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SURFACE TOPOGRAPHY WITH MOIRÉ BY IMAGE PROCESSING. ESTIMATION OF LOCAL LINE CURVATURE FOR THE DESCRIPTION OF BACK SHAPE.

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ABSTRACT

An image analysis software package (SIS) was used to realize a projected moiré method on a PC/framegrabber combination. Video sequences were studied using a camcorder. A CCD camera was also used for evaluating paper prints or film negatives obtained from photographic moiré. The essential steps of image processing were: multiplying the reference grid with the distorted line image and Sobel filtering. Anatomical landmarks, or predefined points on the moiré fringes were marked interactively; from the binarized image, coordinates were extracted directly, or transferred to AutoCAD. An estimate of fringe curvature by way of three-point-reconstruction of arcs thus became possible, but was also accomplished with the measurement functions of the image analyzer. The method's reduced sensitivity makes it robust and versatile, but quite capable of quantitative studies on the body surface, with the subject in a position at will. Examples suggest that the method may be useful for a more rational understanding of physiotherapeutic effects.

Keywords: Curvature, image analysis, moiré topography, physiotherapy, posture, surface analysis.

INTRODUCTION

A moiré method with projected grating (Miles and Speight, 1975), the possible medical significance of which had been demonstrated in this journal (Leder and Kurz, 1987), was successfully applied for investigations on the body surface of singers (Kurz et al., 1989, 1990, Kurz and Leder, 1989, 1990a,b). For improved performance, it was modified to function on a PC-based image analyzer (Kurz and Leder, 1990c). It now works with diverse optic media: photographic negatives or prints, and CCD or video camera recorder (camcorder). Having evaluated coordinates and differences thereof in the earlier publications, local curvatures and curvature changes are considered in their relation to physiological quantities like muscle tension in current studies. This paper describes moiré formation by image processing, the interface to a CAD system and the estimation of fringe curvature, together with first results from the documentation of physiotherapy.

HARDWARE, SOFTWARE AND OPTICS

The framegrabber PIP 1024 B (Matrox, Canada) was installed in a PC/386 (Pyramid, Freiburg) with numeric coprocessor 80387, 10 MB RAM, 184 MB SCSI harddisks and Video Seven FastWrite VGA board. Two analog monitors were connected, an Eizo 9070S (1024x768) to the VGA and a Mitsubishi EUM 1481A (800x600) to the PIP.

The image analysis system (SIS, Münster) is a modular software package, written in C. It operates on four 512x512 pixel images with 256 gray levels and offers, besides standard routines of image analysis, the possibility to convert detected, binarized pixel images to vector graphics in the DXF (Drawing eXchange File) format. The DXF files were imported by the standard CAD software AutoCAD 10.0, which was used for 2-D measurements and also 3-D reconstructions (cf. Kurz and Leder, 1989, 1990b). For the video setup, a Video 8 camcorder (Fisher) was used, which had a signal to noise ratio of 52 dB and a resolution of 330 TV lines, and was turned about 90° to increase the resolution power.

The slide projector was a Liesegang projector with a focal length of 85 mm. A special 36x24 mm slide was prepared with 246 lines, which produced an equidistant grating with a constant pitch d = 3.2 mm under oblique projection onto a flat white screen. The angle α = 29.5° between distances L (camera-object) and P (projector-object) determines the distance l (camera-projector) in the orthogonal triangle. This geometry with pitch d of the projected grating leads to a distance δz between moiré fringes of 5.6 mm, according to Eq. 1 (cf. Miles and Speight, 1975, Kurz and Leder, 1990a). With L = 150 cm and l = 85 cm, a focal depth of 30 cm and a viewing field of 40x25 cm were obtained. The setup could reliably assembled at the physiotherapist's, where the camera and projector were mounted in rails under the ceiling for vertical viewing of the supine patients. For the analysis of paper prints or negatives, a CCD camera with normal or macro objective was mounted over a light box (cf. Kurz and Leder, 1990c).

