed. Processing to rectify this situation is discussed later.



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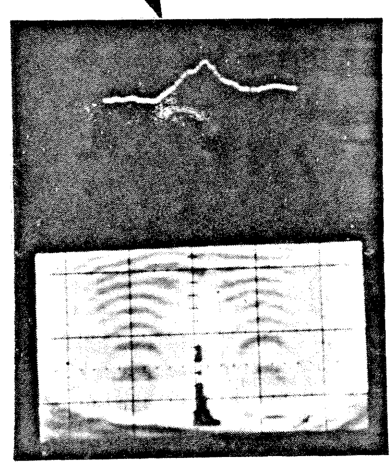

c

Figure 5:

(a) Video display of a moving screen moiré fringe pattern after digitization and storage. (Note loss of high and low intensity levels due to the restricted dynamic range of the video display).
(b) Windowed portion of (a) indicated for correlation/convolution.
(c) Left-right convolution of windowed portion of (b). The singular cusp indicates a high degree of left-right symmetry in the pattern.

A portion of the image is windowed electronically, Fig. 5(b), and directed to the image matching processor (sub-frame processor, Fig. 1). The windowed image resides in a high speed memory which is the source for high speed digital correlators. These correlators accept two streams of data from the memory. The "A" stream is the windowed image, depicted in Fig. 5(c). The "B" stream is the left-right transposed image shifted horizontally in memory. Since the dedicated sub-frame processor memory has two address generators, any relative motion can be programmed to occur between the images, or between two completely different images if the memory is partitioned. In this application the left-right transposed image (not visible in Fig. 5(c)) is slid horizontally in vertical registration with the stationary image, visible in Fig. 5(c). For each horizontal pixel shift, the matching "score" is obtained via the correlators (Real, 1984). The digital value of each score is converted into an analog display in the form of a dot above the image in Fig. 5(c). Each dot, representing an entire sub-frame correlation, has a vertical deflection proportional to the degree of match between the images, and a horizontal position proportional to the relative horizontal image-shift. The convolution trace in Fig. 5(c) consists of 64 such dots. This seemingly longer than necessary shift length allows some latitude in the horizontal positioning of the subject relative to the screen. Vertical window positioning, yet to be implemented, may be done by directing a pen-light at the point on the subject's back where the center of the first line in the window is to be. The camera will receive the reflected light and the starting vertical address for the window will automatically be set.

The trace in Fig. 5(c) does not exhibit a desirably narrow cusp due to contour thickness and the fact that left-right symmetry is only approximate. How can this signal automate the positioning? The concept is to have the subject stand unconstrained and approximately centered behind the screen. The moiré apparatus will be moved through a small horizontal arc so that the pattern at the buttocks goes through a cycle extending from fringe phase unbalance at the buttocks through a balance condition. At phase balance the convolution cusp grows to its maximum, indicating approximate or "best" left-right pattern symmetry. This peak, as well as cusp shape and detection of a singular cusp of correct sign, is determined in a digital processor following the correlator/convolver (included as part of the sub-frame processor, Fig. 1). This concept is currently being tested for its soundness and reliability.

### 3.4. <u>Operation of Processor in Scoliosis Screening</u>

The electronics designed as an aid in scoliosis screening, Fig. 1, permits the following sequence to be realized:

(1) Electronic image capture, digitization and storage (30 frames per second) as seen in the example, Fig. 5(a).
(2) Windowing (see Fig. 5(b)) of a portion of the digitized image at 30 frames per second. The high speed sub-processor memory in current use is 32k pixels in extent. Window positioning for the buttocks pattern symmetry check will be automatic as previously described.

(3) Remapping of grey scale by digital spatial filtering at a rate of 10 frames per second for a single stage, 5 for two serial stages. An example of this is seen in Fig. 6(a), which is the data of Fig. 5(a) processed with the coefficients indicated to strip the essential intelligence from the background shading and convert it into an image of almost digital character. Note that this result will not be possible by simple thresholding or slicing of the data, which will cause a loss of information. The processed image, Fig. 6(a), which has a flattened dynamic grey scale range, is a better match for the capability of the video display because detail is rendered visible in regions where it is not in Fig. 5(a).

