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SHAPE IDENTIFICATION USING MOIRÉ TOPOGRAPHY

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Abstract

The shape identification method, including measurements of shape with incoherent light, is shown in the present article. This method is based on the data of Moiré sensor and linear regression method. We give general formulas and an algorithm for such computation and some results obtained by using this algorithm.

Keywords: Moiré topography, Moiré fringes, 3D surface measurements, matching histograms, linear regression.

1. Introduction

We use Moiré topography as a method for measuring and comparing 3D shapes [H. TAKASAKI, 1970; A.M.F. WEGDAM, O. PODZIMEK, H. HALLIE, 1992; A.M.F. WEGDAM, O. PODZIMEK, H.T. BOSING, 1992; SEUNG-WOO KIM, HYUN-GOO PARK, 1992; J. HARTHONG, H. SAHI, 1992; XINJIN XIE, John T. ATKINSON, 1996]. Recently, two main types of the Moiré designing, namely shadow and projection modes were successfully used for solving given problems [A.M.F. WEGDAM, O. PODZIMEK, H. HALLIE, 1992; A.M.F. WEGDAM, O. PODZIMEK, H.T. BOSING, 1992; SEUNG-WOO KIM, HYUN-GOO PARK, 1992; Z. TURI, K. WENZEL, 1989]. In our work we use the projection mode [K. WENZEL, H. TEMESSZENTANDRÁSY, 1994; K. WENZEL, H. TEMESSZENTANDRÁSY, 1985]. Two gratings of similar frequencies are projected on the surface of an object, with the gratings, projected and reference, respectively, spaced on a certain distance. The thirst grating is projected on object surface and Moiré fringes have been observed through the reference grating. The obtained fringes present surfaces as contour lines [K. WENZEL, G. ÁBRAHÁM, 1988; K. WENZEL, 1990; K. WENZEL, G. ÁBRAHÁM, 1987; K. WENZEL, A. FARKAS, Á. ANTAL, Z. MUSCH, 1989].

The mathematical description of our algorithm is based on the computation of linear regression and correlation coefficients. The regression presents the statistic dependence on some random values and the correlation coefficient is measure of correlation between the random values. For example, if we compare two bodies that are similar in shape but different in size, the Moiré pattern will be the same, but histograms after proceeding the two Moiré patterns will be different.

2. System's Description

In our experiments we use the principle of the projection mode. The experimental device was developed in the Department of Precision Mechanics and Optics of Technical University of Budapest [Z. TURI, K. WENZEL, 1989; K. WENZEL, H. TEMESSZENTANDRÁSY, 1985] and is shown in *Fig. 1* and *Fig. 2*.

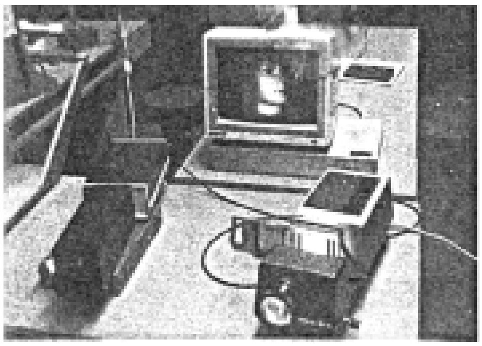

Fig. 1. Experimental setup

In *Fig. 2*: 1 – projector; 2 and 5 – equal projected and reference gratings A and B; 3 and 4 – Equal lenses; 6 – CCD camera; 7 – the object; 8 – lamp; 9 – initial plane.

The *Eq.* (1) presents the angles dependence:

$$w = \frac{N_A np}{\operatorname{tg}\alpha + \operatorname{tg}\beta'}, \tag{1}$$

where:

N_A – the magnification of lens A; n;
p – the pitch of Moiré fringes [mm];
α – the projected angle [°];
$\beta \cong \beta'$ – the reference angle [°]:

$$\operatorname{tg}\alpha + \operatorname{tg}\beta' = \frac{D}{L+w}; \tag{2}$$

D – the centre-to-centre distance of lenses 3 and 4 (*Fig. 2*), [mm];
L – the distance between initial plane and centres of lenses 3 and 4 [mm];

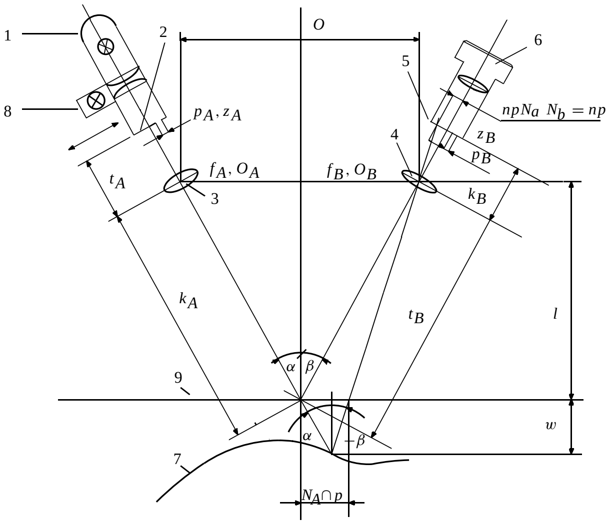

Fig. 2. Optical configuration [7]

If $w \ll L$, and $L + w \cong L$ then:

$$w = \frac{npLN}{D}. \tag{3}$$

3. Matching Histograms

Let two histograms be characteristic of field frequencies of two Moiré patterns. Moiré patterns can be seen in *Fig. 3a* and *Fig. 3b* and histograms in *Fig. 4a* and *Fig. 4b*.