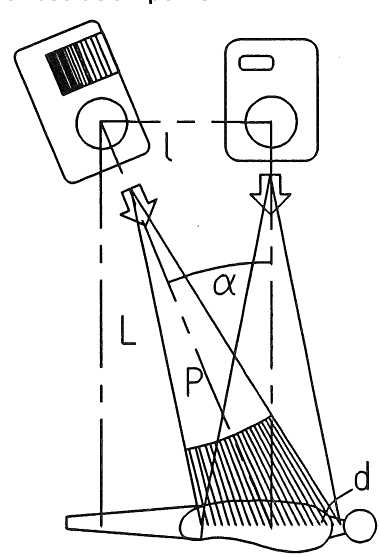

Figure 1. Video recording of the supine patient with oblique projection of the grating from above.

$$\delta z = d \times \cot \alpha = d \times \frac{L}{l} \qquad (1)$$

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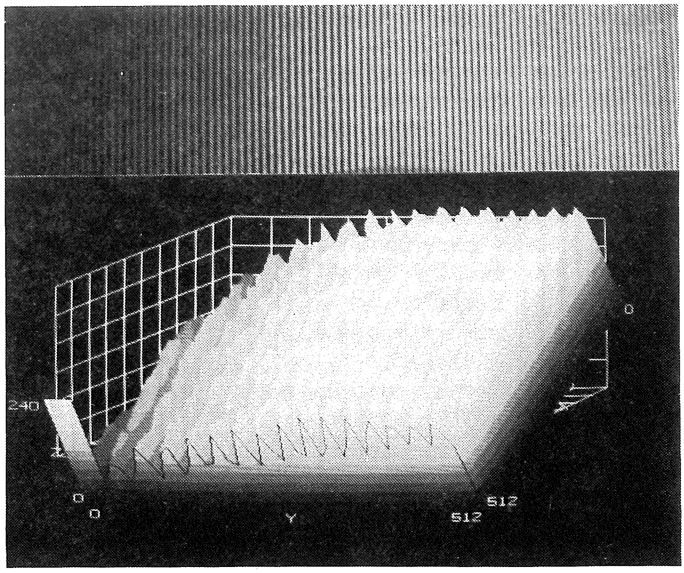

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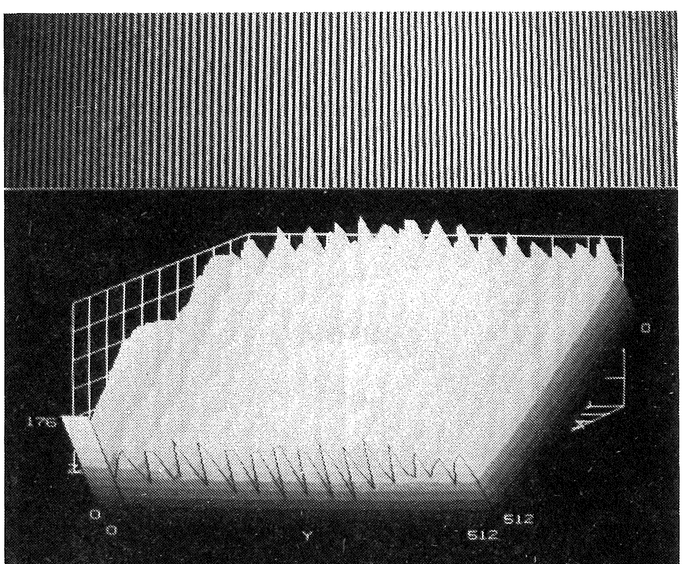
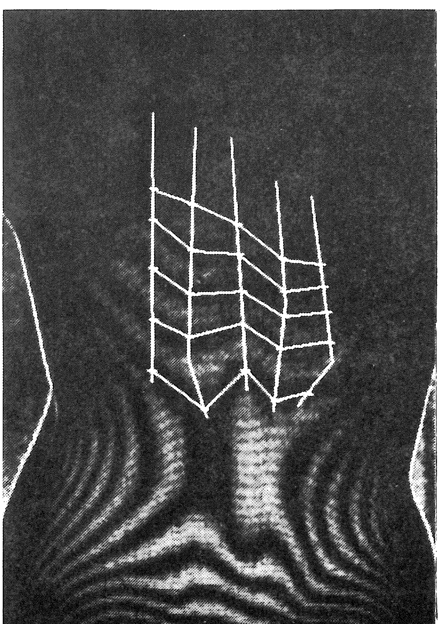


Figure 2. Untreated reference grid with strong gradient; its gray value distribution shows a corresponding slope and an interference pattern. Maximum gray value 240, minimum 40.

Figure 3. Subtraction of two grids, shifted laterally by one pixel, eliminates the gradient; the relative modulation has been enhanced slightly, but peak gray values have been reduced to below 176, valleys are above 64.

