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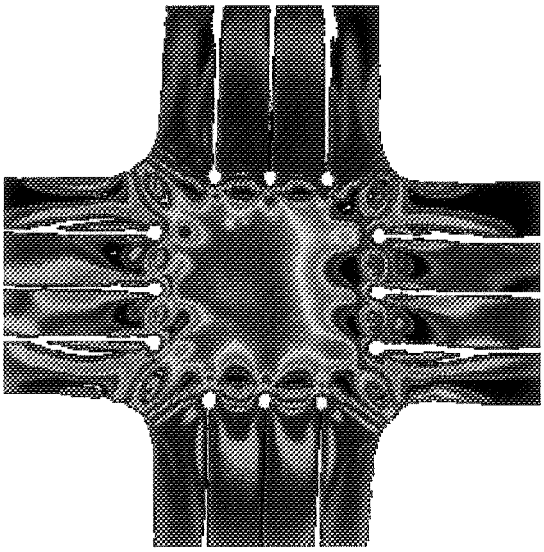

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PSEUDO STOKES VECTOR CORRELATION FOR MICRO-DISPLACEMENT MEASUREMENT

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ABSTRACT: Instead of the intensity correlation used widely in conventional speckle metrology, we propose a new technique for displacement measurement based on the pseudo Stokes vector correlation from the complex signal representation of a speckle pattern generated from Riesz filtering. Experimental results are presented that demonstrate the validity and advantage of the proposed technique as compared with conventional intensity correlation.

1. INTRODUCTION

Correlation-based speckle metrology has been studied extensively, but existing techniques are, for the vast majority, based on the cross-correlation function of the intensity information of the speckle pattern [1]. As an alternative, we propose a new approach that makes use of the pseudo Stokes vector associated with the complex signal representation. Based on the formal analogy between the polarization field of a vector wave and the gradient field of the complex signal, a set of Stokes-like parameters has been used to characterize the local structure of a speckle pattern. Instead of speckle intensity information, the displacement measurement has been made based on the newly derived pseudo Stokes vector correlation (PSVC) technique. We also conduct the comparison between the proposed PSVC with conventional intensity correlation (IC) to demonstrate its advantage.

2. PRINCIPLE

2.1 2-D isotropic complex signal representation of the speckle pattern

Let $I(x,y)$ be the ac component of the original intensity distribution of the speckle pattern obtained after subtraction of the mean value (average dc component), and let its Fourier spectrum be $\Im(f_x,f_y)$. We can relate $I(x,y)$ to its isotropic analytic signal $\tilde{I}(x,y)$ through Riesz filtering. Thus, our definition of a 2-D isotropic complex signal for the speckle pattern is [2,3]

$$\tilde{I}(x,y)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}V(f_x,f_y)\cdot\Im(f_x,f_y)\exp[j2\pi(f_x x+f_y y)]df_x df_y\,, \tag{1}$$

where $V(f_x,f_y)$ is a Riesz filter defined as $V(f_x,f_y)=(f_x+jf_y)\Big/\sqrt{f_x^2+f_y^2}$.

2.2 Pseudo Stokes vector correlation

Usually, the real and imaginary parts of the complex signal in the immediate vicinity of four pixel neighbourhood (2x2 arrays) can be expressed as: $\mathrm{Re}[\tilde{I}(x,y)]=a_r x+b_r y+c_r$ and $\mathrm{Im}[\tilde{I}(x,y)]=a_i x+b_i y+c_i$, where the coefficients: $a_k,b_k,c_k\,(k=r,i)$ can be obtained by the least-square fitting method from the detected complex values at the pixel grids. Therefore, the associated gradient of the complex signal $\tilde{I}(x,y)$, can be expressed as: $\nabla\tilde{I}=(a_r+ja_i)\hat{x}+(b_r+jb_i)\hat{y}$.

Noting the mathematical analogy between the complex vector field: $\nabla\tilde{I}$ and the vector polarization field [4], a Stokes-like vector can be introduced as $\vec{S}=(S_1,S_2,S_3)$, where $S_1=a_r^2+a_i^2-b_r^2-b_i^2$, $S_2=2(a_r b_r+a_i b_i)$, $S_3=2(a_r b_i-a_i b_r)$. The vector $\vec{S}$ is referred to as pseudo Stokes vector to distinguish it from the true Stokes parameter used for the polarization field of a vector wave. Instead of the intensity information used widely in conventional speckle photography, we make use of the newly derived pseudo Stokes vector from the complex signal representation of the speckle pattern. Thus, the proposed pseudo Stokes vector correlation (PSVC) can be defined by

$$C_S(\Delta x,\Delta y)=\left\langle\vec{S}(x,y)\vec{S}'(x+\Delta x,y+\Delta y)\right\rangle, \tag{2}$$

where primed parameters denote the speckle pattern after displacement.

