XIII Congress of the
International Society for Photogrammetry
Helsinki, 1976

Commission V
Working Group V/3
Invited Paper

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Simultaneous All-Around Measurement of a Living Body by Moiré Topography

The equipment for such photography, and its alignment and calibration, are described.

INTRODUCTION

MOIRÉ TOPOGRAPHY, which is a new technique of three dimensional measurement by the use of moiré,[1-5] is most welcomed by those who wish to study the living human body, because of the simplicity, high accuracy, real time advantage, and low operating cost of the method. The fundamental problems which would be encountered when the method is applied to a full size living body were studied separately and reported.[4-5], but an actual quantitative all-round measurement had not yet been made. A new instrument which is capable of taking contour moiré pictures of a full-size living body from two opposing directions in an instant has been constructed. The construction, procedures of alignment and calibration, and the performance of the instrument are described.

ABSTRACT: *An instrument capable of taking contour moiré imageries of a living body from two opposing directions is presented in this paper. The construction, procedures of alignment and calibration, and the performance of the instrument are described.*

RÉSUMÉ: *On décrit un appareil avec lequel on peut prendre des images moiré des corps humains de deux directions opposées. La construction et la performance de cet appareil, ainsi que les procédés d'alignment et d'étalonnage sont discutés.*

ZUSAMMENFASSUNG: *Ein Gerät wird vorgestellt, mit dem Moiré-Bilder eines menschlichen Korpers von zwei Seiten aus hergestellt werden können. Die Konstruktion und Leistung des Gerätes sowie die Aufnahmeanordnung und Kalibrierung werden beschrieben.*

PRINCIPLE

Let us review the principle of the technique using a simple but accurate approach. Suppose an object is illuminated with a point light source through a plane grating and the object is observed through the grating. The small areas on the object which are illuminated through the grating and also seen through it appear bright and form moiré fringes.

Referring to Figure 1, which shows the projection of light paths to a plane vertical to the ruling of the grating, the depth of the fringe changes with the position on the object when the height of a viewpoint from the grating surface is different from that of the light source (Figure 1, left). When the height of viewpoint is equal to that of light source, the depth of each fringe is constant (Figure 1, right). The depth of *Nth* bright fringe is obtained as follows:

$$h_N = Nl \,/\, (d/S_o - N) \qquad (1)$$

where l is the height of light source and view point from the grid surface, S_o is the pitch of the grating, and d is the distance between light source and the viewpoint, measured normal to the ruling of the grating. This means that the light source need not necessarily be a point, but may be a linear light source or several light sources aligned with a straight line which is parallel to the ruling of the grating (multiple light source). The same fringe can be obtained also with the light source on either side of the viewpoint. So, it is possible to erase the shadow on the object by using two light sources, one on each side of and equidistant from the viewpoint, (shadow free illumination).

Suppose now the grating is translated parallel in its plane. The bright spots move, keeping the same depth from the grating. Thus, if the grating is moved during exposure, the fringes formed by the succession of bright spots become continuous lines, and the grating structure is averaged out (i.e., eliminated from) in the picture. As a result, the picture becomes clearer and the accuracy of the measurement is improved because the pitch errors in the grating are averaged over the length of translation (technique of moving grating).

Apparatus

A schematic diagram of the apparatus is shown in Figure 1. The purpose of this apparatus is to take contour moiré pictures from opposing directions in a very short time in order to make all-round measurement of a living body. Details of the instrument are as follows: Camera position l = 1880 mm, source offset d = 613 mm; grating, effective size 1800 × 800 mm, pitch 1.50 mm, width and clearance of threads 1 to 1, blackening 3M 101 C velvet coating, separation 600 mm, vertical movement; light source, four 500 watt iodyne lamps with cylindrical reflectors for each channel; cameras, Nikon F with motor drive; C.P. Nikkor f = 35 mm lens. The time schedule of operation of the two channels is shown in Figure 3.

