CHAPTER 6

MICRO MACHINED NONLINEAR WAVELENGTH FILTERS FOR IMAGE ACQUISITION

6.1 INTRODUCTION

This chapter delineates the application of Grating Light Valve in non linear wavelength filters for image processing. A key metric for digital imaging systems is the rate at which image information is delivered to the target. Typically, the rate of data delivery is given by the product of pixel modulation, multiplied by number of pixels, multiplied by the number of gray scale bits. Obviously, the method to achieve gray scale is more important. By capitalizing on high-speed analog nature of GLV device, it is possible to deliver many millions of gray-scale pixels per second. The suitability of the GLV device for high data rate application was discussed in the paper by Alexander Pane et al (2004). Using a GLV device, it is quite possible to project an image with 1080×1980 pixel resolution at a rate of 60 frames per second. The reliability of the scanned architecture was discussed in the literature by Corrigan (1998). The goal is to produce natural colours with high resolution by using nonlinear filter characteristics of the grating microstructure called Grating Light Valve. The wavelength selective surface operation of this filter depends on a periodic array of elements and the grating depth of GLV. The depth of the grating element is in the order of one fourth of the electrical wavelength, and the array period is typically several wavelengths for efficient operation. Ronian H. Siew (2002) in his paper, discussed the basic physics of a high power IR imaging system introduced into the prepress industry. Specifically, the author focused his attention on the GLV spatial light modulator used in the imaging system. The GLV-imaging system principle was described in terms of basic partial coherence and Fourier optical ideas. Although the fundamental physics of the GLV is based on the coherent superposition of diffracted waves, simple experimental observations implied that a high degree of spatial coherence from the illumination source is not required for the practical application of the GLV technology in imaging systems.

Colour is a property of enormous importance to human visual perception and is connected with the ability of the objects to reflect electromagnetic waves of different wavelengths. Human eyes detect colours as a combination of primary colours red, green and blue and the wavelength of standardization have been defined as 700 nm, 546.1 nm and 438.5 nm respectively. Hardware will generally deliver or display colour via RGB model; thus a particular pixel may have associated with it a 3D vector (R, G, B) which provides respective colour intensities.

The image can be captured by several sensors, each of which is sensitive to a rather narrow band of wavelengths. Each spectral band is digitized independently and is represented by an individual digital image function as if it were a monochromatic image. This sensor is a nonlinear wavelength filter which filters red, green and blue components of the image, irrespective of the input colours. Recent advances in MEMS technology have made it possible to capture high dynamic range images which have better quality rather than the other bulk devices. A colour image can be acquired by using three filters, sensitive to red, green and blue respectively. A better non-linear filtering response can be obtained by various diffractive optical modulators like GLV and Elastomer based diffractive optical modulator discussed by Srinivasan Uma (2004). In this section, a method to construct a non-linear wavelength filter is proposed, which filters the red, green and blue components of an image using Optical MEMS device called GLV, which provides a high degree of image fidelity.

6.2 NON-LINEAR WAVELENGTH FILTER USING GLV

The electro-mechanical response of the GLV device can be tuned through various design and operational modes to deliver desired performance for a given application. The flexibility of the GLV technology and the Scanned Linear GLV Architecture can support line sequential and frame sequential colour, as well as 3-valve colour systems. The light that strikes the down ribbons, propagates half of a wavelength more than the light that strikes the up ribbon. So the light reflecting from the down ribbon is multiplied by a phase term $E\ exp(j2k\delta)$, where $k = \frac{2\pi}{\lambda}$ (Timothy P. Kurzweg 2002).

Varying the width and deflection depth of the ribbons tunes pixel to deliver a single colour into the light path and thus acting as non-linear wavelength filter. In this architecture there are three separate GLV pixel arrays which are designed with three different ribbon width and deflection depth and illumination source is introduced at an angle off axis of the GLV device. Here the deflection depth and width of the red, green, and blue pixels depends on the wavelength and off axis angle of the incident image.

Figure 6.1 shows the operation of red, green and blue pixels. The red pixel reflects red light components normal to the GLV plane while green and blue light components are refracted at other angles. The green and blue pixels do the same for green and blue light respectively. Thus filtering of different wavelengths is achieved, irrespective of the input colours.

