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Pattern Recognition using Moiré Fringe Topography and Rasterstereography

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Abstract– Moiré fringe topography and rasterstereography are 3-D optical imaging techniques, which provide height and curvature maps of the subject or the object under study. These are non-contact and non-invasive techniques, which project moiré and raster grids on the body. The distorted grids contain height and curvature information, which may be recovered using image-processing algorithms. These techniques are being applied to face recognition. The information may be stored in the database and not easily accessi-ble to ordinary citizen. Hence, the chances of fake pictures or fabricated patterns are mini-mized. Techniques are developed to project, simultaneously, moiré and raster grids and analyze height and curvature information, separately, using selective optical filtering, which could be used to record height and curvature patterns during a certain action, *e. g.*, uttering a standard word. Edge-based algorithms, combined with moiré contours and raster patterns, allow study of face move-ments through changing height and curvature maps. A multiple-level screening of suspects using these technologies is proposed.

Keywords–Face recognition, stereophotography, image processing

I. INTRODUCTION

There is a need for security systems, which do not violate subject's privacy, have high sensitivity (very few or no missed cases) as well as high specificity (very few or no false positives) and avoid human exposure to harmful radiation. Photogrammetry has come up with the solution. Being non-invasive, non-contact and non-disruptive technique, it avoids risks involved in hurting, infecting or distorting the human subject being studied. Photogrammetry can make it easy to measure objects otherwise inaccessible or difficult to measure and has the capability to either discard images or provide permanent record. Any desired degree of accuracy may be achieved by making a suitable choice of equipment and technique. Data obtained from photogrammetric measurements, especially if put in coördinate form, may be easily utilized by computer systems [1].

The different photogrammetric systems, which could be employed in security technologies, are stereophotography, holography, thermography, 3-D video laser scanning, edge-based and intensity-based algorithms, moiré fringe topography [2-4], rasterstereography [5, 6] and edge-based moiré [7]. This paper deals with the application of last three techniques and introduces edge-based raster as well as a multi-level screen-ing of suspects. The checks located at the top level are designed to be highly sensitive. The checks located at the bottom level are chosen to be highly specific. The same concept was used in the multi-level screening proposed for scoliosis [8].

II. 3-D IMAGING TECHNIQUES: SYSTEMS

In this section, systems for moiré fringe topography, rastersterography, simultaneous moiré and raster recording, edge-based moiré and edge-based raster are discussed:

A. Moiré-Fringe Topography

Moiré fringe topography provides a 3-dimensional height map of the human face without using X rays or any other ionizing radiation harmful for human beings [9-11] and can be handled using various algorithms [12]. Moiré fringes are a series of interference fringes arising from the superposition of sets of parallel lines or threads, the sets being slightly inclined to one another. Width of the grid lines should be equal to the space between them. It has been applied in the detection [8, 13-18],

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the documentation [19-21], the quantification [22-27] and the follow up [28] of trunk deformities, posture [29] and gait analysis [5, 6, 30] as well as study of neurological disorders [31, 32]. Various forms of moiré systems are described below:

i) Basic Form or Shadow Type Moiré: The shadow type moiré fringe topography apparatus [33] in use in Karachi consisted of a lightweight wooden frame of external dimensions 57 x 133 cm (grid 52 x 108 cm). Black nylon fishing line of diameter 0.85 mm was wound vertically using a spring of pitch 0.75 mm. Special reinforcement techniques are needed to prevent breaking of frame from thread tension. This method is simple and gives a lot of information, but it requires a large scale of equipment and it is difficult to maintain the standard of human bodies. In Malmö, Sweden the author worked on a moiré system, in which the moiré grid was sandwiched between two glass panes.

ii) Projection Type Moiré: In projection type moiré-fringe topography the human body is supported on a standard holder and a grid image is projected on the face to form a transformed image according to shape of the face. This image shall, then, be formed on a standard grid through a lens so as to generate contour line moiré fringe by superposing the transformed grid on the face. This method gives a large amount of information. Accuracy can be changed by changing grids.