The lens should be stopped down to *f*/11 to get good fringe visibility at the maximum depth of the field, 600 mm, but in most cases

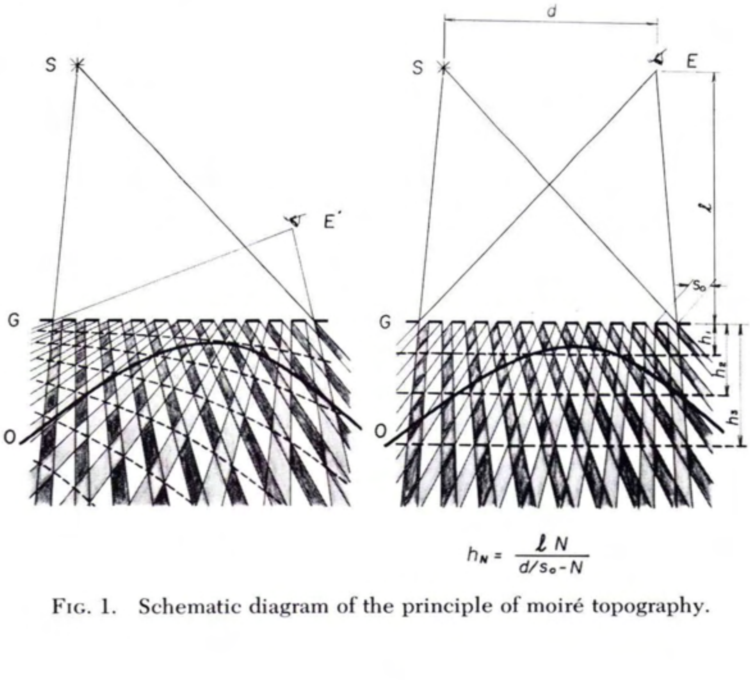

Fig. 1. Schematic diagram of the principle of moiré topography.

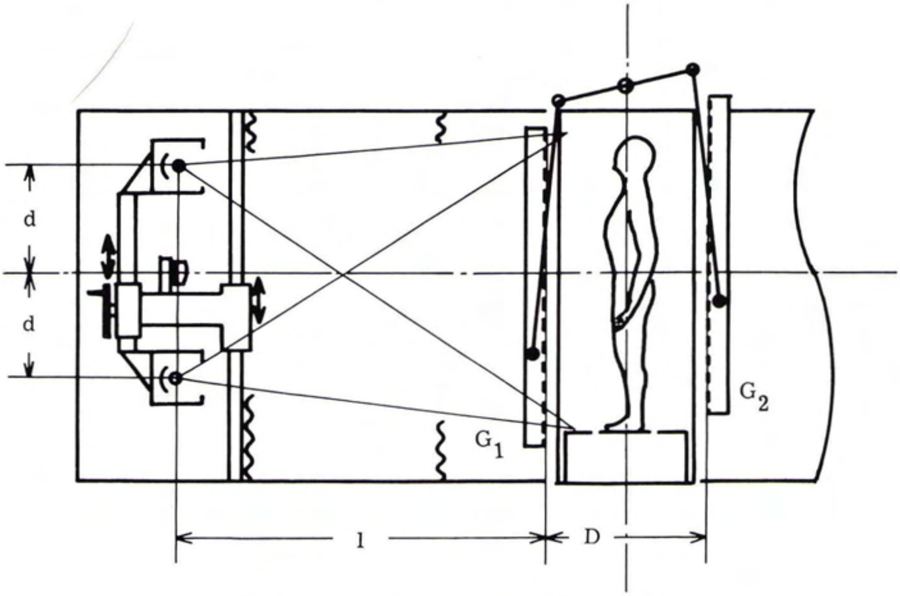

FIG. 2. Schematic diagram of the apparatus.

f/8 is satisfactory. The shutter speed depends upon the sensitivity of the film and the brightness of the subject. For a subject with approximate skin color of 7.5 YR 6/4, the appropriate conditions are *f*/8 at 1/15 sec with ASA 3200 development.

The design of the vertical movement of a grating with horizontal rulings introduces some difficulties in construction. The main reason for selecting this design against anticipated difficulties was its free choice of base length in the case of taking stereo pairs.

ALIGNMENT AND CALIBRATION

The "multiple light source" introduces even and shadow-free illumination as well as a higher illumination level, but requires troublesome alignments. All the alignments are made referring to water level, plumb line, and visibility of the fringe. The flatness of a grating is aligned with the aid of optical cutting. Two vertical lines are stretched along the both sides of grating with a small clearance, 1 − 2 mm. The shadows of the threads are overcast on the grating obliquely, with an angle of approximately $\tan^{-1} 5$ and the screws which support the bridges of the grating are adjusted referring to the parallelism of the vertical lines and their shadows.

All the light sources should be in a plane parallel to the grating. This alignment is also made using a plumb line. The camera should be placed in such a position as to be the same distance from the upper and lower light sources and be in the same plane with the light sources.

