An optical multiplier setup with dual digital micro-mirror array devices

Hui-feng Liu*, Yun-long Ma, San-wen Li and Yong-ming Nie
Satellite Maritime Tracking and Controlling Department, Jiangyin, Jiangsu, China, 214431

* Corresponding author: Liuhuif@mail.ustc.edu.cn

Abstract. An optical multiplier setup is demonstrated. The key of the setup is the dual digital micro-mirror array devices which can afford optical vectors by properly designing. The output light passing through the mirror arrays and lens is collected by a CCD camera which outputs the calculating result.

1. Introduction
Optical computing has very good properties in parallel data process, which can be 10^3 faster than the electric calculating method and has been widely used in areas such as numerical calculation, information management, process control, supplementary system and artificial intelligence. Early in 1978, J. W. Goodman had proposed theory model of the optical vector matrix multiplier and used in pulse beam shaping, spectral analyzing and filtering [1]. Based on that model many novel setups were demonstrated [2-5]. More than ten years later, E. P. Mosca designed an acousto-optic optical multiplier, which can finish calculating vectors with 128 multiplying 128×128 matrix fastly as 8×10^5 per second and correctly. The setup is too big and optical efficient is low [6]. Using large scale integrated circuit technology Matthias Gruber designed planar-integrated optical multiplier, which had good properties with low crosstalk [7-9]. In 2004 Lenslet Company generated Elight256 products which are the first digital vector processing with optical heart. The information transmission distortion is small, and the energy consuming is much little. In this manuscript, we designed an optical multiplier setup that can be also used as an optical logic operator is demonstrated. The key of the setup is the dual digital micro-mirror arrays which can afford optical vectors by properly designing. The output light passing through the mirror arrays and lens is collected by a CCD camera which outputs the calculating result. Experimental results indicate that the setup can realize optical logical operator function effectively.
2. Theory analysis

The key theories are the optical vector-matrix multiplier calculating formula and the digital micro-mirror device working principal, which will be given in the following.

2.1. Theory of the optical vector-matrix multiplier

Based on the model proposed by Goodman as shown in Fig. 1 the calculating formula can be written as following.

\[ c_i = \sum_{j=1}^{n} a_{ij} b_j, \quad (i = 1, 2, \cdots, m) \]  

(1)

The setup is composed by the following elements. An optical source array provides the light. A lens collimates the beam. Two cylinder lenses and spatial light modulator and detector are also important devices. Vector B with n-dimension is presented as \( b_j \). Matrix A with \( m \times n \) dimensions is presented \( a_{ij} \).

![Figure 1. Schematic of optical vector-matrix multiplier, S presents optical source, L presents lens, CL presents cylinder lens, SLM presents spatial light modulator and D presents detector.](image)

2.2. Principal of the digital micro-mirror device

The digital micro-mirror device is a novel reflecting spatial modulating with high energy efficiency which may be higher than 25\%. The micro structure and diffraction properties are shown in Fig. 2.
Figure 2. Schematic of single DMD micro mirror working principal. (a) is normal state, (b) is ‘on’ state, and (c) is ‘off’ state.

The light inclined irradiating the mirror, when the DMD is working on ‘normal’ state, the mirror is horizontal. When the DMD is working on ‘on’ state, the mirror has angle with horizontal. When the DMD is working on ‘off’ state, the mirror has angle with horizontal. It is just when the DMD is working on ‘on’ state the light can reach the object detector. The DMD diffraction optical intensity distribution schematic is shown in Fig.3.

3. Experimental results
In order to analyze the feasibility of using DMD as the spatial light modulators in the optical vector matrix multiplier system, on the basis of the primary structure and principle of the digital micro-mirror device and the optical vector matrix multiplier, an optical vector matrix multiplier system which introduces two digital micro-mirror devices is proposed as shown in Fig.4. In the system both the input of the optical vector and the matrix is finished by the digital micro-mirror devices.
The key of the setup is the optical vector designing, which is shown in Fig.5. In this manuscript several kinds of optical vectors and corresponding experiments are given. As shown in Fig.5, the first vector is generating when the light passes through the DMD1 and the first step of the multiplier is accomplished when the light passes through the second DMD. At last, when the output light is collected by the CCD, the result is given.

The input light is He-Ne laser with 2mm diameter at 632.8 nm central wavelength. After expanded by a pair of lenses the beam diameter is 10mm. Then the light incidents on the DMD1 which is loaded the information as shown in the left part of Fig.5. The reflected light
after DMD1 is the incident light to DMD2 which is loaded the information as shown in the right part of Fig.5. At last the output light is collected by a CCD camera.

The theoretical and experimental results are shown in Fig. 6. The experimental results are average values after ten times experimentations.

**Figure 6.** Schematic of the vectors generated with DMD. The left vector presents 01001 and the right vector presents 01010.

Vector 01001 multiplies vector 01010 and the result is 01000 as shown in Fig. 6(a). The experimental results are shown in Fig. 6(b). It can be easily found that though the result is zero, there is still light being detected, which is caused by diffraction by the optical devices. However, when the optical intensity is quantified according to proper scales and properly deal with the dirraction interfering, results with high precision can be obtained.

4. Conclusions

In this manuscript an optical multiplier setup that can be also used as an optical logic operator is demonstrated. The key of the setup is the dual digital micro-mirror arrays which can afford optical vectors by properly designing. The DMD is working in reflecting form, so the energy efficiency is high than normal liquid crystal spatial light modulators. The output light energy efficiency can be about 25%. By theory analyzing and experiments, we gain the optical properties of the DMD and the influence on the system introduced by the DMD. The results we gain are in accordance with the anticipation. It is proved that by matrix-coding and orderselecting the influence of diffraction and interference can be reduced a lot. These conclusions are meaningful for the designation and coding methods of the optical vector matrix multiplier. They are useful for the study of the key applications of the optical multiplier and have some significance for the designation of the optical vector matrix multiplier.

Acknowledgements

The authors acknowledge Doctor Yun-fei Mao and Jia-li Liao for fruitful discussions.

References

[1] Goodman J W and Diaz A R 1978. Opt Lett 2 1
[2] Gruber M, Jahns J and Sinzinger S 2000 Appl. Opt. 39 5367
[3] Atthale R A and Lee J N 1984 Proc. IEEE 72 931
[4] Caulfield H J, Rhodes W T, Foster M J and Horvitz S 1981 Opt. Commun. 40 86
[5] Carlotto M and Casasent D 1982 Appl. Opt. 21 147
[6] Reif J H and Oshida A Y 1993 Appl. Opt. 32 159
[7] Mosca E P, Griffin R D, Pursel F P and Lee J N 1989 Appl. Opt. 28 3843
[8] Ibrahim T A, Amarnath K, Kuo L C and GroverVan V 2004 Opt. Lett. 29 2779
[9] Barros S, Guan S and Alukaidey T 1997 Journal of System Architecture 43 391