In both the shadow and the projection type, the fringes are visible to the naked eye and, hence, can be used in setups, where a permanent record in the form of a photograph is not required. The fringes could also be recorded on videotape. However, mis-positioning cannot be corrected after the picture is recorded.

iii) Grating Hologram Type Moiré: Grating hologram type moiré fringe topography has the capability of adjus-ting the moiré fringes after recording. Grating hologram type of system consists of projecting a moiré grid (Fig. 1) on a child's back and photographing the distorted grid. The reference grid is re-projected at the same angle and with the same magnification on the photograph of the distorted grid to view moiré fringes. For gait analysis and simultaneous moiré and raster recording, grating-hologram type was found to be most suitable.

B. Rasterstereography

Rastersterography is very similar to stereophoto-graphy. Difference is that one of the cameras is repla-ced by a slide projector projecting a raster (Fig. 1*b*) on the face [5, 6]. Because of the curvature of the body the raster is distorted. Study of this distortion provides infor-mation about the topological properties of the surface under study. The remarkable feature of rasterstereo-graphy is that it does not require a specific arrangement of apparatus to obtain meaningful rasters, whereas only a specific geometry of the moiré set up would provide contours with the desired mathematical properties.

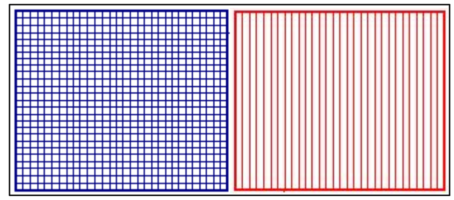

Fig. 1*a, b*. Grids for rasterstereography and moiré fringe topography (right)

C. Simultaneous Moiré and Raster Recording

For simultaneous moiré and raster recordings our group used a camera, 2 projectors, a raster grid and a moiré grid (Fig. 1) [6]. Moiré grid was prepared in red color and raster grid prepared in blue color. Both the grids were simultaneously projected on the body using two projectors as shown in Fig. 2. After a color photograph was obtained, a red filter matching with the color of the original moiré grid was placed on it. The red moiré grid became invisible and the blue raster grid appeared black. These were, then, fed in the scanner for analysis using rasterstereography algorithms. Similarly, a blue filter matching with the color of the raster grid was placed on the picture. Raster was suppressed and the moiré grid appeared black. Then a standard moiré grid was projected at the same angle to produce moiré fringes. Success of this procedure depends, critically, on proper matching of the colors.

D. Edge-Based Moiré

This is a combination of edge-based algorithm and moiré pattern [7]. Since moiré contours provide height maps in a plane perpendicular to the image, moiré patterns would change if the object is performing infinitesimal movements towards or away from the observer. Consider moiré patterns of face of a person. If that person starts speaking, the moiré patterns would, also, move. If the person's lips are moving away from the observer (lips are convex surfaces) the patterns would start converging and appear to sink. Movement away from the observer, therefore, corresponds to a sink field in the moiré patterns of the convex surface (Fig. 3a)