DIGITAL MOIRÉ

The reference grid presented with a strong intensity gradient due to the oblique projection. This was eliminated by subtracting a copy of the grid, shifted laterally by one pixel, from the original image, which also led to a considerable noise reduction (cf. Figs. 2,3). One period of the projected grating was made to cover four pixels of the image matrix on the framegrabber board, resulting in 512/4 = 128 grid lines per frame. The modulation of the gray values, due to the combined effects of optical distortions and digitizing artifacts was constantly observed, but did not interfere with the steps of image processing to follow.
The reference image was stored to disk and served as a control for reference grids recorded later; only minor deviations could be observed, after the apparatus had been moved and repositioned. From the replay of the video recordings, single frames were digitized and stored, using the audio recording as a protocol. The 'distorted line images' of the back were multiplied with the reference grid to



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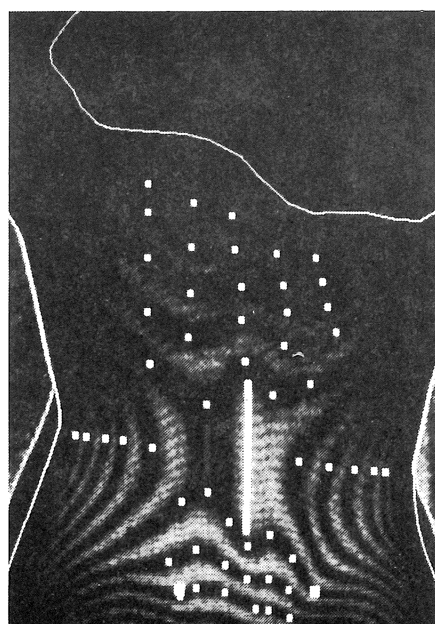

5

Figure 4. Back of a girl with scoliosis, at rest (patient of U. Schauer, Freiburg). Moiré fringes on the paravertebral back show local curvatures similar to conic sections and were measured according to Eq. 2.

Figure 5. Same subject as in Fig. 4. Discrete points were marked for digitization and measurement in AutoCAD.

produce the moiré pattern of differing spatial frequencies of gray values, which was made distinctly visible with a Sobel filter. Image processing steps were combined into a macro routine to run in about 10 s.

ESTIMATION OF FRINGE CURVATURE

The radius r of the circumscribed circle in a triangle with one side of length c and the angle γ between the two other sides is given by $r = c/2 \sin \gamma$. Now, if three points are chosen on a curved line, the mean local curvature K may be estimated according to Eq. 2, with K = 1/r (cf. Fig. 4).

$$K = \frac{2 \sin \gamma}{c} \tag{2}$$

Another way was to first mark the required points on the moiré fringes interactively with a defined gray value (e.g. 249: cf. Fig. 5). These points were detected and stored as a binary image, which, after conversion to the DXF vector format, were exported to AutoCAD for three-point reconstructions of approximating arcs. The 'dimensioning' function then was used for measuring the radii of the arcs.

RESULTS

The two ways of radius estimation are compared in Tbl. 1. Deviations of about 5% were recorded also for other patterns, with a tendency for the SIS method towards slightly greater values.

Table 1. Comparison of estimated radius of curvature r (mm) of the two methods. The values were obtained from the resting position for three fringes on either side.

	F1l	F2l	F3l	F1r	F2r	F3r
r_S (SIS)	22.95	32.71	34.49	19.24	34.10	35.34
r_A (AutoCAD)	23.86	30.19	32.84	18.93	32.76	35.51
r_S-r_A	-0.91	+2.52	+1.65	+0.31	+1.34	-0.17

The approximation and measurement of moiré fringes on the paravertebral back with arcs is shown in Fig. 6. Local mean fringe curvatures are given in Tbl. 2 for a girl with scoliosis, who had been treated by U.S. with physiotherapy according to Vojta (1988) for several years. Only the lowermost three fringes were used for estimation of curvature, and only positive values were considered. The measurements were made before, during and after therapy and it may be concluded that paravertebral muscles were activated. Since the girl presented with a right convex scoliosis in the thoracic portion of the spine, the scoliotic deformity might have been counteracted by the persisting muscle tension on the right side. The fringe pattern was split up into a medial and a lateral portion on both sides during manual stimulation. The sign of curvature changed for the upper arcs on the left side,

