TECHNISCHE
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Optomechatronics - Designing programmable optical systems based on micromirror arrays

Introduction

A variety of applications from direct laser machining to optical micro manipulation require modulated light intensity distributions on a sample plane. Energy efficiency and sometimes limited laser source power demand for phase-only light intensity modulation. Micromirror arrays are reflective devices that control the phase with a high energy efficiency. The phase distribution is a direct function of the height profile: $\phi = -2kh$, with k representing the wave number [1].

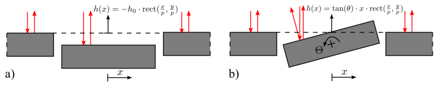

Fig. 1: Reflective phase SLM types, with respective height profiles $h(x,y)$ for a single pixel of size $p \cdot p$ [2].

An optical 4f-setup consists of two lenses and two modulators placed in the consecutive focal planes. The output field u_{out} for a 4f system is calculated from the input field u_{in} and the Fourier plane filter H with two consecutive Fourier transforms (Fraunhofer diffraction) [1]:

$$u_{\mathrm{out}}(x', y') = \mathfrak{F}\{H(f_x, f_y) \cdot \mathfrak{F}\{u_{\mathrm{in}}(x, y)\}\} \,. \tag{1}$$

Therefore, 4f approaches feature a one-to-one relationships between output intensity and input phase and no online calculation is needed. The resulting low computational complexity makes them attractive candidates for real-time applications.

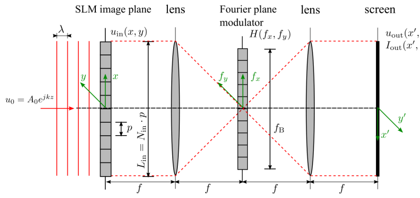

Fig. 2: Generic optical 4f setup with transmission filters [2].

Pattern Generation

Tilt micro mirror arrays (MMAs) may form a programmable grayscale mask with a static amplitude filter in the Fourier plane [3]. The input phase of the tilt mirror array is a saw-tooth phase grating, where the angle Θ_i of each pixel can be individually controlled. The grayscale output intensity is determined as a direct function of the tilt angle [2] in case the spatial amplitude filter excludes the first and higher diffraction orders from the imaging path:

$$H_{\mathrm{MMA}}(f_x, f_y) = \mathrm{rect}\left(\frac{f_x}{2\zeta p^{-1}}, \frac{f_y}{2\zeta p^{-1}}\right) \text{ with } \zeta \in \; [0, 1] \,. \tag{2}$$

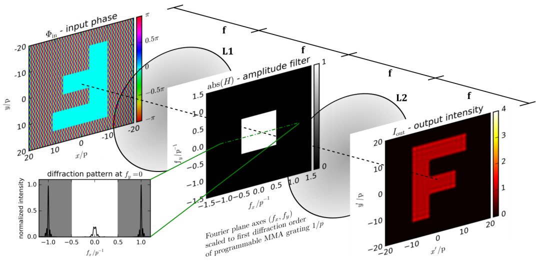

Fig. 3: Numerical image formation with a tilt-type phase modulator array. The input is illuminated with a unity amplitude plane wave and the static amplitude filter has a size of $\zeta = 0.5$ [2].

The Generalized Phase Contrast method (GPC)[4] converts a phase pattern to an intensity pattern by creating constructive interference of the modulated 'pattern wave' with the unmodulated 'background wave'. GPC light shaping applies a static phase filter in the Fourier plane acting on the zero diffraction order [4]:

$$H_{\mathrm{GPC}}(f_x, f_y) = 1 - 2\,\mathrm{rect}\left(\frac{f_x}{2\eta_x L_x^{-1}}, \frac{f_y}{2\eta_y L_y^{-1}}\right);\; \eta_x = \frac{L_x f_{\eta,x}}{2},\; \eta_y = \frac{L_y f_{\eta,y}}{2} \,. \tag{3}$$

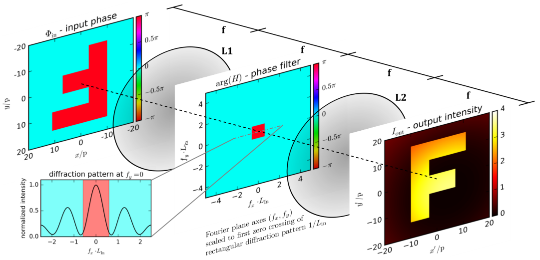

Fig. 4: Numerical simulation of pattern generation with GPC using a piston-type modulator. The static Fourier plane phase filter has the ideal size for this input pattern [2].

By using two phase-only filters, GPC may reach very high energy efficiencies for a variety of patterns [4, 2].

Generation of multiple spots

GPC may be combined with matched phase filtering, then termed mGPC [4]. This technique creates peaks of high intensity via an optical operation similar to autocorrelation. The input phase consists of a set of N identical user-specified phase correlation targets Φ_{T} (eq.(4)). The corresponding matched filter is determined by the Fourier transform of the phase target. It can be combined with the GPC filter to a single phase function (eq.(5)):

$$\Phi_{\mathrm{in}}(x, y) = \sum_{k=1}^{N} \Phi_{\mathrm{T}}(x - x_{\mathrm{p},k}, y - y_{\mathrm{p},k}) \tag{4}$$

$$H_{\mathrm{mGPC}}(f_x, f_y) = \arg\left(\mathfrak{F}(\exp(j\Phi_{\mathrm{T}}))\right) \cdot H_{\mathrm{GPC}}(f_x, f_y) \cdot \mathrm{rect}\left(\frac{f_x}{f_{\mathrm{B}}}, \frac{f_y}{f_{\mathrm{B}}}\right) \,. \tag{5}$$

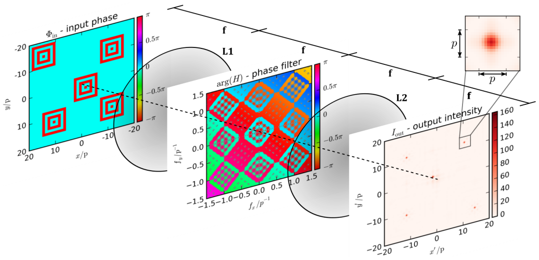

Fig. 5: Numerical simulation of mGPC with a tilt-type phase modulator in the input plane [2].

References

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[2] M. Roth, J. Heber, and K. Janschek, "System design of programmable 4f phase modulation techniques for rapid intensity shaping: a conceptual comparison," in *Proc. SPIE*, vol. 9736, 2016.

[3] T. Sandstrom and H. Martinsson, "RET for optical maskless lithography," in *Proc. SPIE*, vol. 5377, 2004, pp. 1750–1763.

[4] J. Glückstad and D. Palima, *Generalized phase contrast / applications in optics and photonics*, ser. Springer series in optical sciences. Springer, 2009, no. 146.

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