Real-time optical processor using a digital micromirror device

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A high-speed optical processing system that incorporates a digital micromirror device has application for real-time automatic target recognition and holographic data recording.

Pattern recognition using optical processors promises to be 100 times faster than state-of-the-art digital processors. However, the lack of low-cost electronic-to-optical conversion input devices (also called spatial light modulators, or SLMs) has prevented optical processors from achieving widespread commercial application.

To address this challenge, we previously developed a grayscale optical correlator (GOC) system using a 4f (frequency configuration) optical Fourier transform (FT) architecture and demonstrated its application in real-time automatic target recognition (ATR).1–3 In that design, the GOC consisted of a pair of ferroelectric liquid crystal SLMs (FLC SLMs) as the input and filter devices, a pair of FT lenses, and a CMOS sensor to detect the sharp spike(s) of light that reveal the spatial locations of the detected target(s) in the input range. We recently updated the GOC architecture using the relatively low cost, emerging digital micromirror device (DMD) developed by Texas Instruments as the SLM. The new GOC design uses a pair of DMDs to replace the FLC SLMs.4–6 In addition to their cost-effectiveness, which will facilitate both defense and commercial use of the system, the advantages of the DMD SLMs include high resolution (HD format, 1920 × 1080 pixels) and high-precision correlation operations.

Figure 1 shows a schematic diagram of the GOC architecture using a pair of DMD SLMs. Because these are reflection-type devices, the input laser beam impinging on the input SLM is reflected back toward the FT lens. The input and output laser beams each subtend an angle of 12° with the perpendicular axis of the SLM. The FT lens focuses the input beam onto the filter SLM placed at the rear focal plane. The light beam reflected by the filter SLM is inverse-transformed by the inverse FT lens. A CMOS photodetector array is placed at the output correlation plane.

Figure 2. Illustration of a data display system incorporating a DMD SLM.4 The input data with 4-bit (16 gray levels) is encoded using pulse width modulation.
Figure 3. Optical implementation of a Burckhardt-type computer-generated hologram (CGH) using a DMD SLM. (a) The digital Fourier transform of a NASA astronaut image was used as the input for synthesizing the CGH. (b) Inverse transform of the CGH. The central zero-order component was eliminated. (c) The output of the optically inverse Fourier transformed CGH. The result matches that of the simulation shown in (b).

Figure 4. Experimental testing of an analog holographic recording of a grayscale image using a DMD SLM: (a) 8-bit ‘train station’ input and (b) holographic readout.

A DMD uses pulse width modulation to achieve various levels of light intensity on each of the pixels in the DMD array (see Figure 2). The filter function is ‘complex-valued’ (i.e., it includes both the amplitude and phase component), whereas the positive ‘real-valued’ modulation scheme used by the DMD can only directly display the amplitude component. Consequently, we used a computer-generated hologram (CGH) technique to encode a complex-valued pixel into a set of positive real-valued pixels. To generate a complex-valued correlation filter that could be implemented in the DMD SLM, we employed the CGH algorithm proposed by Burckhardt, which decomposes a complex-valued function into three real and positive components.

To test our methods, we computed a CGH simulation. We used an image of a NASA astronaut—see Figure 3(a)—as the input object. We computed a Burckhardt-type CGH filter and then Fourier transformed it. Figure 3(b) shows the Fourier transformed output (the impulse response of the CGH filter). Note that the central zero-order response has been digitally removed from the output. During a follow-up experimental verification, we first downloaded the CGH filter into a Discovery 4100 DMD SLM. We then optically Fourier transformed the laser readout beam from the DMD. Figure 3(c) shows the output of the Fourier transformation. The DMD CGH output could be further improved by optimizing the optical system alignment.

We also developed an analog holographic recording scheme that uses the DMD SLM as the data input device. In our experimental investigation, we displayed an 8-bit grayscale image in a DMD SLM and recorded a hologram in a photorefractive crystal. Figure 4(a) shows the input 8-bit ‘train station’ image, and Figure 4(b) the readout holographic image.

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In summary, we designed a new high-speed optical processing system architecture using the emerging high-speed, high-resolution DMD SLM. We have also designed an optical implementable complex-valued CGH correlation filter and experimentally demonstrated its implementation using a DMD SLM. In addition, we have shown experimentally that the DMD SLM can be used as the input device for a real-time holographic data recording system. Our results suggest, for the first time, that DMD SLMs can be used effectively to synthesize complex-valued optical spatial filters, including correlation and bandpass filters. As a next step, we are investigating system implementation of our optical processor.

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References