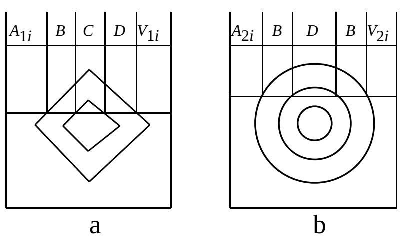

Fig. 3. The Moiré patterns

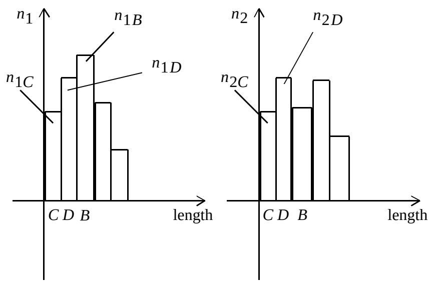

Fig. 4. he histograms of Moiré patterns

In *Fig. 3* A_{1i}, A_{2i} are the lengths of the first section from the left edge of the Moiré picture to the first Moiré line on the i-th cut. B, C, D, etc. are the different lengths of the sections between the Moiré lines. V_{1i}, V_{2i} are the lengths of the last section from the last Moiré line in a cut to the right edge of the Moiré picture on the i-th cut. In *Fig. 4* $n_{1B}, n_{1C}, n_{1D}, \ldots,$ are numbers of lengths, B, C, D, etc. in *Fig. 4a*, and $n_{2B}, n_{2C}, n_{2D}, \ldots$, are the numbers in *Fig. 4b*, respectively.

Let us make a linear regression between both histograms. The regression line is shown in *Fig.5*.

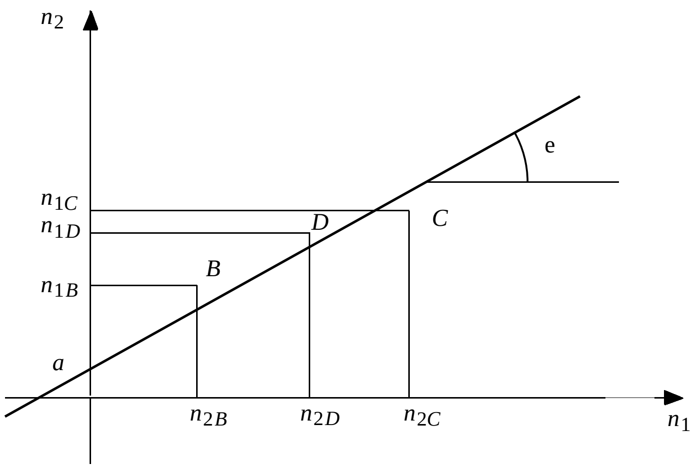

Fig. 5. The regression line of the histogram

The regression formulas are known. In *Eq.* (4) the equation of the regression line is shown:

$$n_2 \cong bn_1 + a. \qquad (4)$$

The tangent of angle ε of the regression line is:

$$\operatorname{tg}\varepsilon = b \cong \frac{k\sum_{i=1}^{k} n_{1i}n_{2i} - \sum_{i=1}^{k} n_{1i}\sum_{i=1}^{k} n_{2i}}{k\sum_{i=1}^{k} n_{1i}^2 - \left(\sum_{i=1}^{k} n_{1i}\right)^2}. \tag{5}$$

The factor 'a' from *Eq.* (4) and *Eq.* (5) is:

$$a \cong \frac{\sum_{i=1}^{k} n_{1i}^2 \sum_{i=1}^{k} n_{2i} - \sum_{i=1}^{k} n_{1i}\sum_{i=1}^{k} n_{1i}n_{2i}}{k\sum_{i=1}^{k} n_{1i}^2 - \left(\sum_{i=1}^{k} n_{1i}\right)^2}. \tag{6}$$

The correlation coefficient p is:

$$p \approx \frac{\sum_{i=1}^{k}(n_{1i} - \overline{n}_{1i})n_{2i} - (\overline{n}_{2i})}{\sqrt{\sum_{i=1}^{k}(n_{1i} - \overline{n}_{1i})^2}\sqrt{\sum_{i=1}^{k}(n_{2i} - \overline{n}_{2i})^2}}, \tag{7}$$

where:

$$\overline{n}_{1i} = \frac{\sum_{i=1}^{k} n_{1i}}{k} \qquad \overline{n}_{2i} = \frac{\sum_{i=1}^{k} n_{2i}}{k}. \tag{8}$$

