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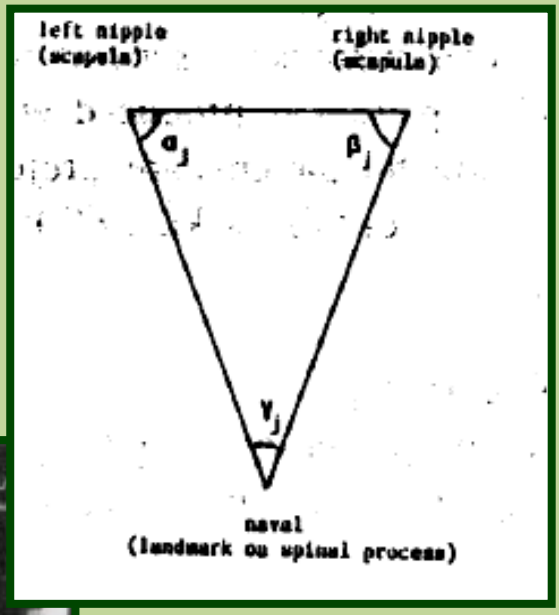
# A Study to Test the Reproducibility of Moiré Topographs




For a biomechanics researcher, the reproducibility considerations fall into two groups — stability and objectivity. By stability we mean if one takes several moiré pictures of an object and measures them, one should obtain the same values. By objectivity we mean if several people take moiré pictures of an object and measure them, they should obtain the same values. A reproducible moiré topograph is defined as the one, which is similar to the original one. It is only then possible that measurements on the two subsequent moiré topographs could be compared. Let us define two moiré topographs to be similar if they can be brought into an exact ⇒

⇒ match of each other by any or a combination of the following operations:

(*a*) change of scale (enlargement or reduction)

(*b*) translation of origin (a reference point marked on the body)

(*c*) rotation about an axis perpendicular to the plane of photograph

The last condition may be generalized for grating-hologram-type-moiré topographs. For these patterns, rotation about any coordinate axis or a combination of these rotations may be performed. Results of this study suggest that to obtain reproducible frontal moiré topographs, symmetric fringes on knees should be considered.

**Syed Arif Kamal, Göran Benoni and Stig Willner**

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# A STUDY TO TEST THE REPRODUCIBILITY OF MOIRE TOPOGRAPHS

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**ABSTRACT**

Moiré fringe topography is a simple, inexpensive, noninvasive optical technique which provides a three-dimensional map of human body without using ionizing radiations. The usefulness of this technique is somewhat limited unless there is a method to obtain reproducible pictures. This paper reports the results of a study conducted in Malmö, Sweden to test a reproducibility method proposed by one of the authors (SAK). The results indicate that the proposed method may be useful in obtaining reproducible pictures.

**Keywords:** moiré topography, spinal deformities, reproducibility

## INTRODUCTION

Moiré topography is an optical technique which produces shadow patterns (fringes). The patterns can be arranged to provide a map of three-dimensional surfaces by generating contours which are curves of constant height. When two gratings are superimposed on each other by an angle of less than 45° a pattern is produced which is called the moiré pattern. Depending on how the patterns are projected the techniques may be subdivided into three types (Takasaki, 1979):

(*a*) Shadow type
(*b*) Projection type
(*c*) Grating hologram type

In the shadow type and projection type the fringes cannot be adjusted for possible mispositioning. However, the fringes could be aligned in the

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grating hologram type of moiré topography. The technique has been widely used in surface analysis of human body because it does not pose any risk to participating subjects (Adair, van Wijk & Armstrong, 1977; Takasaki, 1970; 1973). One of the areas in which the moiré technique is extremely useful is the study of spinal column especially in children suffering from scoliosis. For the last few years moiré topography is being used in diagnosis and documentation of scoliosis. Several commercial systems are available for exact moiré topography (Drerup, Frobin & Hierholzer, 1983; Harris & Turner-Smith, 1986; Moreland, Pope & Armstrong, 1981; Stokes, Pekelsky & Moreland, 1987).

The interest in moiré is due to the fact that it does not use X rays, and it provides information about surface shape in patients having spinal deformities. Such information is not available from the standing AP roentgenogram. However, the use of moiré in the follow-up of scoliosis rests on the possibility of obtaining reproducible moiré pictures. During recent years there has been considerable concern over the accuracy and repeatability of moiré topographs (Bannon & Tred-well, 1987; Csongradi, Jefferson, Turner-Smith & Harris, 1987; Jones, Scull, Dutton, White, Slinger & O'Connor, 1987). Recently a reproducibility criterion has been proposed for moiré topographs (Kamal, 1990). In this paper we describe a study conducted in Malmö, Sweden to test the stability aspect of this criterion (see the following section).