Then a large plane panel is placed obliquely behind the grating, the fringe is ob-

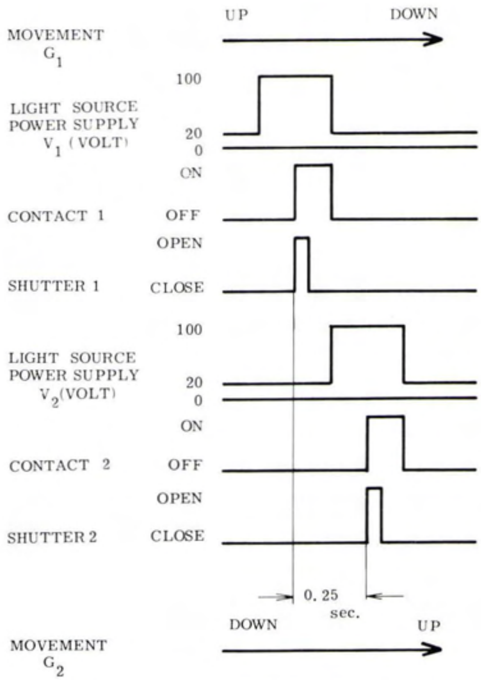

FIG. 3. Time schedule of operation.

served through the camera, and the height of a frame carring the light sources is adjusted until high fringe visibility on the plane panel is obtained in the same height of the camera. With the adjustment the "same distance condition" is satisfied. The fringe visibility differs along the vertical direction at this stage. The fringe visibility is made uniform by back and forth adjustment of the camera, and thus the optical alignment of the system is completed.

The l and d are calibrated finally using a standard object as shown in Figure 4. The distances between the fiducial marks are made exactly the same. Very thin wings are stretched beyond the standard object to touch the grating surfaces, so it is possible to count the fringe order which corresponds to each fiducial mark without ambiguity. A picture of the standard object is shown in Figure 5.

Three equations are rewritten for the depth of three fiducial marks from Equation 1.

$$\begin{aligned} h_1 &= N_1\, l/(d/S_o - N_1) \\ h_2 &= N_2\, l/(d/S_o - N_2) \\ h_3 &= N_3\, l/(d/S_o - N_3) \end{aligned} \quad (2)$$

$$\begin{aligned} h_2 - h_1 &= \ldots \\ h_3 - h_2 &= \ldots \end{aligned} \quad (3)$$

Because $h_2 - h_1 = h_3 - h_2 = H$, d/S_o is obtained as follows:

$$d/S_o = [N_2(N_1 + N_3) - 2N_1N_2]/[2N_2 - (N_1 + N_3)] \quad . \quad (4)$$

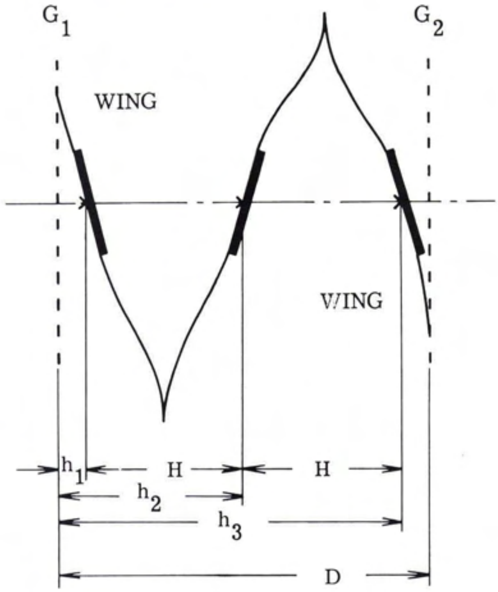

FIG. 4. Standard object for calibration of d and l.

Substituting d/S_o in one of the Equation 3, l is obtained.

RESULTS

A set of pictures of a living body with natural skin is shown in Figure 6. The forward facing pictures from a stereo pair with a 400 mm base length. The contour step is approximately 4.5 mm. Another stereo pair (Figure 7) is presented as a comparison of fringe visibility. The object is a mannequin.

