Measurement of Very Small Changes of Object Position Using Speckle Correlation Method

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Abstract: - The paper deals with measurement of very small changes of the object position using speckle correlation method. An object translation is very often measured by deformation tensor components. Often used measuring method is based on direct contact with the object, which can be destructive. Presented contactless method uses statistical approach which means computation of the cross-correlation function of two speckle patterns recorded before and after object translation.

Key-Words: - Speckle, Laser, Contactless measurement, Change of object position.

1 Introduction

Problems of contactless optical measurement of translations rotations and deformations achieved two significant phases up to now. The first one occurred in 50th and it was primarily characterized by photoelasticimetry. The second one came in 70th and it was characterized by holographic interferometry and speckle holography method. However, not a single one method from these due to their complexity found wider use in practice. Recently, in times of turbulent development of computer techniques, light sources and detectors the restoration of methods using coherency grain arises. Above all, methods using cross-correlation function of two coherency grain intensity fields which are measured before and after surface change of an object. From the point of contemporary mechanics, main advantages of mentioned methods are non-contacts measurement, variability, possibilities of mechanization and also automation of measured data processing.

This optical method is based on speckle phenomenon which is also often called coherency grain. It occurs during reflection of coherent light from coarse interface; pass of coherent light through coarse interface or pass of coherent light through environment with random fluctuations of refractive index.

Physics of this phenomenon is interference of light waves originating either from number of microscopic surfaces which are considered on object's surface during reflection or from dispersion on randomly distributed particles during pass. As a result, a visible figure (speckle field) consisting of light and dark stains which is possible to observe on a shade located whenever in front of the lens (during reflection) and located behind the lens during pass. Size and appearance of grains depend on coherency stage of incident light, on its polarization and also on properties of dispersing environment [1], [2]. Change of speckle field can be quantitatively described with change of maximum position of statistical cross-correlation function between two intensity fluctuations of coherency grain from object before and after its deformation [3],[4],[5]

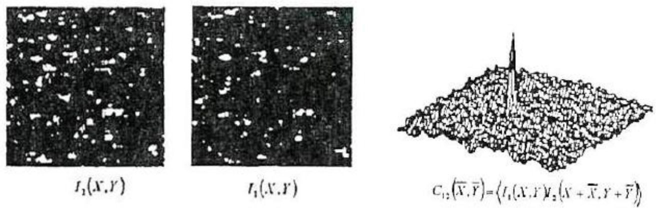

Fig. 1. Illustration of speckle field with corresponding cross-correlation function.

In Figure 1 can be seen two photos of speckle field before and after translation and corresponding cross-correlation function. During object deformation, the correlation has always non-zero position and it represents an extent of change of measured object position. Simultaneously, value of maximum is decreasing which is caused by change of speckle field structure during deformation.

Used instruments

AXIS 221 Network Camera

It is a high performance camera for round-the-clock surveillance over IP networks. The camera provides high quality images (up to 45 frames per second in VGA resolution - 640 x 480 pixels) under all lighting

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conditions, which makes it an ideal solution for indoor/outdoor applications.

JDS Uniphase Helium Neon Laser

It features a patented close-cathode design that provides improved thermal stability for superior beam pointing and power stability, as well as a patented field concentrator design that enables fast turn-on. The precisely aligned cylindrical housing on the JDS Uniphase HeNe laser and electrical interconnect system simplify system integration. JDS Uniphase units are rugged enough for the most demanding applications.

M110 Compact Micro-Translation Stage

It is an ultra-high resolution (0.007 µm) motorized translation stage providing linear motion of 5 mm in an extremely compact package. They feature a precision leadscrew with sub-micron resolution and precision linear ball bearings guaranteeing <0.5 µm straightness of travel.

3 Experimental

Measuring system consists of source of coherent light which is focused on a rough part of measured object, the camera watching coherence grain and the computer which evaluates video data (Figure 2).

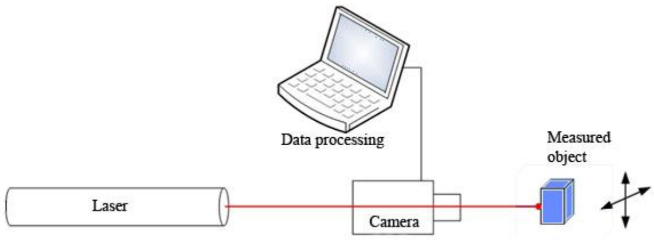

Fig. 2. Scheme of measuring system.

