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COMBINATION OF MOIRE CONTOURS AND EDGE-BASED ALGORITHM TO STUDY MOTION IN THE SAGITTAL PLANE

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ABSTRACT

Moiré fringe topography is a noninvasive, noncontact, nondestructive 3-D optical imaging technique which provides height maps of the body parts to be studied. Edge-based algorithm may be used to study infinitesimal movement of the edge in the plane of the image. Application of edge-based algorithm theory to moiré contours enables one to study and quantify motion along an axis normal to the plane of an image.

Keywords: Moiré fringe topography, veto scheme, edge-based algorithm

INTRODUCTION

In orthopedics and neurology we are at times interested to accurately monitor posture and gait which may provide clues to skeletal and neurological disorders. Degenerative spinal diseases as well as curvatures of spinal column (scoliosis, kyphosis, lordosis) are of significance to orthopedists and neurologists alike. However, exposing young children to heavy doses of radiation may not be a desirable option to achieve this goal. Therefore, biomedical physicists have looked for other techniques to provide spinal maps in three dimensions and measurement of human body topography. Two-dimensional recordings in human gait are not sufficient at times when we are interested in the position of spine during different phases of gait cycle. The problem immediately suggests that we can not use contact measurements. Even in posture studies it is desirable to use noncontact measurements so as not to disturb the natural posture of the subject. Modeling of the human spinal column is a three-dimensional problem. Ordinary anteroposterior X rays only show spine in the frontal plane. Such an X ray would not show kyphosis or lordosis which could only be observed in the sagittal plane. The biomechanics researchers have recognized this and developed spinal models in three dimensions (Hierholzer & Lüxmann, 1982; Kamal, 1982; 1983; 1987; 1996*a,b*). These models could generate spinal column from projections of spine in the frontal and the sagittal planes obtained from X rays.

Since X rays are harmful to a growing child we are in need of a technique which could provide information about the spinal column without using ionizing radiations. Integrated Surface Imaging System (ISIS), moiré fringe topography and rasterstereography are such noninvasive photogrammetric techniques which can quantify spinal deformities through surface measurements of human back (Kamal, Choudhry & Siddiqui, 1996).

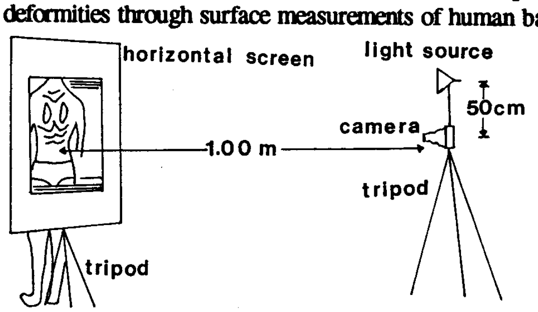

Fig. 1. Set-up for shadow type moiré fringe topography.

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We have concentrated our attention on moiré techniques because they are inexpensive, simple to operate, provide permanent record of the condition of the patient, offer simple surface relationships to spinal position in three dimensions, do not require the patient to be motionless unlike holographic techniques, employ ordinary white light and commercially available cameras. The techniques have been used for the diagnosis, documentation and follow-up of spinal deformities especially scoliosis (Adair, van Wijk & Armstrong, 1977; Kamal & El-Sayyad, 1981; Kamal & Lindseth, 1980).

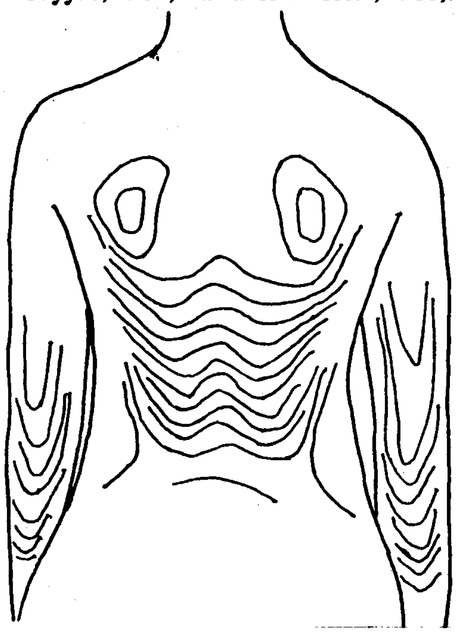

Fig. 2. Moiré pattern of the back of a person.

Moiré Fringe Topography

Edge-based and intensity-based algorithms are known in optics to study shapes and motion of objects (Bülthoff, 1988*a-c*; Bülthoff, Little & Poggio, 1987; Little & Bülthoff, 1988; Little, Bülthoff & Poggio, 1988). In this paper a scheme is provided which combines the moiré contours with edge-based algorithm to study movement in the sagittal plane.

