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MSFLib: A Data Library of Mid-Spatial Frequency Surface Errors for Optical Modeling and Specification

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Abstract: We describe the development of a data library of mid-spatial frequency surface errors for optical components. This resource enables better understanding of specification of mid-spatial frequency surface errors and their connections to optical performance.

1. Introduction

Residual mid-spatial frequency (MSF) surface errors are consequences of sub-aperture manufacturing methods used for the fabrication of radially symmetric and freeform optics that degrade optical performance [1–3]. Deterministic MSF errors can nominally be classified into raster, radial, and azimuthal distributions [4] but can also be more complex, as shown by the range of experimental examples in Fig. 1. The large variety of potential MSF distributions makes it challenging to specify and tolerance MSF surface errors, so access to a range of MSF data examples is desirable for modeling and exploration.

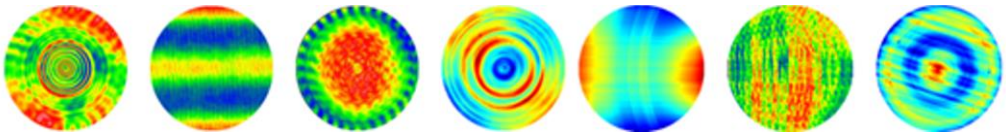


Fig. 1. Experimental samples of MSF surface errors from sub-aperture manufacturing. Modified from the original figure in [5].

To address this issue, the Center for Freeform Optics (CeFO) is developing a data library containing a variety of MSF errors to serve as a resource for optical designers, manufacturers, and metrologists. The MSF library currently contains 38 samples over four manufacturing processes and five metrology methods. While we note that a profile data library has previously been developed in the x-ray mirror community [6], our data library focuses on additional areal measurements and metrics for optical components at visible and infrared wavelengths. We describe the composition of the data library entries below.

2. Methods

Each entry of the data library consists of multiple sections. The *identification* section includes images of surface height maps of the surface (raw and processed if available), whether the surface is real or synthesized, the data resolution, and the aperture shape and size. Filename formats are also included, such as .dat files (for MX), .int files (for CODE V), and .mat files (for MATLAB). An example of this section is shown in Fig. 2.

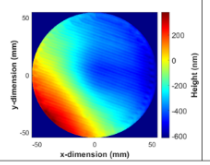
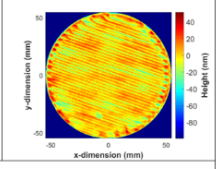
Image of Raw Surface and Processed Height Map (nm)	Raw Surface 	Processed Surface 
Surface type (real/synthetic)	Real	
Resolution (pixels) and pixel size (microns)	733x733 pixels and 148.7 x 148.7 microns	
File: Raw Surface data (MATLAB)	Surface1.mat	
File: Processed Surface Data (MATLAB)	Surface1_36zernikeremoved.mat	
File: Raw Surface data (MX)	1_Int_Pre.dat	
File: Processed Surface Data (MX)	1_pre_int_36zernikesremoved.dat	
Optical Aperture Geometry	Circular	
Aperture Dimensions (mm)	109 mm, diameter	

Fig. 2. Example of identification section.

The *fabrication* section identifies the general manufacturing process and when available the machine that resulted in the MSF surface error. The tool path is also identified, as it has been found that the MSF signatures resulting from different tool paths influence the severity of image performance degradation [7]. The *metrology* section describes the measurement method and equipment (if applicable). Hardware and software settings are specified, and any post-

processing or filtering used to connect the raw and processed surface data are noted. In addition, the filenames of any other relevant surfaces are stated if this surface is part of a process chain. The *surface metrics* section describes the basic statistics (PV and RMS surface error) as well as a range of areal surface metrics that can be used to specify and make connections to optical performance. Current areal surface metrics for each entry include: the polar RMS plot [7], the areal power spectral density (PSD) in both cartesian and polar formats [8,9], a fitting of the surface using the Rapidly Decaying Fourier (RDF) series N_b=1 [10], and moments of the Pupil-Difference Probability Density (PDPD) [11]. Samples of representative areal surface metrics are shown in Fig. 3.

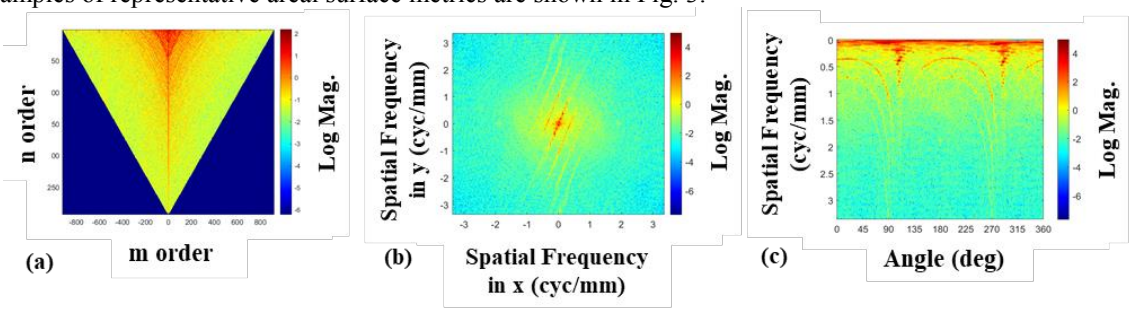


Fig. 3. Example areal surface metrics from the processed surface in Fig. 2. (a) RDF coefficient map, (b) cartesian areal PSD, and (c) polar areal PSD.

The *special notes* section includes any additional information that could prove helpful. Typical examples include technical drawings or any other details that do not fit into the definitions of the other sections. Finally, each entry contains multiple data files for both the surface data and the calculated areal surface metrics.

3. Discussion

We have described the development of a library containing areal surface data and metrics and information on manufacturing and metrology for a wide range of MSF surface error distributions. This library is intended to serve as a resource for optical designers, manufacturers, and metrologists by providing a range of MSF distributions seen in sub-aperture manufacturing and providing areal surface metrics for complex MSF surface errors that enable optical performance evaluation. Work is underway on adding additional MSF patterns, areal surface metrics, and connections to optical performance.

4. Acknowledgments

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5. References

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