At first, a verification of measured method was accomplished, so some simplifications were considered. We assumed only motion in horizontal or vertical line. Due to this fact, only one row or column of the video data was taken for evaluation of intensity fluctuations of coherency grain. In this paper, we only dealt with evaluation of motion in vertical line so that one column of pixels was processed. To verify measuring method, the micro-translation stage was used and it was controlled by PI Mercury software via RS232 interface. Translation change of the stage was accomplished only for linear vertical line, length of translation was 2 mm, velocities were chosen 17.5, 35, 70, 140, 280, 560 and 1120 µm/s. Lens of Axis 221 was removed and the camera was properly adjusted in order that coherence field which is reflected from measured object surface can drop on the CMOS sensor. The camera was connected with the computer via RJ-45 interface, frame rate was set at 30 frames per second.

Essential algorithms in Matlab were created for complete evaluation of measured data, such as program for calculation of: presence time of speckle, speckle size, intensity of speckle field, distance in pixels and velocity of motion. Presence time of speckle is an average period of time when individual speckle originates and then is lost. This parameter defines range of measuring method and also means the longest permissible time between two neighbouring evaluated frames (see Figures 3 and 4). Speckle size is an average size of speckle in evaluated column of CMOS sensor. This parameter represents sensitivity of the method (see Figures 5 and 6).

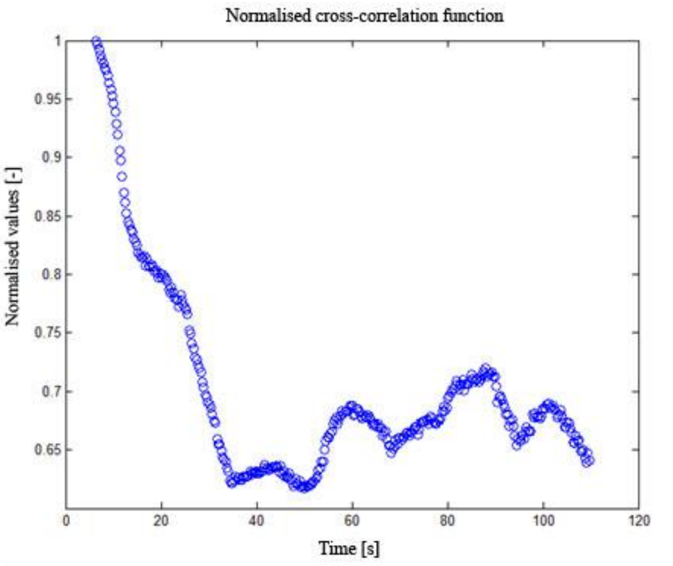

Fig. 3. Normalized cross-correlation function.

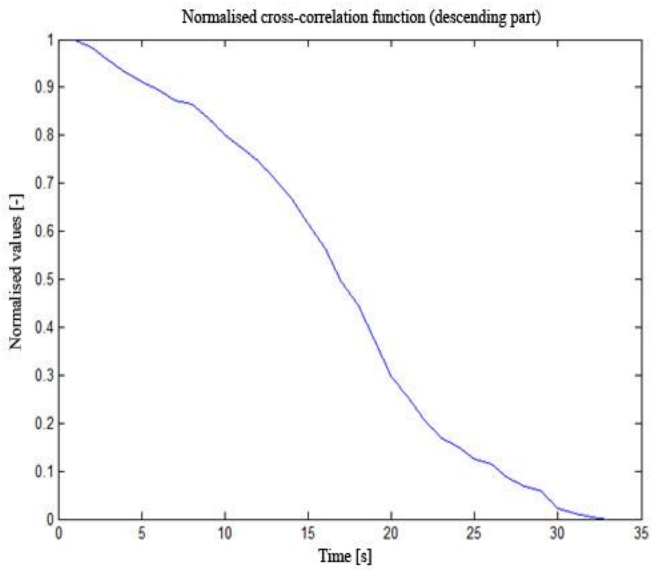

Fig. 4. Normalized descending part of curve, it represents presence time.