In the simplest words the technique of moiré topography consists of photographing the part of body through a specially constructed screen. Dark fringes are produced on body because of the presence of screen. Fig. 1 shows the set-up of a shadow type moiré system and Fig. 2 shows the moiré patterns of the back of a person. If the light source and the camera both lie on a line parallel to the plane of the moiré screen, the fringes on the human body are contours of constant distance from the screen. This mathematical property may be used for surface mapping and developing different algorithms for surface relationships. For the study of movement the screen is replaced by a moiré grid which is projected through a slide projector at a certain angle on the back of a subject. Since the grid is projected on a curved surface it is deformed. A photograph of this deformed grid is mounted on the wall and the reference grid is projected on it at the same inclination such that its magnification is same as that of the deformed grid in the picture. A superposition of the reference grid and the deformed grid produces a moiré pattern which is a map of height from the frontal plane (Kamal, Choudhry & Siddqui, 1996).

Edge-based Algorithm

It is a parallel motion algorithm for computing the optical flow (Little & Bülthoff, 1988), motivated by Veto-Scheme, and based on voting for consistent motion (Bülthoff, 1988*a*). It is assumed that the optical flow is locally uniform. Physical constraints on motion (uniqueness, continuity) limit the spatial variation of the optical flow field. Uniqueness means each image point has a unique velocity. Continuity means the surfaces are locally smooth. To vote for motion, all points in a neighborhood of a feature identify the correct motion. The sequence of operations may be expressed as (Bülthoff, 1988*b*):

a Find and label edges.

b Match edges.

For $(-\delta \leq \Delta x \leq \delta, -\delta \leq \Delta y \leq \delta) = D$ shift $edges_1$ over $edges_2$.

c Find local support.

For each $(\Delta x, \Delta y)\ \varepsilon\ D$, count the matches in a single neighborhood N of a pixel.

d Vote.

At each (x,y) choose motion $(\Delta x, \Delta y)$ which has maximum local support. All points in the neighborhood of N identify the correct motion. Lines are not disambiguated, since there are no features to match. Heuristic may select motion of smallest magnitude, in case of ambiguity.

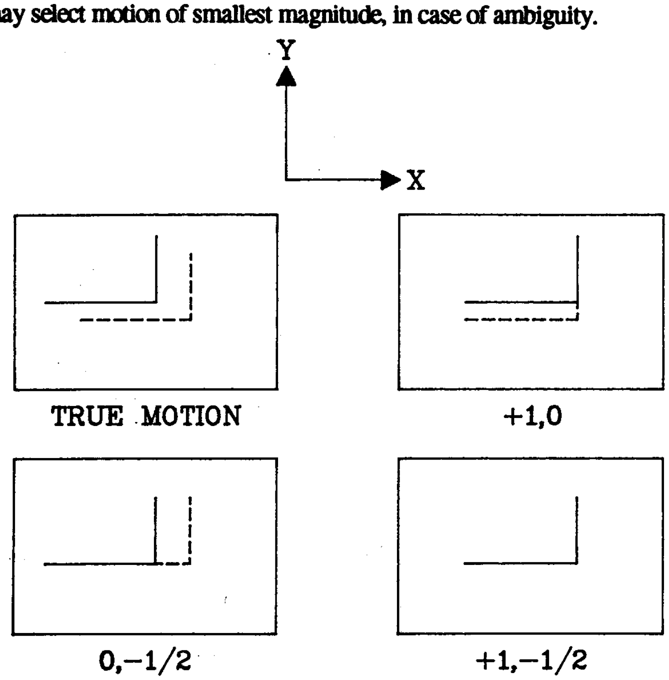

Fig. 3. Computation of Optical Flow.

Edge-based VMA (Voting Motion Algorithm) is constructed in the following manner (Bülthoff, 1988*b*):

a Local comparison of edge maps over displacement range.

b Record matches for each displacement.

c Gather local spatial support for each displacement (area-based).

d Find maximum votes for the displacement vector.

e Winner takes all.

Fig. 3. shows the first step in the computation of optical flow, shift and compare. The second step would be local summation and in the end the winner takes all. To express it mathematically, let us denote ϕ to represent a comparison function which measures the pointwise match between two images and I a binary edge map produced by an edge detector. The three steps may now be expressed as:

a Shift and compare $\phi(I_1(x),I_2(x+\delta))$

b Local Summation $\int \phi(I_1(x),I_2(x+\delta))$

c Winner-take-all $\max \int \phi(I_1(x),I_2(x+\delta))$

This algorithm claims to partially solve the aperture problem. The aperture problem, an instance of the correspondence problem, may be understood by noting that local detectors can only compute the normal component of motion.Without features, corresponding points can not be matched, e.g. straight lines with constant intensity. This is the aperture problem of the first kind. For curved contours or lines with intensity variations the aperture problem can be solved. This is the aperture problem of the second kind.

