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Ivana VAŠKOVÁ*, Petr ŠMÍD, Pavel HORVÁTH***, Miroslav HRABOVSKÝ******

NONCONTACT MEASUREMENT OF MOVING OBJECT VELOCITY BY USING SPECKLE PATTERN CORRELATION

BEZKONTAKTNÍ MĚŘENÍ RYCHLOSTI POHYBUJÍCÍHO SE TĚLESA VYUŽITÍM KORELACE POLÍ KOHERENČNÍ ZRNITOSTI

Abstract

This contribution contains description of a speckle pattern correlation method for detection of time-variable processes, especially measurement of moving object velocity. The introductory part is devoted to a general principle of the measurement method, then attention is focused on measurement of velocity of an aluminum object under investigation. A designed experimental setup is described and some of the achieved results are mentioned.

Abstrakt

Příspěvek obsahuje popis metody korelace polí koherenční zrnitosti pro detekci časově proměnných dějů, konkrétně měření rychlosti pohybujícího se předmětu. Úvodní část je věnována obecnému principu měřicí metody, poté je pozornost soustředěna na měření rychlosti tuhého tělesa reprezentovaného hliníkovým hranolem. Je popsán návrh experimentální sestavy a jsou uvedeny některé dosažené výsledky měření.

1 INTRODUCTION

The optical noncontact methods for detection of time-variable processes have many advantages in comparison with other methods used earlier, especially the contactless principle, high measurement resolution and possibility to detect extremely low velocities. One of these methods uses well-known effect called speckle [1].

The method described in this contribution is based on the fact, that developed speckle field detected in front of a diffusely reflective object moves in dependence on movement of the object under investigation. The intensity distribution of speckle pattern is gradually recorded and data corresponding to change of object's location before and after its motion are mutually correlated. A position of the global maximum of cross-correlation function determines direction and extent of the movement. Hence if a time interval of detection of moving speckle pattern is known, it is possible to determine object's velocity.

A short theoretical description of a performed experiment is mentioned and an experimental setup is proposed. Then a procedure of the experiment is described including presentation of achieved results of the velocity measurement. The object under investigation is represented by an aluminum object.

* Mgr., tel.(+420) 58 563 4284, e-mail: vaskova@jointlab.upol.cz
** RNDr. Ph.D., tel.(+420) 58 563 1575, e-mail: petr.smid@upol.cz
*** RNDr. Ph.D., tel.(+420) 58 563 1569, e-mail: pavel.horvath@upol.cz
**** prof. RNDr. DrSc., tel.(+420) 58 563 1501, e-mail: miroslav.hrabovsky@upol.cz
Joint Laboratory of Optics of Palacky University and Institute of Physics of the Academy of Sciences of the Czech Republic, Tr.17. listopadu 50a, 772 07 Olomouc, Czech Republic

2 THEORETICAL BACKGROUND

The state of deformation of an elementary area of object's surface under investigation is expressed by means of a small deformation tensor (translation, rotation and elastic deformation components). Let us suppose, according to Fig. 1, an object with a diffusely reflecting surface is located in an object plane (f_x, f_y). The object's surface is illuminated by a spherical wave originating from a point *S*. Reflected coherent light forming speckle field is investigated in a detection plane (g_x, g_y). A thin lens with a focal length f' is placed between the detection plane and the object plane. The use of this optical component makes better measurement resolution in contrast to free-space field [2] possible to achieve.

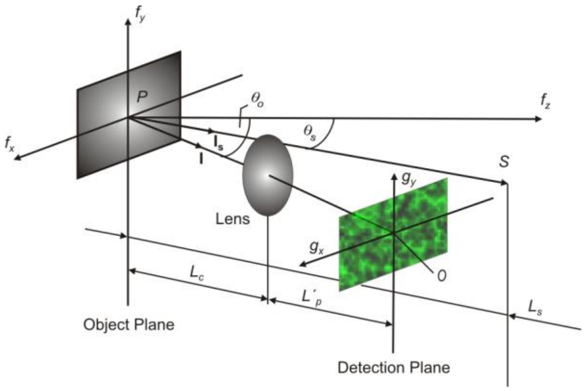

Fig. 1 Co-ordinate system for observation of speckle pattern in image field

With reference to the geometrical arrangement in Fig. 1 and [2-4] the relation between movement of speckle field and the small deformation tensor can be derived. Let us suppose that the object is translated as a rigid body in the f_x-axis direction. Consequently elastic deformation and rotation components are equaled to zero. The relation between movement of speckle field A_x and the translation component a_x is following

$$\frac{A_x f'}{L'_p - f'} = a_x \left(\frac{L_c (L'_p - f') - f' L'_p}{L_s (L'_p - f')} \frac{\cos^2 \theta_s}{\cos \theta_o} + \cos \theta_o \right), \qquad (1)$$

where L_c, L'_p are the distances between the lens and the object plane, the detection plane respectively, L_s is the distance between the source *S* and the object plane, θ_o is the angle of an observation direction and θ_s is the angle of an illumination direction. Further f' is the focal length of the thin lens and A_x is a component of the movement of speckle field in the g_x-axis direction.

Assuming that the interval of detection of moving speckle pattern is known and it is possible to suppose the movement of the object to be a uniform rectilinear motion [5], then a component v_x of the in-plane velocity is derived from the translation component a_x according to

$$v_x = \frac{a_x}{t_s}, \qquad (2)$$

where t_s is the time interval of detection of moving speckle pattern.

3 EXPERIMENT

This section deals with experimental verification of Eq. (1) for the translation component a_x. To find appropriate geometrical and optical parameters of the designed experimental setup, measurement sensitivity and measuring range has to be analyzed.