1. When the correlation coefficient is large (more or equal ≥ 1), then the similarity between the two histograms (and between the two 3D-figures) is strong.
2. When the coefficient $a = 0$ and the coefficient $b = 1$, then the two histograms (and the two 3-D figures) are equal.
3. When $b > 1$ and $a = 0$, then $n - s$ are larger than $n - s$. It means that the second 3-D figure has a larger dimension in the height than the first one, but they are similar. (Their angles are equal.)
4. When just $b = 1$, then the two 3D-figures are of similar type, but their angle dimensions are not equal.
5. A_{1i} and V_{1i} or A_{2i} and V_{2i} show the distances of the 3D-figure from the edges of the picture:

$$A_1 = \frac{\sum_{i=1}^{k} A_{1i}}{k} \qquad A_{2i} = \frac{\sum_{i=1}^{k} A_{2i}}{k}. \tag{9}$$

A_1 and A_2 are the average distances between the left edge *Eq.* (9) of the pictures and the 3D-figures in *Fig. 3a* and *Fig. 3b*.

4. The Results

The object is a cone-shape model. The Moiré fringes were obtained with using two equivalent gratings with 1 mm pitch, shown in *Fig. 6*. These Moiré fringes were transformed into binary image and then the histogram was obtained, *Fig. 7*.

The computer system was created. The algorithm, which is used as the basis of this system, was described above. The program consists of several main modules. This program allows defining a source object with a certain probability by using a two-dimensional Moiré pattern, that was produced using a video camera and was transformed into standard graphical format file (TIFF).

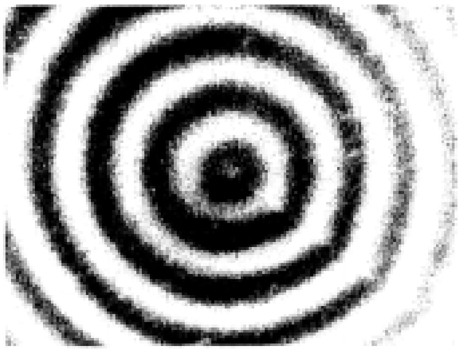

Fig. 6. The cone Moiré fringes

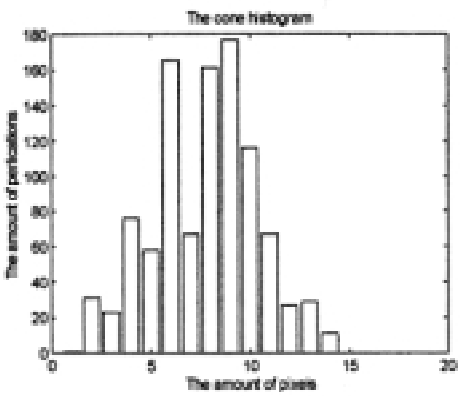

Fig. 7. The cone histogram

First the image is digitized and after this filtration is used to achieve a quality feasible for implementation of the algorithm. The working result of the program is shown in *Fig. 8*.

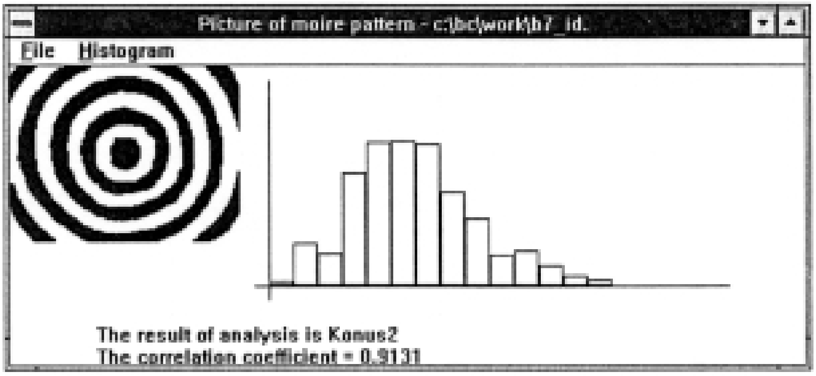

Fig. 8. The result of program (histogram of the cone)

5. Conclusion

For implementation of three-dimensional objects recognition problem by using their Moiré patterns a computer system was created. The algorithm which is used as the basis of this system is also described. The routine of image processing was conducted over the two-dimensional array and that allows to make a statement about flexibility of the proposed method, i.e. possibility of implementation of this algorithm on different platforms using different software.

In this work we show possible ways of using Moiré effect in systems of technical vision and to find appropriate methods for implementation of recognition algorithms of some objects from Moiré pictures that are obtained as a result of real experiments. Moreover, the goal of this work is to discover some ways of further development of image processing systems on the basis of employment of these algorithms, and also means of application of systems like this under real conditions of manufacturing processing. Brief review of theoretical methods of mathematical analysis for Moiré patterns, which are used in strain analysis allows considering one of the most perspective possibility for employment of these research results.

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