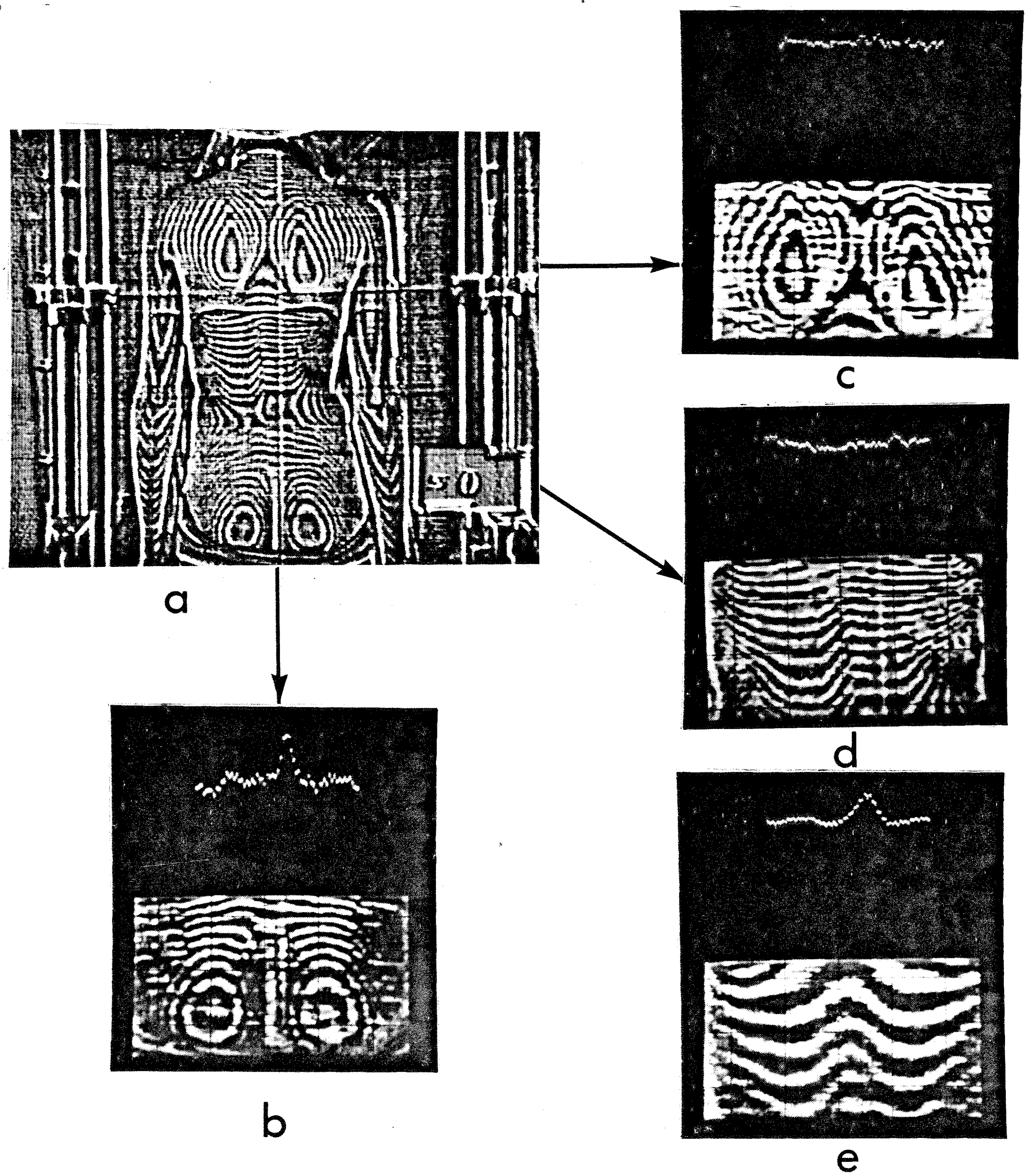


Figure 6: (a) Frame of Fig. 5(a) processed with convolution filter kernel

$$\begin{bmatrix} 8 & +14 & 8 \\ -15 & 0 & -14 \\ 8 & -14 & 8 \end{bmatrix}$$

(b) Patch of pattern at buttocks undergoes left-right convolution; approximate symmetry is indicated by the cusp in the trace.

(c), (d) Portions of the moiré back pattern undergo test for left-right symmetry, seen lacking due to absence of a large singular cusp in the convolution trace.

(e) An example of a patch of a different moiré back pattern where a degree of left-right symmetry is indicated.

(4) Convolve the windowed buttocks region in the search for best left-right symmetry; that position being displayed in Fig. 6(b). Note the cusp indicating the near symmetry is narrower than that in Fig. 5(c) where the data was unprocessed. The coefficients selected for the convolution kernel, Fig. 6(a), act as a high pass filter, resulting in edge enhancement and thinning of the original contours. This permits a more precise determination of the position of best left-right symmetry. The generation of images Figs. 6(a,b) is continuous and dynamic. The process of image acquisition, grey-scale processing and window convolution proceeds, once commanded to start, until a signal is generated indicating a match as the equipment is moved in a small arc around the subject. At that point the image captured in digital memory is frozen.

(5) Once the desired symmetry is found and the image frozen in memory, other regions of the back are checked for symmetry to determine if the subject is normal. This is illustrated by Figs. 6(c), (d). The convolution trace in this case shows no singular cusp hence the subject is positive, indicting either unnatural posture or scoliosis. A symmetrical pattern is shown, Fig. 6(e), to illustrate the formation of a singular cusp during convolution.

(6) Upon detection of a positive subject, either the unprocessed image, Fig. 5(a), or processed image, Fig. 6(a), or both, may be stored digitally or on analog video tape.

The disadvantage of analog storage is loss of metric accuracy, which is, after all, paramount in the subsequent computer analysis. If facilities exist, the stored image can be downloaded directly to a computer, but this is only currently practical if the scoliosis screening takes place in a central facility.

## 4. Conclusion

A real-time digital electronic aid for proposed use in scoliosis screening was described. Its function is to automatically capture moiré topographic patterns on subjects which are in a standardized alignment relative to the screening apparatus, to signal which subjects are normal and to store the processed or unprocessed topogram digitally for further analysis. Emphasis has been upon a high-speed, low cost, portable implementation of digital image processing to achieve this goal. The system is reported upon at the laboratory breadboard stage and is undergoing preliminary tests and modifications. It represents the continuation of a recent trend towards real-time, filmless diagnostic techniques in medicine, a trend that will undergo rapid acceleration commensurate with revolutionary developments in the semiconductor industry.

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