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A Modified Schlieren Diffraction Signal Processor for Contrast Enhancement

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ABSTRACT

Enhancements of any imagery means improvement in its visual appealing, interpretations and understanding. The purpose of the image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features in the scene. Normally, image enhancement involves techniques for increasing the visual distinctions between features in a scene. In this paper we present a technique for contrast enhancement using a modifying schlieren diffraction signal processor. This modified schlieren diffraction signal processor enhances the contrast in the image with light toned areas appearing lighter and dark areas appearing darker, making visual interpretation much easier.

INTRODUCTION

Optical methods offer tremendous potential to perform various processes as addition, subtraction, integration, differentiation, complex spatial filtering, correlation, linear and non-linear transformations etc. in parallel and real-time[1,2]. These operations provide a strong basis for optically signal processing. It is considered that the subject of optical processing is a recently developed area of research and development but, in fact, it has many important roots that should not be ignored. The well-known Foucault knife-edge test, first described in 1859 and known as a schlieren technique, is really a method of optical signal processing to remove the direct image light and keep the scattered or diffracted light. Schlieren techniques are one of the simplest and well-known techniques for optically signal processing[3]. In conventional schlieren signal processor a knife-edge filter is used to block out half of the Fourier spectrum of the phase object but the dc (containing maximum amplitude of the incident light) is allowed to pass. It may be noted that the low contrast results due to a relatively large value at the zero order (dc) whilst the higher frequencies have relatively low value. This is generally balanced by placing a small partially transmitting, precisely fabricated and accurately placed filter over the dc, which allows less light to pass through to image plane and redresses the balance between the low spatial frequency content and higher spatial frequencies. In this paper we present a new technique for contrast enhancement of optical signals in schlieren optical processors. Leading edge of a front surface coated plane mirror is used to diffract light from the d c component (diffraction from Airy disk[4,5]) resulting in contrast enhancement of the low as well as high component frequencies. This is due to the facts: (i) a stronger diffracted light serves as an inbuilt reference beam which interferes with the geometrical beam modulated by the frequency components of the input plane signal and (ii) otherwise unutilized diffracted beam in conventional schlieren optical processor is recombined in the described folding mirror geometry. This further facilitates other filtering techniques which otherwise were difficult to perform. Experimental results validating this configuration has been presented.

OPTICAL SIGNAL PROCESSING

A conventional optical signal processing system is schematically shown in Fig. 1. The input to be processed is inserted in the input plane. Lens L_1 Fourier transforms the input, producing an amplitude distribution according to spatial frequency of the input function.

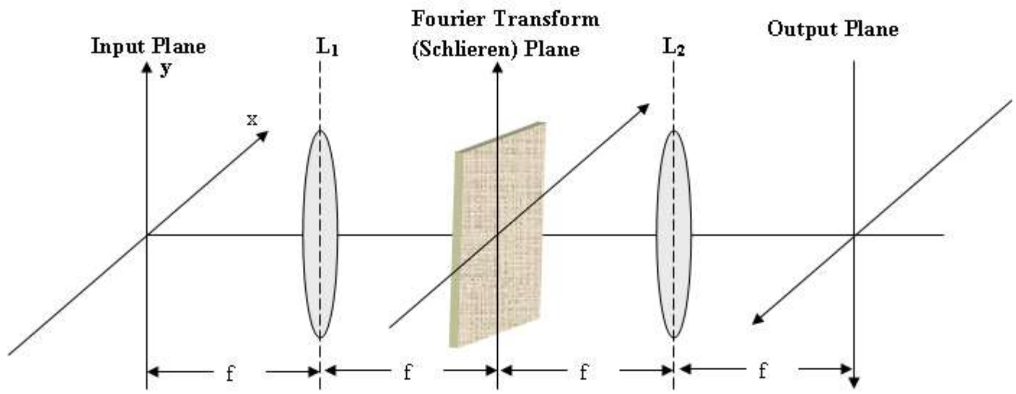

Figure 1- Schematic configuration of an optical signal processing system

A filter is inserted in this plane (Fourier transform or Schlieren plane) to manipulate the amplitude and phase of the spectrum. The amplitude distribution in the image plane is thus dependent on the input and the schlieren filter transmittances. Here schlieren plane filter known as the schlieren stop works on the frequency spectrum to perform optical signal processing.

CONTRAST ENHANCEMENT USING MODIFIED SCHLIEREN TECHNIQUE

In the present work a mirror-edge is used as a diffracting element to generate a stronger inbuilt diffracted reference beam in the schlieren interferometer to provide high contrast information even of the low frequency contents (Fig. 2). In order to enhance contrast of the signal, mirror edge acts as a diffracting aperture and generates the well-known finite fringe mode Fresnel diffraction pattern in the observation plane. The first bright fringe of the diffraction pattern containing maximum amplitude of the diffracted light has been broadened to cover the whole field of view[4,5], by bringing the mirror edge in close proximity of the focus. This results in enhancement in the contrast of schlieren pattern due to the fact that at this position mirror edge diffracts light from the Airy disk (containing about 84 percent of the free field light) and thereby an increase in the amplitude of the diffracted light and the folding mirror geometry further doubles the amplitude of the diffracted light.