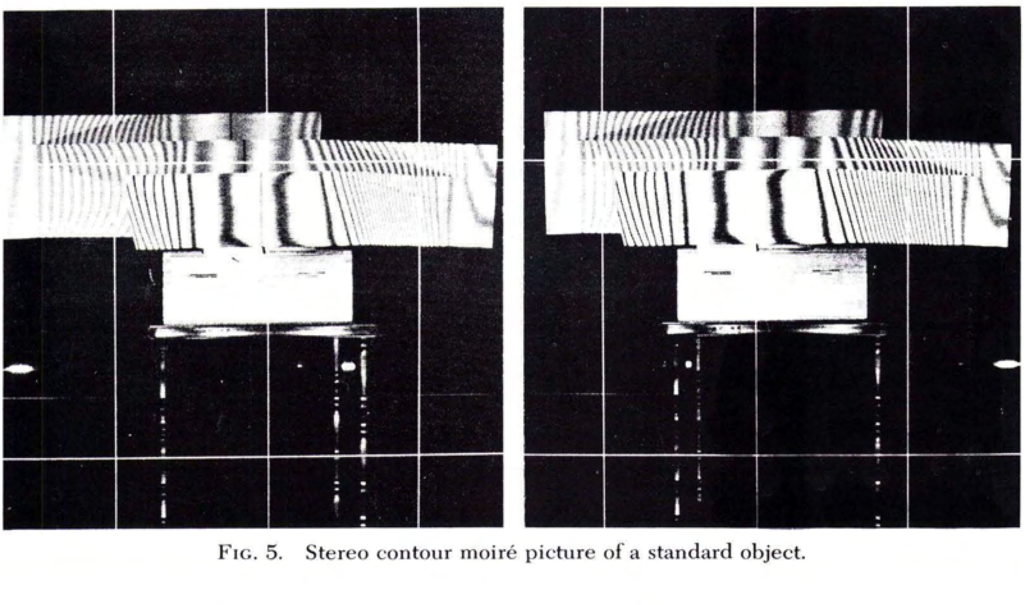

FIG. 5. Stereo contour moiré picture of a standard object.