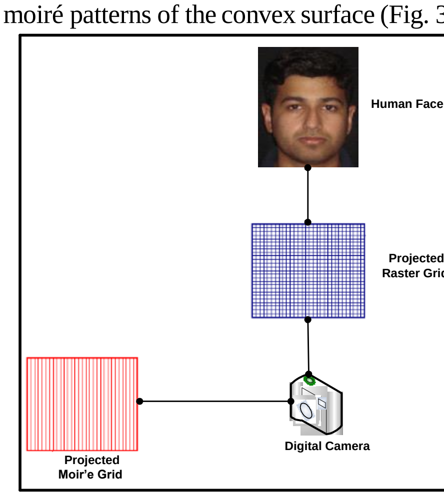

Fig. 2. Layout for simultaneous moiré and raster recording

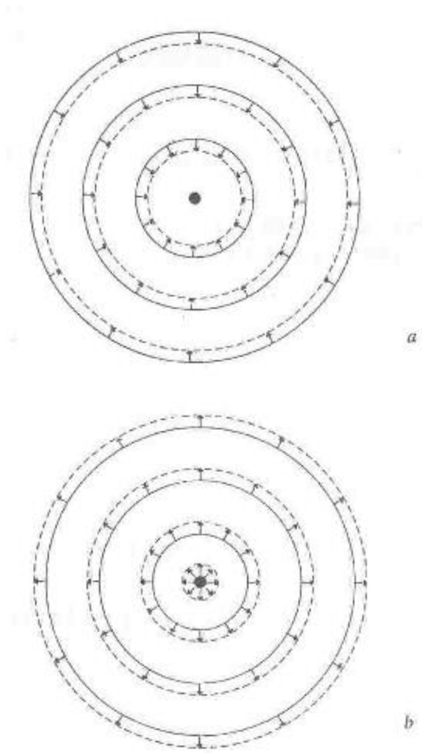

Fig. 3*a*, *b*. *Edge-based moiré* for movement normal to plane of paper for a convex object (top picture) object receding from the observer and object coming towards the observer

When the person's lips are moving towards the observer, new diverging patterns would appear (Fig. 3b). Movement towards the observer, therefore, corresponds to a source field in the moiré patterns of a convex surface.

E. Edge-Based Raster

This is a combination of edge-based algorithm and raster pattern. Since raster contours provide curvature maps, raster patterns would change if the object were performing infinitesimal movements towards or away from the observer. Consider raster patterns of face of a person. If that person starts speaking, the raster patterns would, also, change. The new and the old patterns could be connected by edge-based algorithm and curvature change could be represented as a vector field.

III. 3-D IMAGING TECHNIQUES: PARAMETERS FOR STUDY

In order that the information obtained from these photogrammetric techniques is scientifically relevant, one must consider the following**:**

A. Image Quality

Image quality depends on a number of factors. Some of the considerations are**:**

of the considerations are:

i) Sharpness of Image: To obtain sharper fringes for our fishing line shadow type moiré system we used parallel light from a slide projector and applied talcum powder on child's back. Image quality depends critically on the choice of light source. Our group is in the process of evaluating fringe quality using torchlight, gaslight, candlelight and collimated candlelight.

ii) Distortions: The more are the optical elements in the system the more is the distortion. Therefore, one would realize that as compared to shadow type the distortion error in projection type and grating hologram type is a factor of 2-3 in the depth and in the sides. Distortions in our grating hologram type system have been minimized.

B. Reproducibility

Our group found the moiré technique to be 99.5% reproducible [34, 35]. Tests were conducted using Swedish system (pitch 2 *mm*) with moiré grid sand-wiched between two glass panes.

C. Accuracy and Precision

There has been an interest in accuracy analysis of moiré systems used in scoliosis screening [36, 37]. Accuracy and precision of our fishing-line-shadow system (pitch 1.5 *mm*) have been estimated as 99.61% and 91.21%, respectively [38].

D. Sensitivity and Specificity

99.7% sensitivity of moiré fringe topography is reported in the literature in the context of scoliosis screening [39]. However, sometimes because of mis-positioning subjects a large number of false positives are generated [13]. To reduce these false positives (that is, increase specificity of moiré) we took moiré topographs on a level surface [8, 16], sometimes used an alignment system [40] and corrected leg-length inequalities. Further, referrals were based on more than one test and not on a single test. Similar criteria need to be established for face-recognition algori-thms.

IV. A MULTI-LEVEL SCREENING SYSTEM TO ESTABLISH IDENTITY

To establish identity with a high level of sensitivity and specificity, the following system is proposed**:**

Level 1: Height + Blood Group + 2-D Face Photographs (frontal plane and sagittal plane), without glasses, ear(s) exposed (high sensitivity)

Level 2: 3-D-Height and -Curvature Maps (frontal plane and sagittal plane), using moiré fringe topo-graphy and rasterstereography (Fig. 4), subject silent

Level 3: 3-D-Height and -Curvature-Video Clip (frontal plane and sagittal plane), using moiré fringe

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topography and rasterstereography, subject uttering a standard sentence (high specificity)

Once the algorithms are developed, the system could be used to store data on a mega scale. The parameter, height, at the initial level is applicable to individuals, who have reached their peak height, *i. e.*, boys after the age of 21 years and girls after the age of 19 years.