Advantages of this method over differential approaches to motion detection (Little, Bülthoff & Poggio, 1988) include handling of larger motions (for displacements up to 20 pixels), without sacrificing discrimination of small motions, reduction of noise by summing over large support regions and not using derivatives, uniform integration of many image transformations leading to dense optical flow fields.

Combination of Edge-based Algorithm and Moiré Pattern

Since moiré contours provide height maps in a plane perpendicular to image, moiré patterns would change if the object is moving towards or away from the observer. Consider the moiré patterns of back of a person as shown in Fig. 2. If that person starts moving the moiré patterns will also move. If the person is moving away from the observer the patterns would start converging and appear to sink in the scapula. Motion away from the observer corresponds to a sink field in the moiré patterns of convex surfaces. For a person moving towards the observer, new patterns will appear from the scapula. These patterns will be observed to be diverging. Motion towards the observer, therefore, corresponds to a source field in the moiré pattern of a convex surface. For a concave surface, the roles shall be reversed. For a concave object moving towards (away from) the observer the patterns appear to converge to (diverge from) a point where depth has a local maximum, corresponding to a sink (source) field.

Applying edge-based algorithm to motion of moiré contours shall result in visual description of motion normal to image plane. Motion of a simple sphere away and towards the observer, represented by *edge-based moiré*, is shown in Figures 5(*a*,*b*).

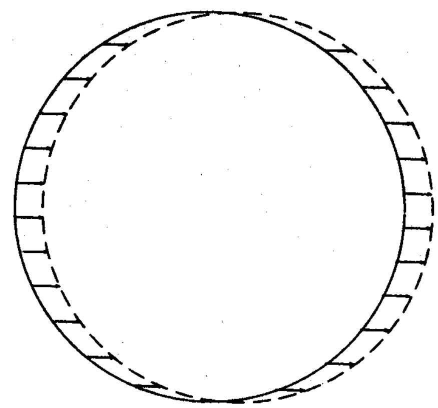

Fig. 4. Representation of motion in paper plane using edge-based algorithm.

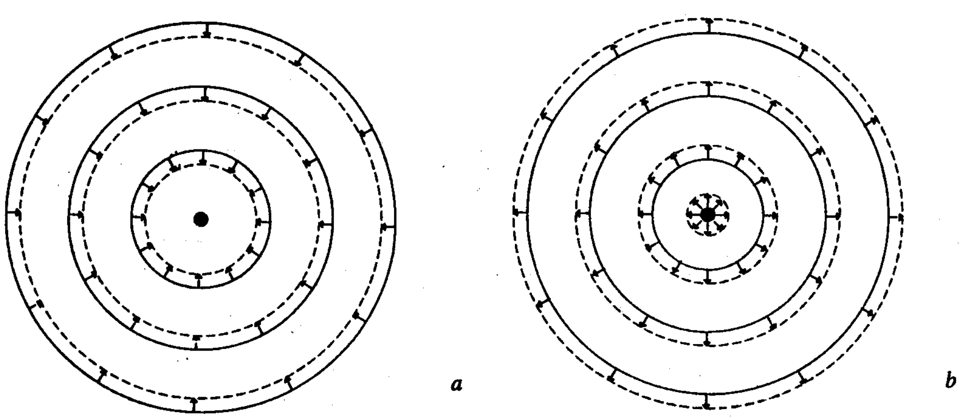

Fig. 5. Motion normal to plane of paper represented by "edge-based moiré"

a object receding from the observer,

b object coming towards the observer.

CONCLUSION

Moiré fringe topography provides a three-dimensional map of an object to be studied. It may also describe infinitesimal motion of the object. However, an immediate visual illustration of the magnitude and direction of motion is available by combining edge-based algorithm and moiré contours. Therefore, this technique now makes it possible to have three-dimensional map (position) and three- dimensional motion (velocity) without involving differentiation. This may be applied to study of human gait. It may also be applicable for studying mechanical structures and small motions (vibration testing) using image processing.

The data may be processed using an image processing package e.g. SPIDER (System for Processing Image Data in Electron Microscopy and Related Fields) (Frank, Shimkin & Dowse, 1981). Computations may be simplified using multigrid techniques (Stüben, 1992).

With the introduction of edge-based moiré algorithm gait in neurological and muscoskeletal disorders may be studied, chest-wall movements may be monitored, stomach movements may be quantified. This technique combined with other 3-D imaging techniques e.g. rasterstereography (Kamal, Choudhry & Siddiqui, 1996) may prove to be useful in providing non-contact, nondestructive, noninvasive, safe and reliable techniques to study trunk asymmetry.

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