Origami Optics

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1. Introduction

With smaller, slimmer and lighter cameras in high demand for consumer portable devices and military applications, optics is challenged with the question- how can we make optics smaller without giving up the functionality associated with larger cameras? A big part of the problem is simply scalability. As conventional imaging systems are scaled down, the focal length (i.e. magnification) scales down with the allowed optical thickness. Being additionally limited by the size of the smallest available image sensors, we find that these cameras are usually limited to short focal length, small aperture lenses- what you find in the majority of cell phones. While fine for many applications, there are others, such as surveillance and high-end portable device cameras that could benefit dramatically from larger magnification and better light collection with minimal added bulk or thickness.

With up to eight reflections, large ray angles, a thin aspect ratio and a large field of view (for a reflective design); “origami optic” designs can be seen as a somewhat extreme extension of traditional reflective telescope design. Light enters the optic through an annular aperture and is reflected or "folded" multiple times within the optical thickness. Compared to a refractive lens, where light propagates in one direction as it is focused to the image plane, the multiple-reflection geometry reflects or "folds" the optical path multiple times back onto itself and allows for greatly reduced overall thickness for a given focal length.

The enabling technology for this type of optical design is single-point diamond turning (SPDT). The recent maturity of SPDT for visible light optics in addition to its ability to maintain tight tolerances and fabricate complex surface shapes makes it a nearly ideal fabrication method for our designs.

2. Demonstration

For our tech demo at SIGGRAPH 2008, we will demonstrate our four-reflection or "fourfold" camera prototype shown in Figure 1. This prototype design has an 18 mm focal length, field of view of 16.6º, effective F/# of 1.1, diameter of 28 mm and an optical thickness of just 5.5 mm. The optical element is fabricated as two Calcium Fluoride parts pressed together with index-matching gel and a nominal separation of 300 µm. This gap is made adjustable by a 120 pitch, 128 tooth focus adjusting gear and a 12 tooth pinion to provide fine linear translation of the gap.

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This adjustment allows for an extremely sensitive method of refocus where less than 40 µm of travel is required to refocus the optic from close range to infinity. The small travel of this focus adjustment may be especially suitable for use with a voice coil or a piezoelectric actuator in future prototypes.

The sensor used in the four-reflection prototype is a ¼-inch Forza/Sunplus 1.92 Mpixel CMOS color sensor interconnected via ribbon cable to a USB interface PCB. MDOSim- a custom software interface created by Distant Focus Corporation is used to control the sensor and capture image/video data with a laptop computer.

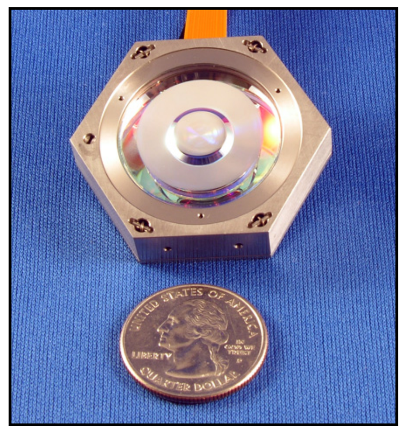

Figure 1. A four-reflection origami optic prototype

3. Conclusion

Origami Optics may play an effective role in achieving larger magnification, optical zoom functionality and better light collection in space-constrained applications such as tomorrow's high-end cell phones and micro-UAV imagers. The compact, thin form and long focal length of Origami Optics makes it an attractive approach for applications where the additional bulk and thickness of refractive optics is problematic.

This research was supported by DARPA via the MONTAGE program, grant no HR0011-04-I-0045; and by the Natural Sciences and Engineering Research Council of Canada (NSERC) through a graduate student scholarship.

SIGGRAPH 2008, Los Angeles, California, August 11–15, 2008.
ISBN 978-1-60558-466-9/08/0008