Using Wavefront Coding in presence of non-symmetric aberrations

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***Abstract*—Wavefront coding is a hybrid technology designed to increase depth of field of conventional optics but it can also be used to compensate for other aberration and ease tolerancing. The goal of our research is to apply this technology to panoramic imager. Panoramic imagers suffer from an increase level of aberration due to the large field of view and it is also subject to a special tolerance process. They also typically have a wide variation of the point spread function (PSF) across the field of view and suffer from non-symmetric aberration like coma and astigmatism. To obtain the best result using wavefront coding, the PSF should be as invariant as possible over the whole field of view. Asymmetric phase masks, when used in systems having non-negligible asymmetric aberrations, generate variations in the final image quality. For that reason, a model that predicts the final image quality of wavefront coded system is needed. The possibility of using two surfaces for wavefront coding has been studied. The final results were analysed using a variance based image quality criterion. From these results, it is possible to optimize phase mask for panoramic imager and predict the resulting image quality.**

Keywords-component; Wavefront coding; wide angle; Panomorph

I. INTRODUCTION

Wavefront coding was developed as a mean to increase depth of focus of conventional optics [1]. By introducing a phase mask in the pupil of the system, it is possible to make the PSF invariant to a certain amount of defocus. The resulting system has an increased depth of focus but a lower resolution. The resolution can then be brought back to an acceptable level or even, in certain case, improved from the original system [2], by the use of deconvolution algorithm. This technique is generally used in conventional system where the most important aberration is often the scene defocus. This is not the case for panoramic imagers because the short focal length generally leads to less scene defocus but the large field of view often leads to more aberrations. These systems could regardless be improved because some of these aberrations are focus related aberrations (like astigmatism and field curvature). Moreover, the post-processing phase required in wavefront coding would be easily implemented since image processing is already used with most panoramic imager in order to compensate for distortion. The important variation of the PSF across the field of view and the importance of non-symmetric aberration remains a problem. Deconvolution is optimum if the filter PSF is the same as the PSF that generated the image. If the two PSF are significantly different the reconstructed image is going to be degraded. How and how much the image is to be degraded by that effect remains to be seen. That is why, in order to apply wavefront coding to panoramic imager, we need to be able to predict the image quality.

II. IMAGE QUALITY OF WAVEFRONT CODIGN SYSTEM

A reliable criterion is needed to assess the quality of the image. The modulation transfer function (MTF) of the final image cannot be used in this case because of the artifacts and noise amplification. These effects are difficult to evaluate with the MTF but they create the most important degradation of the image. For example, a system with heavy replication artifact which deforms the image may have an excellent MTF. So in the case of reconstructed image, the variance of the image compare to the object is better suited. Using the normalized illumination, we calculate the variance by subtracting the value of each pixel in the image with the corresponding pixel in the object. This value is then squared and averaged. Of course, this criterion is to be used only for simulated system as the object is not readily available otherwise.

III. SET UP

The system studied is a Panomorph type lens [3] modified with by a phase surface at the stop and the optimization of the last surface. PSF generated at different fields are convoluted with the object (with the optional the addition of noise) and then deconvoluted using the central (0 degree field angle) PSF. The variance of the final image from the object is then calculated.

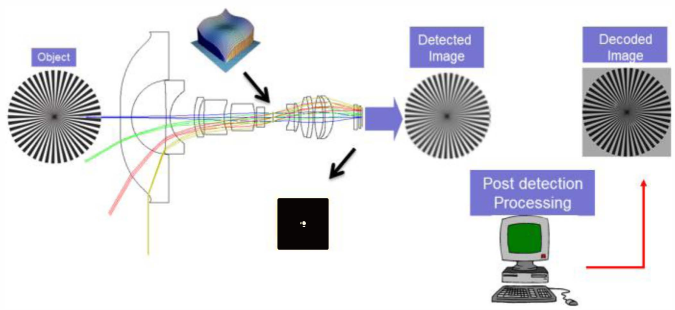

Fig. 1 Schematic of the set up.

IV. Optimization

The goal of the optimization is to minimize the difference in MTF for multiple fields of view while maintaining the MTF sufficiently high. In this regard, the second surface is useful because the phase mask can only add a certain quantity of aberration to the whole system as shown on figure 2. In order to affect the different field independently the other surface used is very close to the detector.

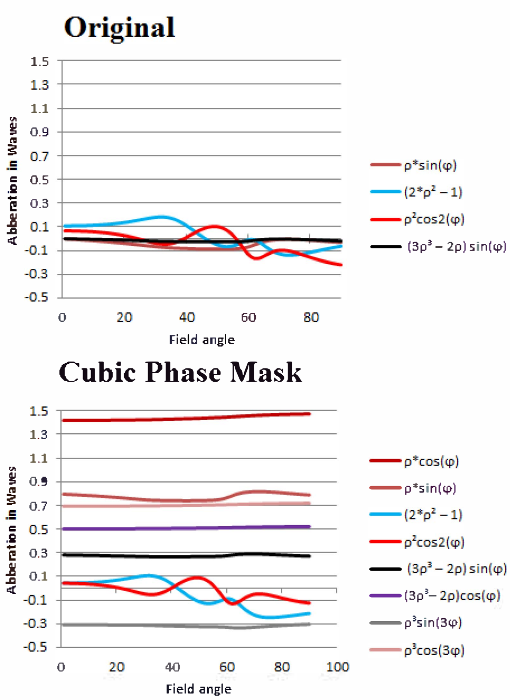

Fig. 2 Zernike aberrations as a function of the field for the original system and the system with a cubic phase mask. The phase mask adds various aberrations but they are almost independent on the field of view.

V. Results

Figure 3 shows that distributed wavefront coding brings MTF closer to each other. The mean variance of the selected fields of view (FOV) for the optimized phase mask is 0.0130 while the optimization of the two surface helped lower this to 0.0106 for the same FOV. In some specific FOV, heavy artifact can produce variance up to 0.3 in both cases. The phase mask alone is limited in its capacity to eliminate the artifact while maintaining a good MTF but even in the case of distributed wavefront coding some artifact remains.

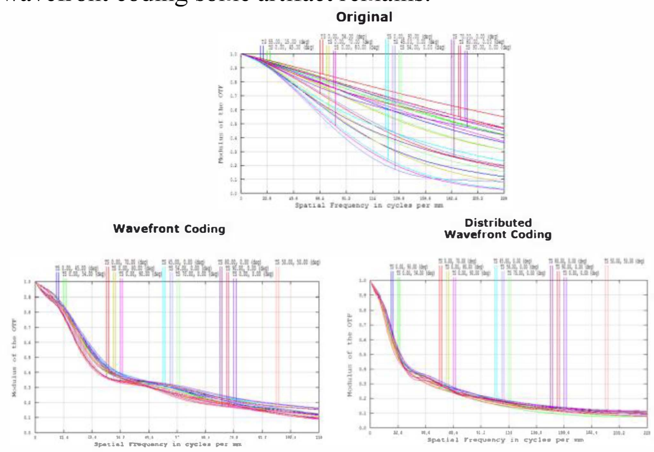

Fig. 3 MTF of the original and modified system.

VI. Conclusion

The non-symmetrical aberrations that characterize a Panomorph system increase the likelihood of artifacts in the final reconstructed image. Distributed wavefront coding can reduce artifacts by correcting non-symmetrical aberrations. However, the method used for optimization cannot account for these artifacts, and so, trial and error must be used and the system is too complex to make this an effective technique. A better optimization method, like one based on object variance instead of the system's MTF, should be used. Work is in progress to implement such a method for this case.

References

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