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A NEW STATISTICAL-OPTICAL DATA PROCESSING FOR DEFORMATION MEASUREMENT

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A new statistical-optical method to deformation measurement is presented. The moments of pattern printed on the model surface are estimated. Using optical processor with a prepared mask, several moments of the pattern are generated. Comparison of the moments computed before and after deformation enables one to determine the model deformation.

1. Introduction

Much research work in the use of moments in pattern recognition has been done and the results are quite attractive[1,2]. With modification, the moment techniques could be applied to deformation measurement. The idea is like this: the surface of the model under investigation is segmented in such a way that each segment could be considered to undergo uniform deformation, a pattern is printed on the surface of each segment, the moment of the pattern can be computed easily using a coherent optical processor with a special mask. By comparing the changes in moments computed before and after deformation, one could tell the distortion parameter of the printed pattern. Interpolation techniques are restored to find the distortion parameters for the positions where no patterns are printed.

Shown in Fig. 1 is the block diagram of the moment estimator for deformation measurement. The following steps should be taken to contain the accurate distortion parameters, i. e., deformation:

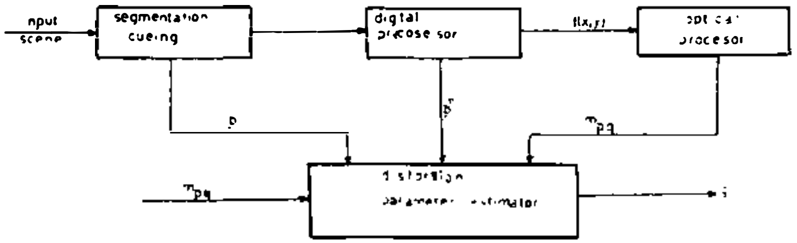

Fig. 1. Block diagram of moment estimator.

1. Compute the moments m_{pq} of each pattern $f(x, y)$ before deformation.
2. Compute the moments m_{pq} of each pattern $f(x, y)$ after deformation.
3. Comparing the moments m_{pq} with the moments m_{pq} to get the coars or initial estimates of the distortion parameters b_0.
4. Using iterative algorithm to optimize b

$$b_j = b_{j-1} + (J^T \Sigma^{-1} J)^{-1} J^T \Sigma^{-1} [\hat{m} - m_i (b_{j-1})] \tag{1}$$

   where j is the iteration index and J is Jacobian $m_i(b)/b$ of the $m(b)$ evaluated at b_{j-1}.

5. Resulting interpolation techniques to get the deformation for the surface positions where no patterns are printed.

In this paper, we will concentrate on: how the moments change when the model undergoes deformation, the measurement sensitivity obtainable, some requirements for the coherent optical processor to compute moments compare to other coherent optical techniques[3,4,5].

2. Moments of a pattern function

For background purpose, we will first briefly review the definition of the moments and derive the moment expressions for certain pattern functions and derive the new technique.

The moments of a function are defined as

$$m_{pq} = \iint f(x, y)\, x^p y^q \, \mathrm{d}x\mathrm{d}y \tag{2}$$

where the order of the moments is the sum $p + q$. The lower order moments have some physical significance. For example, the zero order moment m_{00} corresponds to the energy in the function, whereas the first order moments m_{01} and m_{10} give the centroid of the function in the x-direction and the y-direction, respectively. From mechanics, the combination of the second order moments $(m_{02} + m_{20})^{1/2}$ is the radius of the gyration of the function about the origin (this is related to the moment of inertia of function).

The moments for simple pattern function

$$f(x, y) = \begin{cases} 1 & 0 < x < a \quad \text{and} \quad 0 < y < b \\ 0 & \text{otherwise} \end{cases}$$

can be written as

$$m_{pq} = a^{(p+1)}b^{(q+1)}/(p+1)(q+1). \tag{3}$$

Because of the simplified moment expression, a square pattern will be used for the following studies.

3. *Changes in moments and deformation*

When the model undergoes some deformation, the printed pattern will be distorted correnspondingly, therefore the moments of the pattern will change. Changes in moments enables one to determine the model deformation. Both in-plane deformation and aut-of-plane deformation will be discussed on the assumption that the pattern undergoes uniform deformation.

