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# Overcoming practical limitations of Even Order Missing gratings and Diffractive Optical Elements to improve diffraction pattern fidelity and contrast in machine vision applications.

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## Summary

We show how inevitable Diffractive Optical Elements (DOEs) fabrication imperfections lead to parasitic orders in the diffraction patterns of Even Order Missing (EOM) gratings and DOEs, limiting the attainable pattern signal to noise ratio (SNR) in machine vision applications. Using odd pixel numbered target patterns is then shown to be a highly effective simple way of eliminating the problem.

## Introduction

Spot array generators or array illuminators (AIL) used to transform a laser beam into a regularly spaced array of uniform light spots are one of the most widely used types of DOEs. However, it is remarkable that the vast majority of commercial AILs produce arrays with odd numbers of spots. To produce arrays with even numbers of spots the special EOM geometry must be used [1]. The particular arrangement of DOE periods in this approach causes the even numbered orders to be suppressed. However, in practice this suppression is not complete and weak parasitic orders generally appear between the desired spots (Fig.1) – hence the preponderance of odd numbered spot arrays in commercial AILs.

In our presentation we will describe our investigations into the practical causes behind the apparition of these parasitic orders through digital simulations of diffraction by EOM gratings and experimental verifications. These simulations indicate that for a perfect EOM type DOE the even orders are indeed completely suppressed. However if DOE fabrication limitations are taken into account by oversampling the DOE structure and allowing for proximity effect pixel rounding then the parasitic orders do indeed appear. Such limitations are present in all DOE fabrication technologies, only the extent of the effect varies with the different technology used.

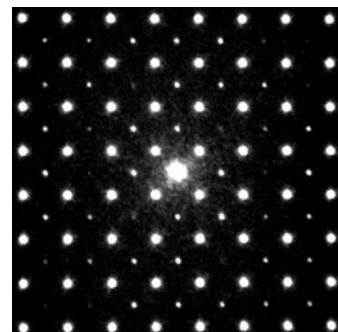


Fig.1. 8x8 spots array generated by an EOM DOE illustrating the apparition of weak parasitic orders (overexposed image to facilitate viewing)

## Discussion

Figure 2 shows a graph of how the SNR (ratio between the total power in the desired spots and the total power in the parasitic spots between the signal spots) varied in these simulations with the total number of spots – the inter-spot angular separation remaining constant – for a given fabrication technology and its limitations. Here the fabrication technology modelled and used for the experimental verifications was our in-house parallel direct-write technique [2], currently with a 750nm address grid, and

write spot modelled as a 750nm wide Gaussian spot. For a perfect, theoretical EOM type DOE the SNR is practically infinite (numerical simulation noise only) but that as soon as real DOEs with fabrication limitations are taken into account, the parasite spots appear and the SNR decreases significantly with increasing numbers of array spots. In the case studied here, the SNR reaches unacceptable levels (visible on an 8 bit camera when signal spots are just below saturation) above 48×48 spots. More importantly we will show that this problem is not restricted to even spot AILs, but to all DOEs (particularly binary phase DOEs) with target images containing even numbers of pixels.

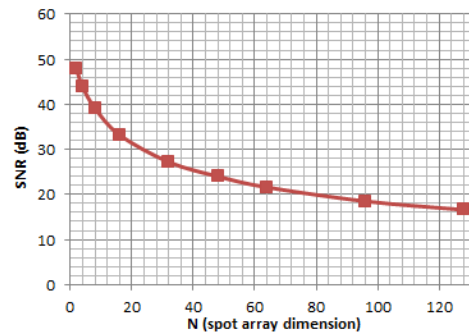


Fig.2. SNR vs total number of spots for real (fabrication errors) EOM type DOEs.

In particular we will show how the problem is linked to the well-known recentering problem of the DFT algorithms used to design DOEs: the zero frequency appears in pixel [0,0] whereas the zero optical spatial frequency is on the optical axis in the centre of the output plane (Fig. 3). To correct this difficulty, algorithms reorder the pixels in the DOE target plane, circularly shifting them by  $(N/2, N/2)$  pixels [3]. However, this pixel shifting can only be done to an accuracy of 1 pixel so odd numbered target images are generally required – otherwise the conjugate image and desired image do not overlap correctly. To generate even pixel numbered target patterns, EOM type DOEs should be used as for the AIL DOEs. However, as indicated above parasite image points then arise, decreasing pattern fidelity and contrast, particularly for large or complex target patterns. In our presentation we illustrate how taking these points into account has allowed us to improve DOE performance in an industrial biometric verification machine vision application.

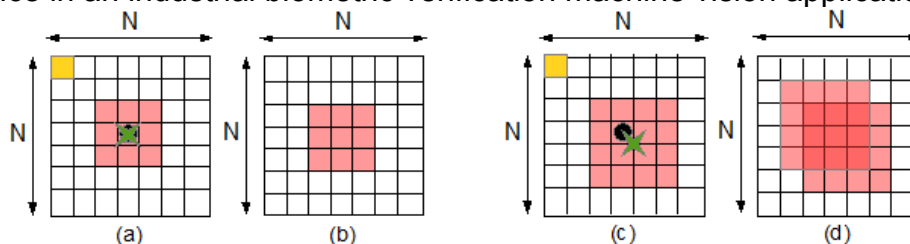


Fig.3. Optical DFT recentering problem. Yellow pixel and black dot represent DFT centre and optical DFT centre pixels respectively. Green cross indicates the centre of the target image. A binary phase DOE with a target image with an odd number of pixels (a) produces a perfect reconstruction in the output plane (b), whereas an even pixel number target image (c) results in an imperfectly centred reconstruction (d).

## Conclusions

Fabrication technology limitations lead to the apparition of parasite diffraction orders in EOM gratings and DOEs, adversely affecting output pattern SNR. In most practical applications the simplest effective solution is often to use odd pixel number targets.

## References

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- [3] D.G. Voelz, Computational Fourier Optics: a MATLAB tutorial, SPIE Tutorial Texts Series, Vol. TT89 (2011)