3.1 Experimental setup

According to Eq. (1), the measurement sensitivity and measuring range depend crucially on geometrical (L_c, L'_p, L_s, θ_o and θ_s) and optical (f') parameters of the designed experimental setup. Let us suppose the following ranges of the mentioned parameters: L_s, $L'_p \in (0.1 - 0.5)$ m, $\theta_o \in (10 - 50)°$, $A_x \in (10 - 60)$ pixel (pixel size is 7.5 μm × 7.5 μm), $f' \in (10 - 35)$ mm. On the basis of the measurement sensitivity analysis [5] it is ascertained that the increasing distance L'_p between the thin lens and the detection plane and decreasing focal length f' increase the measurement sensitivity (*e.g.* $a_{xmin} = 0.20$ μm for $f' = 15$ mm, $L'_p = 0.5$ m and $a_{xmin} = 1.16$ μm for the same focal length $f' = 15$ mm, $L'_p = 0.1$ m, whereas the other values of the geometrical parameters are following: $A_x = 1$ pixel, $L_c = 0.11$ m, $L_s = 0.40$ m and $\theta_o = 28^o$). Further increase in distance L'_p between the thin lens and the detection plane and decrease in the focal length f' raise in transversal magnification of diameter of individual speckles of speckle pattern, and then lower value of the translation component a_x is possible to measure.

On the basis of the provided theoretical analysis [5] of measurement sensitivity, measuring range and measurement uncertainty the following geometrical parameters were chosen: $L_s = 0.40$ m, $L_c = 0.11$ m, $L'_p = 0.49$ m, $f' = 19.96$ mm, $\theta_o = 28^o$ (supposing normal incidence of coherent light, $\theta_s = 0^o$).

The experimental setup designed for the measurement of the in-plane velocity component v_x in the f_x-axis direction is illustrated in Fig. 2. A coherent laser beam from a He-Ne laser falls upright on the aluminum object under investigation fastened to a linear stage. A CMOS (Complementary Metal Oxide Semiconductor) detector captures the arising speckle field. The detector has resolution of 1288 px × 1032 px, where 1 px = 7.5 μm. The state of the speckle pattern, its intensity distribution, is gradually recorded in short time periods $t_s = 90$ ms representing equidistant time steps. Hence two successive intensity records can be regarded as strongly correlated. The obtained data are transferred to a PC and processed consecutively. Each two successive intensity sets are numerically processed in the PC by a program that determines the maximum position of the normalized cross-correlation function and then the motion of the speckle pattern is determined [5].

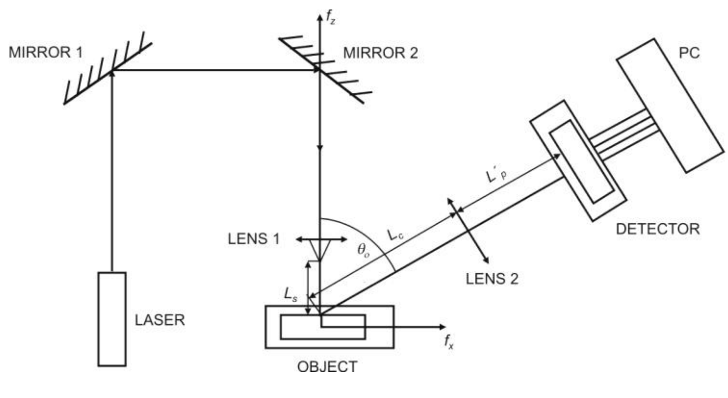

Fig. 2 Experimental setup designed for the noncontact measurement of the object's in-plane velocity v_x

3.2 Experimental results

The graph in Fig. 3 shows the measured velocity v_x as a function of the velocity v_{zv} of the linear stage defined within the interval of (10 - 150) μm·s^{-1}. The solid line belongs to the measured data of velocity v_x. The dashed line belongs to an ideal situation, i.e. the measured values v_x are equaled to the values of velocity v_{zv} and the slope of the line is equaled to one. One can note that measured results only slightly differ from the ideal case.

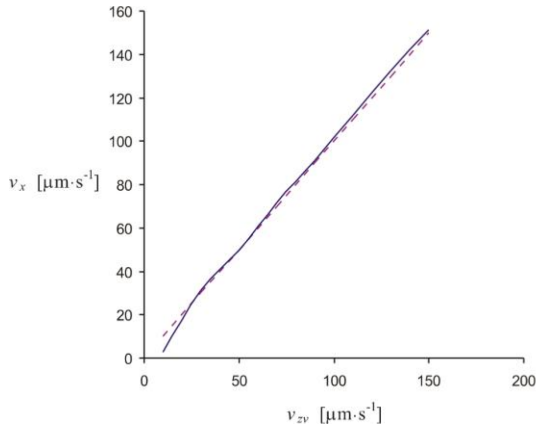

Fig. 3 Experimental results: measured velocity v_x as a function of velocity v_{zv} of the linear stage

4 CONCLUSION

This paper deals with the feasibility of in-plane velocity measurement of an object with a rough surface using the theory of speckle correlation. The measurement of the in-plane velocity is based on the determination of the translation component of the small deformation tensor and hence the geometrical arrangement for the determination of the a_x-component is designed and analyzed.

This presented noncontact optical measuring method uses modern optoelectronic elements and computer technology, which simplify evaluation considerably. Adjustments of the measurement sensitivity, measuring range and measurement uncertainty by suitable selection of the geometrical and optical parameters of the measuring setup are another advantages of the method.

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