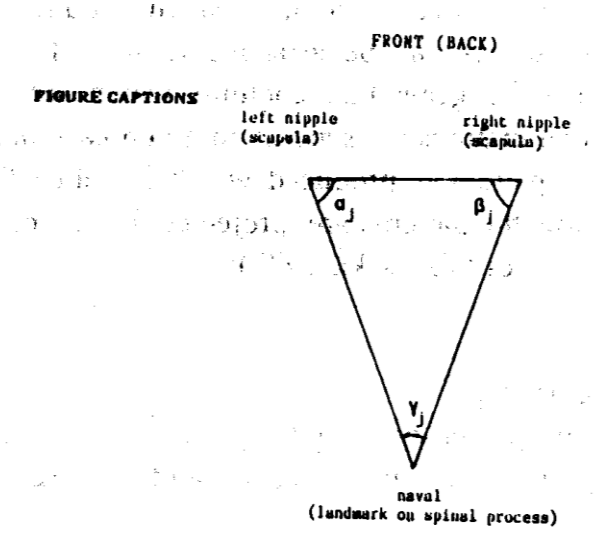


Fig. 1. Anatomical landmarks.

## *Reproducibility Criterion*

For a biomechanics researcher the reproducibility considerations fall into two groups - stability and objectivity. By stability we mean if one takes several moiré pictures of an object and measures them, one should obtain the same values. By objectivity we mean if several people take moiré pictures of an object and measure them, they should obtain the same values.

A reproducible moiré topograph is defined as the one which is similar to the original one. It is only then possible that measurements on the two subsequent moiré topographs could be compared. It is very easy to define similarity for a geometric figure such as a triangle. It can be shown that two triangles are similar if two of the three angles are congruent. However, for a moiré topograph it is much more difficult to define similarity. Two similar triangles have the same motifs but they may have different scales, rotated with respect to each other and trans-lationally shifted. Let us define two moiré topographs to be similar if they can be brought into an exact match of each other by any or a combination of the following operations:

(*a*) change of scale (enlargement or reduction);

(*b*) translation of origin (a reference point marked on the body);

(*c*) rotation about an axis perpendicular to the plane of photograph.

The last condition may be generalized for grating hologram type moiré topographs. For these patterns rotation about any coordinate axis or a combination of these rotations may be performed.

Once we have established the reproducibility criterion we may check if two moiré topographs are reproducible using an image processing algorithm, for example, SPIDER [System for Processing of Image Data in Electron Microscopy and Related Fields] (Frank, Shimkin & Dowse, 1981). However, we want to develop a method to obtain reproducible moiré pictures which incorporates these conditions and yet simple enough to be understood and applied by clinicians. For a reproducibility method to be acceptable, we require that:

(*a*) it should not disturb the natural posture of the patient;

(*b*) it should not involve any landmarks in the spinal area or trunk for scoliosis study and chest and abdomen for chest wall deformity, because these would not remain unchanged during physical therapy;

(*c*) it should be easy to apply.

To do that let us first look into the factors which would contribute to

To do that let us first look into the factors which would contribute to make two moiré topographs taken within a short interval of time nonreproducible. For the purpose of scoliosis study standing moiré topographs are generally taken. The most significant observation is the symmetry (asymmetry) of the two halves of the back (or chest on a front moiré topograph). Therefore, change of scale and shifting of origin are not concerns for reproducibility. The major concern is rotation of either the subject or the camera about normal to transverse plane. Such a rotation in shadow type or projection type could not be adjusted afterwards and would generate false positives and destroy diagnostic significance of the moiré technique. Rotation about normal to sagittal plane would not have any effect on the symmetry of the two halves of the back. Rotation of camera about normal to frontal plane would be visually obvious. It could be simply corrected by rotating the photograph in the reverse direction. Another possibility is rotation of the subject about normal to the frontal plane. This may be caused by: (*a*) different leg length and (*b*) un-equal weight on the feet. The first one would have no effect on reproducibility. This is because the difference in leg length would be constant for the two photo-graphing sessions and hence the pattern would be reproducible. However, this factor is very important when it comes to the diagnosis of scoliosis. An unequal leg length would give a false positive on the standing moiré for a child having a straight spine. Therefore, we suggest that leg length inequality should be corrected before taking a standing moiré. The second factor (i.e. unequal weight on feet) would effect the reproducibility. However, at this point we are assuming that this influence is small. Any attempt to force the child to put equal weight on both feet would influence the natural posture of the child.

A test is, therefore, proposed which is scale and origin independent and checks the effects of rotation about normal to the transverse plane on the reproducibility. In order to find a standard for reproducibility of moiré topographs avoiding the area being studied it was proposed that symmetric fringes on the knees be consi-dered as reference for front moiré topograph provided the child does not have any leg deformity. Variations due to habitual posture could be avoided if the child is asked to stretch both hands above the head in throwing posture with the feet firmly placed on the ground (mild-stretching posture). We are considering a body triangle based on three anatomical landmarks chosen as the vertices of the triangle. For a front moiré they are the left and the right nipples and the naval. For a photograph of the back the anatomical landmarks are the left