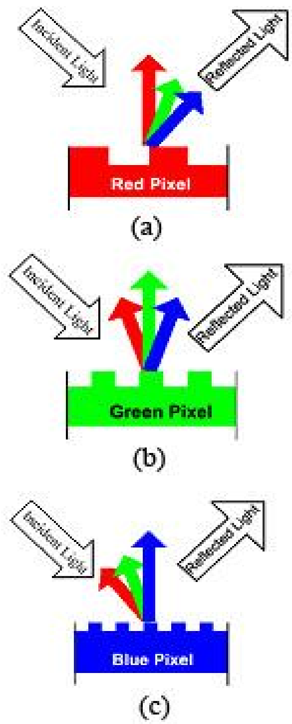

Figure 6.1 Operation of (a) Red (b) Green (c) Blue pixels

The direction of the principal maximum intensity is given by,

$\Lambda \sin\theta_m = m\lambda$, where m=0, ± 1, ± 2, ± 3, and so on.

The zeroth order principal maximum occurs at θ = 0. The grating period (Λ) plays an important role in deciding the output wavelength. Thus if we use a polychromatic source, the central maximum will be of the wavelength decided by the grating period. Thus various spectral components appear at different positions.

For the first-order principal maxima, that is, m=1, $\sin\theta_1 = \lambda_1/\Lambda$, which means the principal maxima of the different wavelengths are separated from one another by some angle. Thus a diffraction grating directs different wavelengths in different directions. Angular separation, also called angular dispersion, can be easily obtained as,

$\Delta\theta/\Delta\lambda = m/\Lambda\cos\theta$, where $\Delta\theta$ is the angular separation of two principal maxima for two wavelengths that differ by $\Delta\lambda$. The diffraction angle can be seen to get larger as the period of grating gets smaller.

The input light containing multiple wavelengths, λ_1, λ_2, λ_3 and λ_m are diffracted by gratings into different directions. The pitch of grating is related by,

$\Delta\lambda/\lambda = \Delta\Lambda/\Lambda$, where 'Λ' is the grating period.

6.3 IMAGE PROCESSING ARCHITECTURE

The phase grating possess a very important advantage over amplitude grating, and this is seen by realizing that the phase grating is no different from an ordinary lens and also tends to negligibly attenuate an optical field having the tuned wavelength passing through it. The spectrum analyzing property of diffraction gratings make them very useful in non-linear filtering applications. According to Floquet's theorem, the grating produces an infinite number of diffraction orders, whose propagation constants are given by

$$\alpha_m = \frac{2\pi}{\lambda}\sin\theta_0 + \frac{2m\pi}{\Lambda} \tag{6.1}$$

where α_m is the propagation constant of m^th^ order. The incident field is assumed to be comprised of a (frequency) spectrum of plane waves, each having a unique frequency and wavelength, but all propagating in the same direction. This means that every frequency component has a unique value of α_0, given as,

$$\alpha_0(\lambda) = \frac{2\pi}{\lambda}\sin\theta_0 \qquad (6.2)$$

The propagation constant for the m = -1 order is given as a function of frequency or wavelength as,

$$\alpha_{-1}(\lambda) = \alpha_0(\lambda) - \frac{2\pi}{\Lambda} \qquad (6.3)$$

where 'Λ' is the period of grating. A frequency near the center of the spectrum is selected and its wavelength is identified as λ_0. If 'Λ' is the grating period such that $\Lambda = \frac{\lambda_o}{2\sin\theta_0}$, then for λ_0, it is stipulated that $\alpha_{-1} = -\alpha_0$, when this condition is satisfied, then $\alpha_{-1}(\lambda) \cong -\alpha_0(\lambda_0)\left(2 - \frac{\lambda_0}{\lambda}\right)$ for the other wavelengths in the incident field spectrum. The deflection angle of m = -1 order for each frequency is found as $\sin\theta = \frac{\alpha_{-1}(\lambda)}{k}$, where $k = \frac{2\pi}{\lambda}$.

Figure 6.2 shows the image processing GLV architecture. Each frequency component is deflected into different directions by the grating structure and the red, green, blue colours can be easily resolved and applied to the colour monitor for further processing.