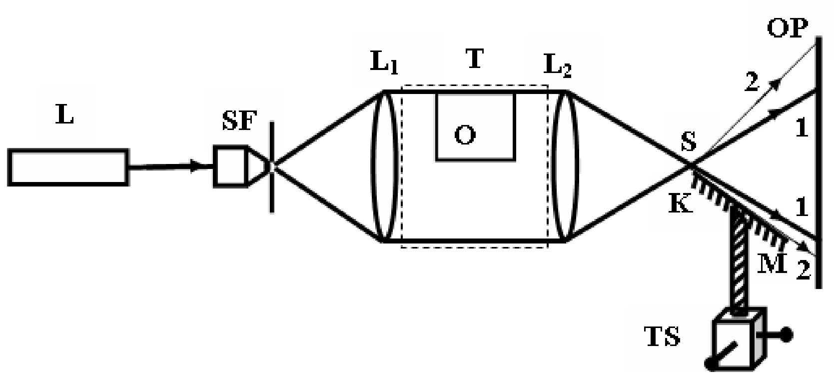

Figure 2- Schematic configuration of modified schlieren optical signal processing system

According to Maggi-Rubinowicz's boundary diffraction wave theory, the diffracted field at point P_1 is a superposition of the geometrical wave, U^g and the boundary diffraction wave, U^d such that

$$U(P_1) = U^g(P_1) + U^d(P_1) \quad (1)$$

where

$$U^g(P_1) = (A/R)\exp(jkR) \quad \text{when } P_1 \text{ is in the direct beam}$$
$$= 0 \quad \text{when } P_1 \text{ is in geometrical shadow,} \quad (2)$$

$$U^d(P_1) = U^{d'}(P_1) + U^{d''}(P_1)$$
$$= (A/4\pi)[1-\exp(jk\Delta)]\int_{\Sigma}\exp\{jk(r+s)\}\cos(\mathbf{n_A},s)\sin(r,dl)\,dl/\{rs[1+\cos(r,s)]\}, \quad (3)$$

$$U^{d'}(P_1) = (A/4\pi)\int_{\Sigma}\exp\{jk(r+s)\}\cos(\mathbf{n_A},s)\sin(r,dl)\,dl/\{rs[1+\cos(r,s)]\}, \quad (4)$$

$$U^{d''}(P_1) = (A/4\pi)\int_{\Sigma}\exp\{jk(r+s+\Delta)\}\cos(\mathbf{n_B},s)\sin(r,dl)\,dl/\{rs[1+\cos(r,s)]\}, \quad (5)$$

and

$$\cos(\mathbf{n_A},s) = -\cos(\mathbf{n_B},s) \quad (6)$$

Σ denotes the boundary of the illuminated part of K, dl is an infinitesimal element situated on Σ, Δ denotes the path difference introduced in the boundary diffracted wave corresponding to a phase change due to reflection and $\mathbf{n_A}$ and $\mathbf{n_B}$ are out and inward unit vectors normal to the plane of diffracting aperture. $U^{d'}$ is mirror edge diffracted wave directly proceeding towards the observation plane and $U^{d''}$ is edge-diffracted wave reflected from the mirror surface. Equation (3) shows that the amplitude of boundary diffraction wave U^d becomes maximum (twice that of the solid knife-edge) whenever the phase introduced in the reflected wave is $(2n + 1)\pi$ and its value becomes zero corresponding to a phase change of $2n\pi$, where n denotes an integer. It may be noted that at grazing incidence a phase change of π radians gets introduced in the beam reflected off the mirror, doubling the amplitude of boundary diffraction wave and thus giving higher fringe contrast which is similar to that what one would get using a well designed and properly fabricated $\lambda/2$ phase knife-edge. Typical result obtained with ordinary this system is shown in Fig (3) whereas typical result obtained with modified schlieren system is depicted in Fig (4).

Figure 3- An optical image with ordinary schlieren system

Figure 4- An optical image processed with modified schlieren system

CONCLUSIONS

A modification in schlieren diffraction signal processor has been reported to enhance contrast of the optical signals. In this modification, schlieren element i.e. mirror-edge is used as a diffracting element instead of as a blocking stop. The beam reflected from the mirror add the phase change of π radians, doubling the amplitude of boundary diffraction wave. This provides a much stronger light giving enhanced contrast in schlieren optical processor. The system is compact and quite stable to external vibrations as both the interfering beams are derived from the same collimating optics.

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