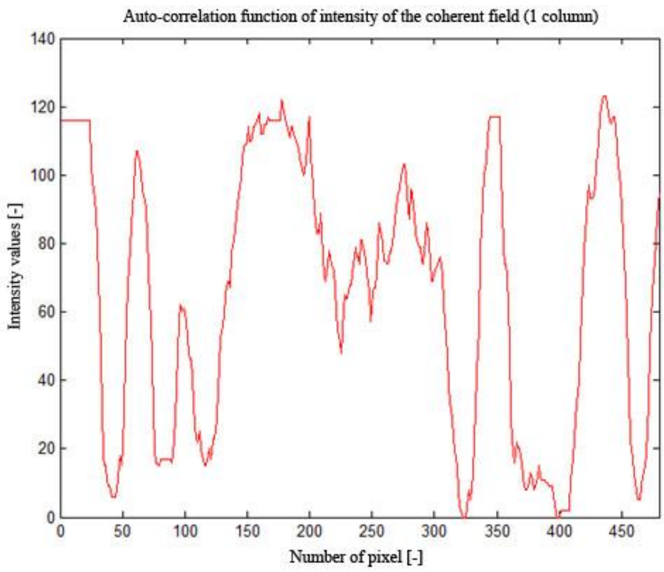

Fig. 5. Normalized cross-correlation function.

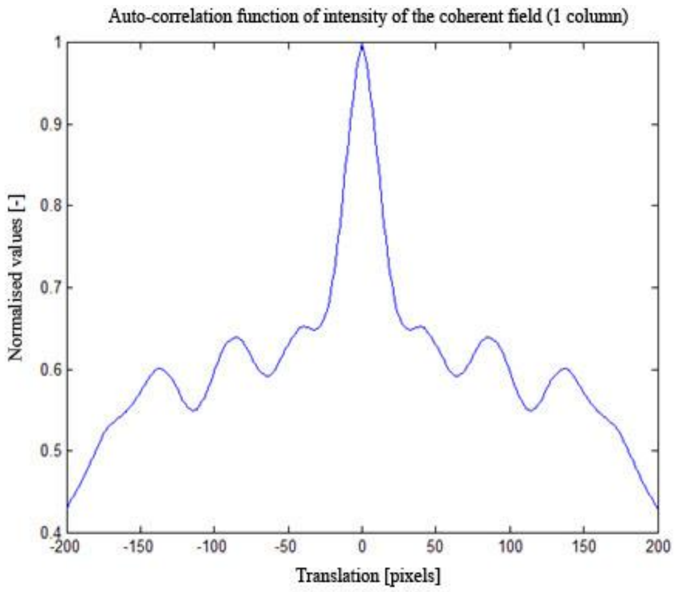

Fig. 6. Normalized descending part of curve, it defines speckle size.

Following table shows results of measuring process where object's known velocity was measured.

Table 1. Velocities of the moving object

Reference velocity	**Measured velocity**	**Difference of velocities**	
[µm/s]	[µm/s]	[µm/s]	[%]
17,5	20,4	2,9	17
35	43,4	8,4	24
70	83,7	13,7	20
140	172,2	32,2	23
280	333,1	53,1	19
560	674,5	114,5	20
1120	1359,0	239,0	21

In the Figure 7, linear dependence can be observed between measured and reference values of velocity.

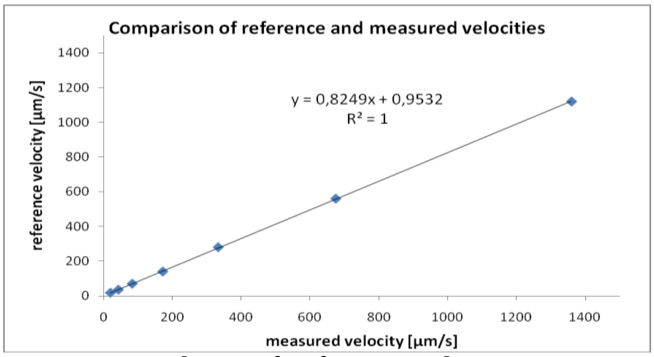

Fig. 7. Dependence of reference velocity on measured one.

5 Conclusion

Position change measurement method of the bodies by using speckle phenomena is from the point of view of nowadays metrology very interesting method, because it is a noncontact method. Unfortunately, this method has some specifics, which essentially limits its using in practice. At the moment of measuring, there must be kept specific conditions and their breach causes a decrease of sensitivity or using of the method itself. Scanned surface should be straight, without any deformation and its roughness must have a value to produce a laser speckle phenomena. From obtained results is evident, that measuring error is about 20 percent but after simple correction it can be very well used for measuring of velocity (Figure 5). If there are kept the conditions mentioned above this method achieves very accurate values of measured data.

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