V. CONCLUSION

Pattern recognition using moiré fringe topography and rasterstereography is expected to become a useful tool in security technologies. These techniques may find immediate applications in computerized re-construction of faces and patterns. Unlike holography moiré and raster techniques do not require the subject (or object) to be still. Hence, these techniques are ideal to describe infinitesimal motion of lips. In case, the visible pattern of face is altered due to plastic surgery, burn or accident, the motion of lips may, still, have signatures for identification. An immediate visual illustration of the magnitude and the direction of motion is available by combining edge-based algorithm with moiré contours. Edge-based moiré, therefore, makes it possible to have a three-dimensional map (position) and a three-dimensional motion profile (velocity) without involving differentiation. The moiré technique combined with rasterstereography may prove to be useful in providing non-contact, non-destructive, non-invasive, safe and reliable methods to study face patterns. Computations may be simplified using multi-grid techniques [41].

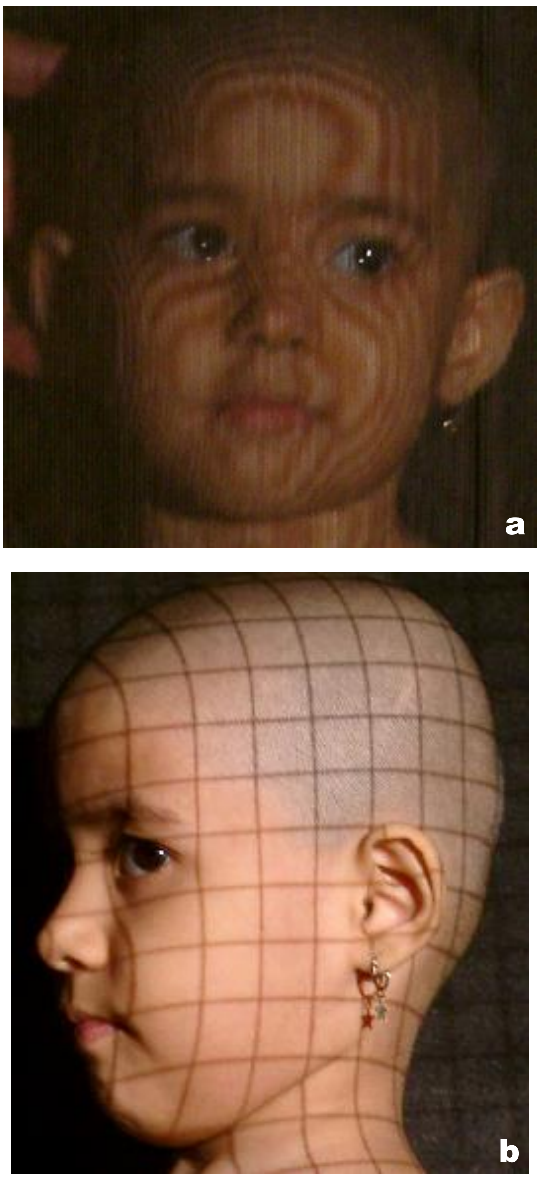

Fig. 4*a*, *b*. Photographs of moiré pattern (top picture) and raster pattern projected on a child's face

There is, however, a need to determine sensitivity, specificity, accuracy, precision and reproducibility of all the tests involved in a multi-level screening procedure. A comprehensive statistical model representing sensitivity and specificity of combination of tests used at a certain level is desirable. For the test to be universally acceptable, combined sensitivity of the top-level-screening module should exceed 95%, and the combined specificity of the bottom-level-screening module should not be less than 95%.

Moiré fringe topography and rastersterography have been applied in the study of posture and gait of children. A future screening system should combine posture and gait analysis with changing face patterns.