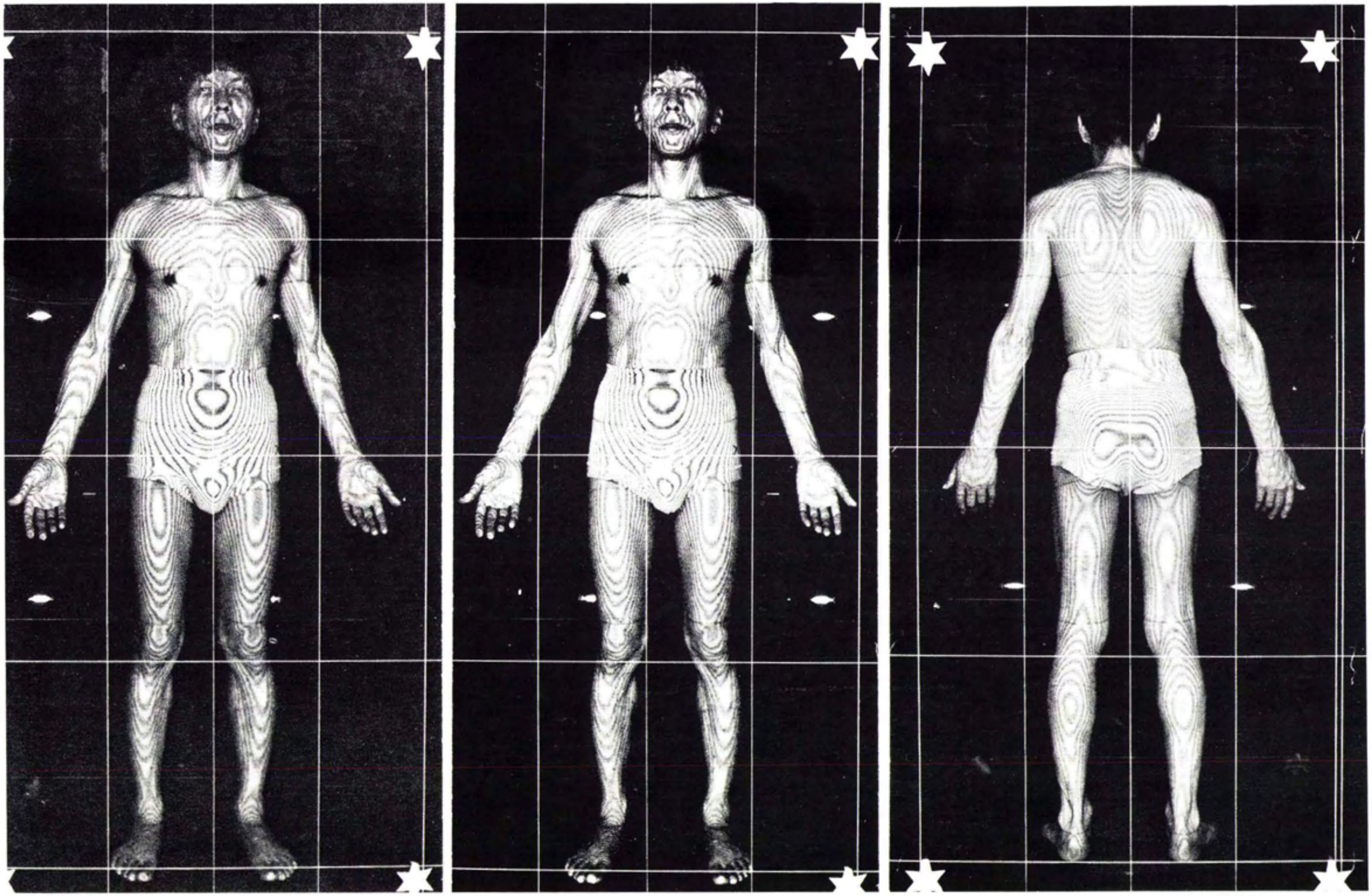

Fig. 6. Front and back contour moiré pictures of a living body with natural skin.

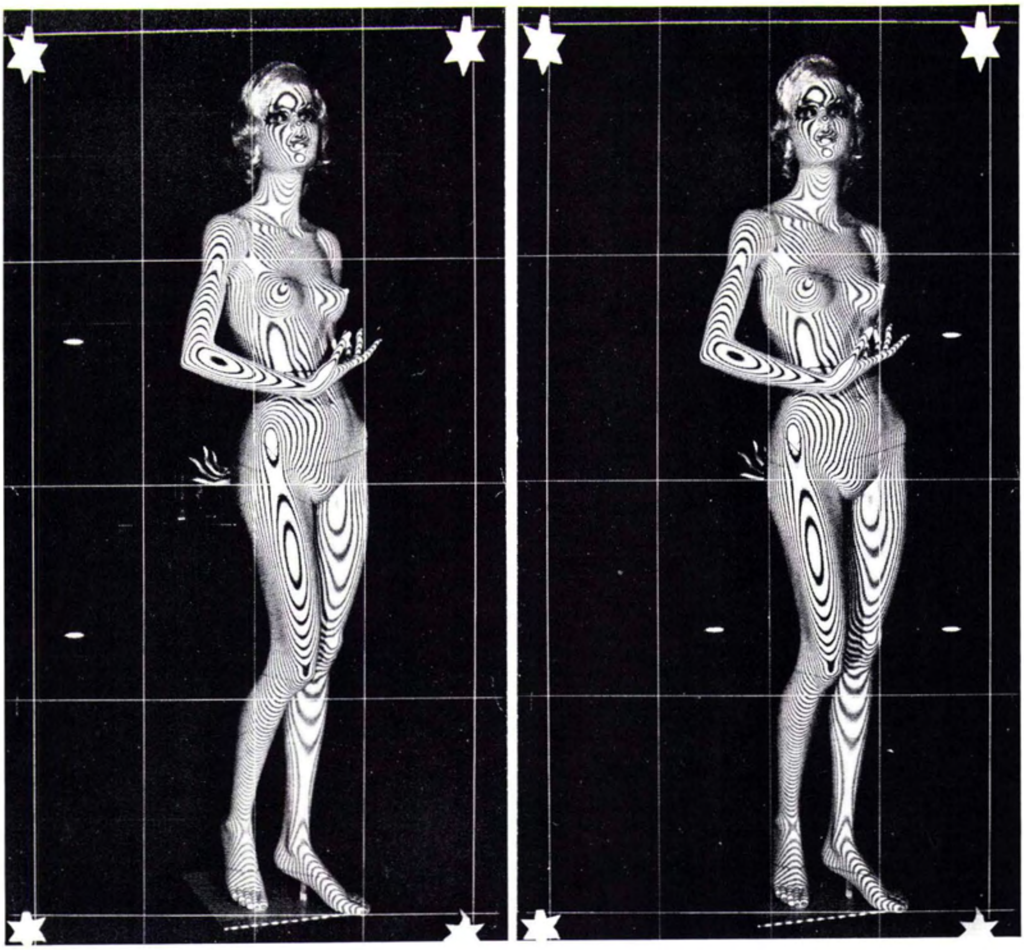

FIG. 7. Stereo contour moiré picture of a mannequin.

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