Optical Engineering

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Freeform Optics

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The use of freeform surfaces in optical system design has evolved from a largely theoretical concept into a fully fledged viable technology capable of solving previously intractable problems. The process of designing real systems with freeform optics, which are now commonly used in commercial optical systems, has been made possible through new developments in many areas, including the fundamental mathematics of shape description, advances in design methods, tolerancing techniques, and simulation tools. In particular, a major catalyst in opening this new practical solution space has been the availability of new manufacturing and testing methods.

Both imaging and nonimaging systems can benefit from freeform optics. Illumination systems employing freeform optics can be found in streetlights, automotive headlights, secondary optics for LEDs, and laser beam shaping. Freeform optical components are also becoming more common in traditional imaging systems. They offer additional degrees of freedom for aberration correction, reduced size and weight, and otherwise improved system performance.

This special section includes contributions advancing the tools and techniques available to design freeform surfaces, shows examples of using freeform surfaces in optical systems, and demonstrates fabrication methods used to reduce the designs to practice.

Several papers cover methods to determine freeform surface shapes. Canavesi et al. advance the supporting ellipsoids reflector design method using a new flux estimation technique. Oliker provides an explicit set of differential equations to design a single freeform lens that achieves a prescribed irradiance distribution. Tsai et al. propose a freeform surface construction technique that combines grid mapping and local differential equation solutions. Abd El-Maksoud et al. extend paraxial theory to systems with plane symmetry and apply the theory to generalize the Scheimpflug principle.

Two papers take on the task of evaluation of design methods and systems. Hicks et al. explore properties of the simultaneous multiple surface (SMS) design method for systems using two freeform reflectors. Herkommer relates phase space transformations to geometric aberrations in order to deduce the impact of freeform optics in both imaging and illumination systems.

Deployment of practical systems includes fabrication and testing of the system components. Su et al. apply a software configurable optical test system (SCOTS) based on deflectometry to accurately measure precision freeform surfaces and demonstrate the tool with measurements on two astronomic mirrors. Challita et al. explore the use of freeform mirrors in astronomical instruments and present a new manufacturing method based on hydroforming. Rossi et al. use electroforming to construct an off-axis toroidal aspheric three-mirror anastigmat and evaluate the applicability of the technique.

Finally, Boye et al. employ freeform surfaces in the design of an all-reflective head-mounted binoculars surpassing the performance of conventional designs.

This special section clearly cannot cover all of the work currently underway in this field, but it does provide a reasonable view of the range of activity from fundamental design to fabrication and testing to deployment of optical systems. The work presented here deals with more traditional optical system applications by exploring the newly expanded trade space made possible by freeform optics. It is exciting to consider the fact that we will with almost near certainty be applying these tools to previously unheard-of applications, requiring completely new optical system architectures that fully exploit freeform surfaces to expand the boundaries of what optics can do.

G. Groot Gregory received degrees in physics, mathematics, and a master's in optics from the University of Rochester. He joined Optical Research Associates, now Synopsys, in 2007 where he is the LightTools Product Manager. His interests in optics include optical design and analysis software, the design and deployment of optical instrumentation, and the promotion of science though professional society involvement and education outreach. He is a Fellow of SPIE.

Craig Olson received a BS in electrical engineering from Georgia Tech and a MS and PhD in optics from the University of Rochester. Since 2005 he has worked as a principal engineer for sensor systems at L-3 Communications, focusing on optical technologies and design methods that enable novel multispectral imaging systems. He is a Senior Member of SPIE.

Florian Fournier received his PhD in optics from the University of Central Florida in 2010, and a MS in optics from the Institut d'Optique in 2005. He is currently an optical software engineer in the Optical Solutions Group at Synopsys, working on the development of the illumination design software LightTools. His research focuses on the design and fabrication of freeform surfaces for illumination systems.