3. EXPERIMENTS

We conducted experiments to demonstrate the validity of the proposed technique. We generate the laser speckle pattern by illuminating a ground glass with He-Ne laser. The generated speckle pattern was imaged with a lens onto a CCD image sensor. By taking two images of the object before and after displacement, we measured the micro-displacement by the proposed pseudo Stokes vector correlation technique.

To make the comparison on equal grounds, we calculated the correlation with a sub-window size of 100x100 pixels, and the shapes of the correlation functions for intensity correlation and PSVC are illustrated in Fig. 1(a). For both techniques, a main correlation peak can be observed at the coordinate $\Delta x = -13$ pixels, which indicates the displacement of the object. Near the main peak, we can also observe other small peaks, which can be a source of discrimination error in displacement measurement. The ratio of the main peak to its highest side-lobe can serve as a reliability measurement of the technique used. In this measure, the ratios of heights are 6.48 for IC and 7.02 for PSVC, respectively. By decreasing the size for the correlation window, we tested the performance of these two correlation techniques as shown in Fig. 1(b). As expected, the side lobes of the normalized correlation function increase with decreasing the correlation area. Unlike a small ratio equal to 1.62 given by the conventional IC technique, the proposed PSVC gives a very large ratio with 4.74, which indicates a strong robustness against decorrelation. In this case, a small sub-window of 30x30 pixels has been chosen for both methods. Figure 1 demonstrates the validity and advantage of the proposed pseudo Stokes vector correlation technique as compared with conventional intensity correlation.

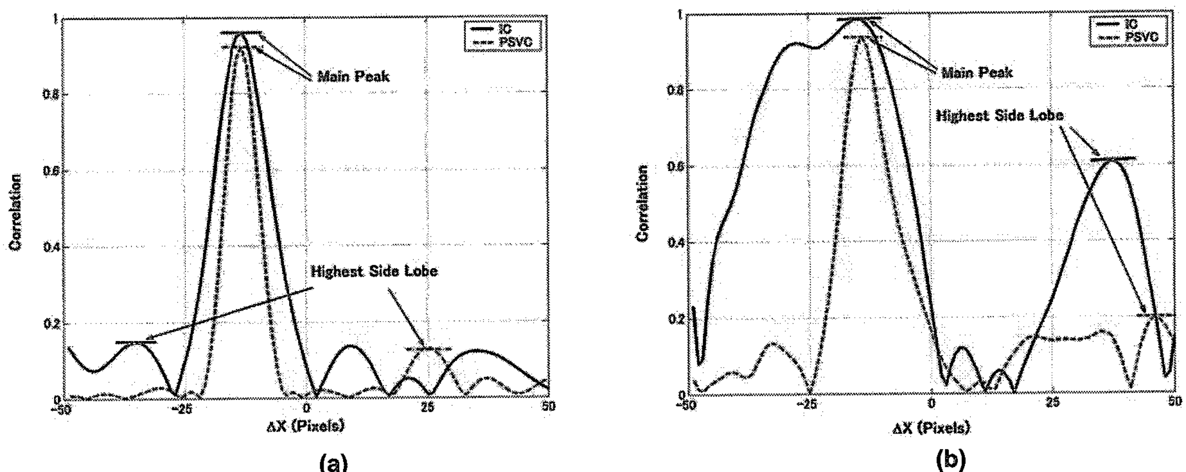

Figure 1. Distribution of correlation functions with different sub- window size (a) 100x100 pixels (b) 30x30 pixels

4. CONCLUSIONS

In summary, we have proposed a technique for micro-displacement measurement, referred to as pseudo Stokes vector correlation (PSVC), which makes use of the gradient field of the complex signal representation of a speckle pattern generated by Riesz filtering. From the experimental results, it is shown that the proposed PSVC has an advantage over the conventional intensity correlation with respect to suppression of spurious correlation peaks.

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