3.1. *In-plane deformation*

We will discuss in-plane scaling, the most common and practical deformation. Assume

1) the dimension of the pattern $a = b = 1$

2) the scale factor in x-direction is and the scale factor in y-direction is then the moments of the scaled pattern can be written as

$$m'_{pq} = \alpha^{(p+1)}\beta^{(q+1)}/(p+1)(q+1) \tag{4}$$

the relative change in moments can be written as

$$c_{pq} = m'_{pq}/m_{pq} = \alpha^{(p+1)}\beta^{(q+1)}. \tag{5}$$

Either factor α or β can be found simply using

$$\alpha = (c_{p0}/c_{00})^{1/p} \tag{6}$$

$$\beta = (c_{0q}/c_{00})^{1/q}. \tag{7}$$

3.2. *Out-of plane rotation*

Suppose the pattern rotates by an angle φ about y-axis. As long as a telecentric imaging system is used to make the transparency of the rotated pattern, the transparency can be considered as projection of the original pattern, and rotation angle can be given by

$$c_{p0}/c_{00} = (\cos \varphi)^p \tag{8}$$

i. e.,

$$\varphi = \cos^{-1} (c_{p0}/c_{00})^{1/p}. \tag{9}$$

The rotation angle about x-axis could be obtained in a similar way.

4. *Requirements for optical processor*

The optical processor to compute moments is shown in Fig. 2 for an input pattern $f(x, y)$. For moment-based deformation measurement, the input pattern is the transparency made by photographically coping the pattern, which is placed in P_1 and imaged onto P_2 in Fig. 2, where a special mask $g(x, y)$ is placed. The light leaving P_2 is thus product $f(x, y)\, g(x, y)$. Its Fourier transform measured on optical axis is

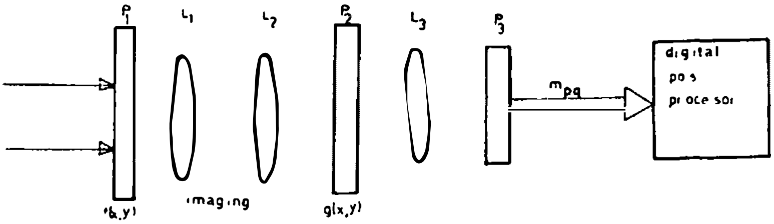

Fig. 2. Optical processor to compute moments.

$$u = \iint f(x, y)\, g(x, y)\, \mathrm{d}x\mathrm{d}y.$$

If the appropriate functions are used for the mask $g(x, y)$, the output P_3 will be the desired moments m_{pq}. For example if $g(x, y) = 1$, $u_3 = m_{00}$, if $g(x, y) = x$ or y, $u_3 = m_{10}$ or m_{01} is obtained, ect. In practice, the transmitance function proportional to all the moments monomials would be placed on a fixed mask at P_2 with each encoded on a different special frequency carrier, the P_3 output would be detected by m detectors. Such a system generates all m desired moments in parallel.

5. *The measurement sensitivity*

We estimated the expected measurement sensitivity for scaling faclor. Several assumption are included: the spatial samling interval is 1/4000, digitized gray levels are 256 (uniform quantization), 1% change in moments m_{pq} is detected. In addition to this assumptions for the scaling factor is obtained

$$a = (0.99)^{1/10} = 0.999.$$

Similiarly one could find the out-of plane rotation angle

$$\varphi = \cos^{-1}(0.999) = 2.56^{0}.$$

The numerical example shows that the moment-based deformation measurement techniques can have high sensitivity.

6. *Concluding remarks*

A new technique has been proposed to deformation measurement. A pattern is printed on the model surface under investigation, a transparency of the pattern is placed at the input plane of a coherent optical processor with a special mask to compute all the required moments of the pattern. Changes in moments enable one to determine the model deformation. The new techniques are shown to have high measurement sensitivity. As was discussed in section 5, a scale change of 0.1% and out-of-plane rotation angle of 2.56^{0} could be detected.

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NOV STATISTIČKI-OPTIČKI PRISTUP OBRADE PODATAKA ZA MJERENJE DEFORMACIJA

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U ovom radu prezentiran je nov optički-statistički pristup za mjerenje deformacija. Izračunati su projekcirani momenti na površini modela. Koristeći optički procesor sa specijalnom maskom generirani su momenti. Uporeďenjem dobivenih momenata prije i nakon deformacija, moguće je odrediti deformacije na modelu.