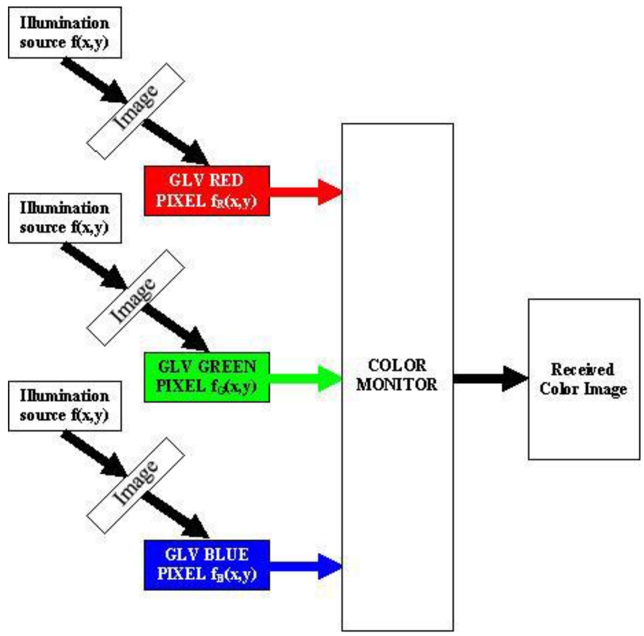

Figure 6.2 Image processing GLV architecture

6.4 DISCUSSION

In the existing image acquisition system using conventional methods, the image-plane irradiance pattern is recorded and the variations in image irradiance caused by speckle lead directly to width variations in the acquired image. By using GLV technology, it is possible to eliminate this speckle considerably.

The resolution of an implemented system is determined by design specifications and the actual measurement accuracy of the system is investigated by performing a series of experiments using different colour images. On line processing is possible through this architecture. One typical colour image shown in Figure 6.3 is taken as reference input image. Using GLV non-linear filter, the colour image is filtered into three different colour components (R, G, and B) and is transmitted. At the receiving end, these R, G, B components are combined using suitable triads and finally the image shown in Figure 6.4 is recovered, which indicates that the proposed method outperforms the existing methods by way of better resolution and image fidelity. Moreover, large scale ringing artifacts which significantly degrade the image quality is eliminated to a greater extent.

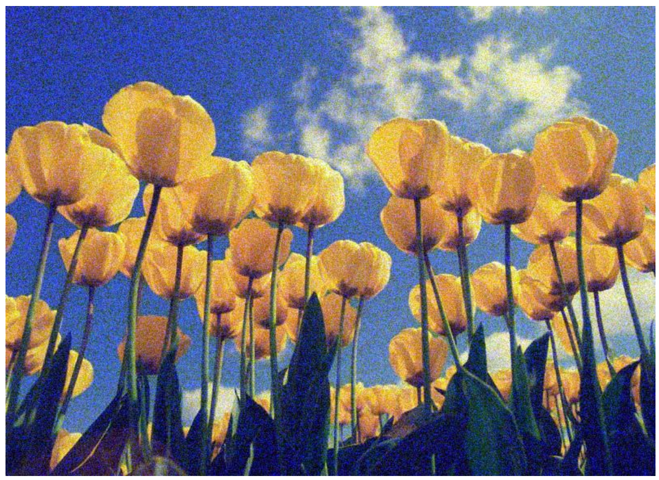

Figure 6.3 Transmitted image

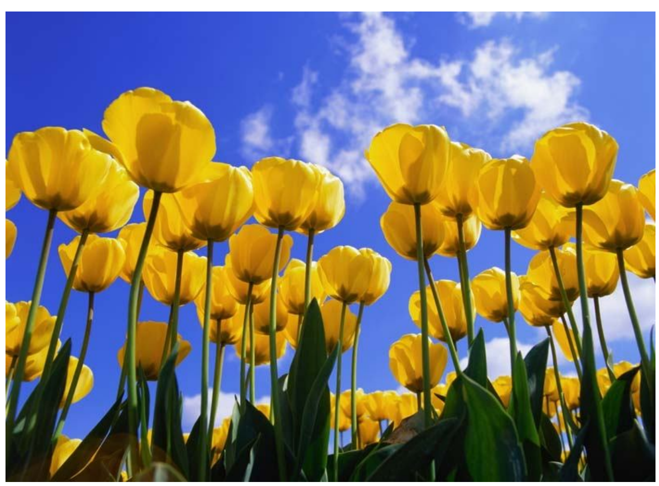

Figure 6.4 Image received using GLV architecture