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APPENDIX A: FORMULAE FOR HEIGHT COMPUTATION FROM MOIRÉ FRINGE TOPOGRAPHS

a. For shadow type moiré apparatus the distance h_n from the n^{th} fringe to screen (the highest elevation must touch the screen) may be found from [42]**:**

$$h_n = \frac{n\lambda}{d/s_0 - n} \quad \text{(A1)}$$

where
λ = distance between the camera and the screen
d = distance between the camera and the light source
s_0 = screen interval (line thickness plus spacing)

b. From the above the height difference between successive fringes in a shadow type apparatus may be calculated as [28]:

$$\Delta h = \frac{\lambda d}{s_0[d/s_0 - (n+1)][d/s_0 - n]} \quad \text{(A2)}$$

For USA studies (1980-82), our group had λ = 100 *cm*, s_0 = 1.0 *mm*, d = 50 *cm*, which gave Δh = 0.20 *cm* for n = 1. For Karachi studies (1988-89), the para-meters were λ = 150 *cm*, s_0 = 1.4 *mm*, d = 110 *cm*, which gave Δh = 0.19 *cm* for n = 1.

c. For the grating hologram type system developed by our group in Karachi, the distance H_n from the n^{th} fringe as compared to the highest elevation is given by:

$$H_n = \frac{nM(M+1)fP_0}{L - nP_0} \quad \text{(A3)}$$

where
M = magnification of the moiré grid
f = focal length of the projector lens
P_0 = moiré grid interval (line thickness plus spacing)
L = distance between camera and projector lens

The above formula may be obtained by adapting the derivation of Suzuki, Yamashita, Yamaguchi and Armstrong [43] for our system.

d. The height difference between successive fringes for our grating hologram system, therefore, may be expressed as:

$$\Delta H = \frac{M(M+1)fP_0}{L[1-(n+1)M\,P_0/L][1-nM\,P_0/L]} \quad \text{(A4)}$$

retaining only the linear term in P_0/L ($P_0 \ll L$). Our group used L = 70 *cm* P_0 = 0.0242 *cm*, M = 18.15, f = 8.5 *cm*, which gave ΔH = 1.04 *cm*. The sensitivity may be increased by using finer grid (decreasing P_0) and a lens of shorter focal length. Increasing L may produce distortions.

APPENDIX B: FORMULAE FOR CURVATURE COMPUTATION FROM RASTERSTEREOGRAPHS

Let us suppose that a given raster grid on a plane surface (reference surface) has a periodic spacing equal to s. On the curved surface the spacing appears to be d (Fig. 5). Let the portion of the curved surface under study may be the part of a great circle of radius ρ. Now, we have $s = \rho\phi$, where ϕ is the angle subtended by arc of length s. Therefore

$$\phi = s(\frac{1}{\rho}) = \kappa s \quad \text{(B1)}$$

Also

$$\begin{aligned} d &= \rho \sin\phi \\ &= \rho(\phi - \frac{1}{3!}\phi^3 + \frac{1}{5!}\phi^5 - .....) \\ &= s(1 - \frac{1}{3!}\kappa^2 s^2 + \frac{1}{5!}\kappa^4 s^4 - ...) \end{aligned} \quad \text{(B2)}$$

Since ϕ is small we neglect fourth and higher powers. Therefore

$$\frac{d}{s} \approx 1 - \frac{1}{3!}\kappa^2 s^2 \quad \text{(B3)}$$

which may be put in the form

$$\kappa = \pm\frac{1}{s}\sqrt{6(1-\frac{d}{s})} \quad \text{(B4)}$$

If $d = s$, $\kappa = 0$ and we have the condition of a flat surface. Appendices A and B are copied here from [6].

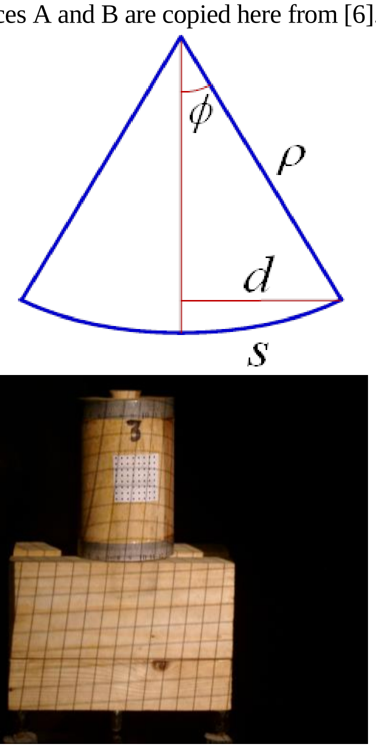

Fig. 5*a*, *b*. Geometry of rasterestereography (top picture) and raster pattern projected on cylinder

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