level as the naval (Fig. 1). Our goal now is to check if we can reproduce the posture in frontal plane based on symmetric moiré fringes on the knee because that is our purpose of obtaining moiré pictures - to quantitatively record the posture (which also includes record of scoliosis). Two moiré topographs will reproduce posture in the frontal plane (no significant rotation about normal to transverse plane) if the body triangles are similar. Now we can quantify this criterion by looking at the dispersion of various angles. Let $\alpha$, $\beta$ and $\gamma$ be the angles measured on the body triangle initially (Fig. 1) and $\alpha'$, $\beta'$ and $\gamma'$ be the angles measured during the second visit. The deviations are:

$$\psi_j = (\alpha_j - \alpha'_j) / (\alpha_j + \alpha'_j) \tag{1a}$$

$$\chi_j = (\beta_j - \beta'_j) / (\beta_j + \beta'_j) \tag{1b}$$

The index j = 1, 2,...., N is the case number (N is the total number of subjects studied). The averages are

$$<\psi> = (1/N) \sum_{j=1}^{N} \psi_j, \quad <\chi> = (1/N) \sum_{j=1}^{N} \chi_j \tag{2a,b}$$

If the posture is reproduced using symmetric fringes on the knees we expect the averages to be close to zero and dispersions very small. If N is a small number, data are not normally distributed and we cannot use sample standard deviations (For most engineering studies standard deviation may be used if N > 60). Under these circumstances we must use mean deviations given by

$$D_\psi = (1/N) \sum_{j=1}^{N} |\psi - <\psi>| \tag{3a}$$

$$D_\chi = (1/N) \sum_{j=1}^{N} |\chi - <\chi>| \tag{3b}$$

The maximum of these deviations is

$$D = \max(D_\psi, D_\chi) \tag{4}$$

The method proposed will be considered reliable if D < 0.05.

## MATERIAL AND METHODS

The moiré equipment was a shadow type apparatus (Willner, 1981). It consisted of a grating 75 x 50 cm made of plexiglass with vertical lines of width 1 mm. The spacing between the two lines was the same as the width of lines. A 250w slide projector was used as light source to obtain parallel light rays. The light source was placed at the side of the grating to avoid reflection at the surface. For photographing black and white ASA 400 film was used in CANNON AE-1 camera (lens 85 mm; aperture 2.8; speed 250). The camera was placed 170 cm from the grid and projector 70 cm on the left of camera. Light source and camera were placed in a plane parallel to the grating to obtain moiré fringes of constant distance from the grating (Willner, 1981).

The study was conducted at Rosengärds Skolan in Malmö, Sweden. 24 children of second form participated in the study. The mean age of children on the date of photographing was 8 yrs 2 mo 16 days. Each child was given a forward bending test by an orthopedic surgeon (GB). The child was photographed without shoes from the front in the mild-stretching posture. Camera was rotated in the horizontal
plane to obtain symmetric fringes on the knees before photographing (Fig. 2). Then the child turned around and stood with back touching to the screen and arms hanging on the sides. A back moiré topograph was taken in this posture. The child was repositioned with chest touching the screen. A second moiré of the front was taken in the mild-stretching posture. All photographs were taken and measured by the same person (SAK).

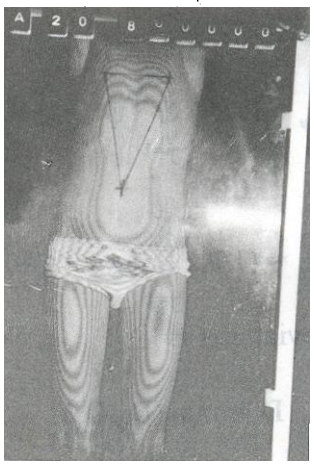

Fig. 2. Front moiré topograph showing symmetric fringes on the knees.

## RESULTS AND DISCUSSION

Angles could be measured on the photographs of 22 children. Since N = 22 mean deviations were applied instead of standard deviations. We obtained $D_{\psi} = 0.0095$ and $D_{\chi} = 0.0079$. Hence D came out to 0.0095. This is a very encouraging result considering that the sample size was small.

The cooperation of children during the study was remarkable. Sometimes it was difficult to locate the anatomical landmarks on the photographs. We suggest that in future studies these landmarks should be highlighted using a skin marker.

The results of this study suggest that there is not much difference between retakes of moiré topographs if symmetric fringes on knees are considered as reference. This model, however, would not take into account of any systematic errors.

## CONCLUSION

Since further statistical analysis could not be done using mean deviation, it is suggested that future studies of stability should be done using a larger sample size (N=100) so that standard deviations could be used. Another method to obtain reproducible moiré pictures is based on symmetric fringes on fist (Kamal, 1990). It would be of interest to compare both these methods to find out which one is more effective. Objectivity studies could also be done for both fist and knee positioning to compare the results of different observers.

We may now obtain moiré topographs which are reproducible to a high degree. Moiré techniques may now be more efficiently applied to follow-up of scoliosis, serial observations of posture in a growing child and in the study of neurological disorders.

## ACKNOWLEDGEMENTS

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