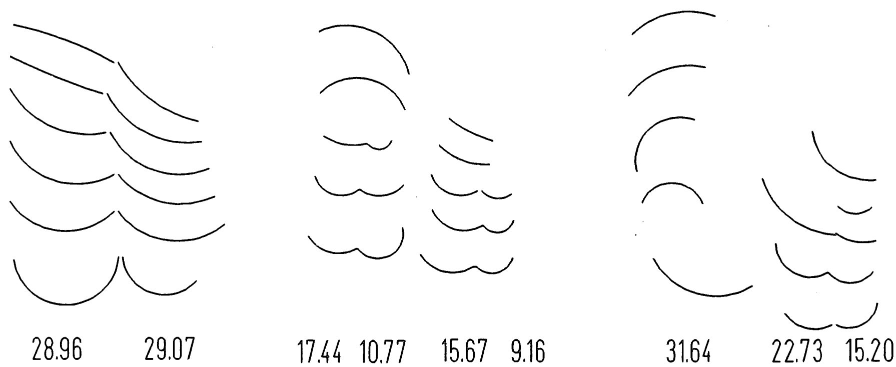

Figure 6. Fringe reconstruction of the paravertebral back before (left), during (middle) and after therapy (right) with approximating arcs in AutoCAD. Mean radii for the three lower lateral and medial arcs, where applicable.

Table 2. Comparison of estimated mean fringe curvature K (m^{-1}) for the paravertebral back of a girl with scoliosis under physiotherapy. If only one arc was observed, its curvature is listed as 'medial'; arcs with negative curvature (convexity upwards) were ignored.

	left		right	
	lateral	medial	medial	lateral
Before	------	34.53	34.40	------
During Therapy	57.34	92.85	63.82	109.17
After	------	31.61	43.99	65.79

indicating an almost complete relaxation of the left iliocostal and longissimus muscles. This pattern was observed for about 10 s, until the position was intentionally changed. The upper arcs were located in the region of the 8th to 10th thoracic vertebra, where the trapezius and rhomboid muscles also determine the back surface relief. The influence of scapula position and orientation may be visualized from the pattern 'after therapy': the medial edge of the left scapula has been forced away from the rib cage, most probably by the combined action of ventral muscles (e.g. pectoralis major and minor muscles), which leads to a concave surface and a negative curvature for the corresponding moiré fringes on the back.

DISCUSSION

The moiré formation with elementary image processing operations has been realized on general-purpose image analysis equipment; the procedures involved are independent of particular hardware or software. This may help to further the application of moiré, which, in contrast to most other 3-D measurement methods, combines an intuitive appraisal of shape with a quantitative assessment of surface topography (cf. Windischbauer, 1989).

A major advantage of the applied Miles-Speight (1975) principle is that the patient need not be confronted with a laboratory surrounding, but merely has to tolerate a slide projector and a video camera. This is important, if field studies (Kurz and Leder, 1990 a,b,c) and long-term observations are to be carried out. The method might consequentially be applied also for the documentation of younger children during physiotherapy; this is relevant for the original Vojta therapy, which had been developed for the treatment of cerebral palsy in young infants.
The estimation of local fringe curvature is reasonably precise, if compared to therapy-induced alterations, but it is a reasonable estimate only in the case of a rather constant, convex or concave bending behavior, i.e. if the second derivative of the curve does not change its sign. This condition will be fulfilled for parts of the moiré fringes on the paravertebral back, which can be considered to represent conic sections, if the three points are appropriately chosen.
The importance of 3-D curvatures (principal, mean or Gaussian) as shape parameters has been stressed earlier by Drerup and Hierholzer (1982) and Frobin and Hierholzer (1987). Measurement of 3-D curvatures, which would be independent of a certain coordinate system, was not intended in this study; since the patient was lying in an almost fixed position on a level surface, perpendicular to the optical axis of the CCD camera, the alterations of the paravertebral fringe pattern due to gross positional changes could be neglected.
Fringe curvature is a further parameter for the description and documentation of surfaces. Moiré fringes are contour lines, which contain the quantitative, three-dimensional information about the surface; their varying form is an immediate illustration of a modified surface topography. This may be of particular value with online moiré methods, but is also meaningful for the analysis of photographs or digital images. The shifting contour lines, together with the measured curvature may be of definite interest for physiotherapists, who by way of moiré methods can perceive an additional, 'graphic' impression of what is caused by their efforts.
This study for the first time demonstrates the application of fringe curvature estimation on the back during physiotherapy and gives support to the hope that different therapeutical approaches to postural disorders may be evaluated with non-invasive methods and may thus be compared on a broader and more rational basis.

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