

ROUTING AND ACTION

MEMORANDUM

ROUTING

TO:(1) Electronics Division (Clark, William)

Report is available for review

(2) Proposal Files Report No.: -DRP

Proposal Number: 58269-EL-DRP.10

DESCRIPTION OF MATERIAL

CONTRACT OR GRANT NUMBER: W911NF-10-1-0214

INSTITUTION: Columbia University

PRINCIPAL INVESTIGATOR: Shree Nayar

TYPE REPORT: Final Report

DATE RECEIVED: 2/11/14 4:27PM

PERIOD COVERED: 7/1/10 12:00AM through 6/30/12 12:00AM

TITLE: Final Report: Imaging System Using Shared Optics and Aberration Exploitation

ACTION TAKEN BY DIVISION

(x) Report has been reviewed for technical sufficiency and IS ☒ IS NOT ☐ satisfactory.

(x) Material has been given an OPSEC review and it has been determined to be non sensitive and, except for manuscripts and progress reports, suitable for public release.

(x) Performance of the research effort was accomplished in a satisfactory manner and all other technical requirements have been fulfilled.

(x) Based upon my knowledge of the research project, I agree with the patent information disclosed.

Approved by SSL\WILLIAM.CLARK on 2/20/14 10:50AM

ARO FORM 36-E

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188		
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1. REPORT DATE (DD-MM-YYYY) 11-02-2014		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 1-Jul-2010 - 30-Jun-2012	
4. TITLE AND SUBTITLE Final Report: Imaging System Using Shared Optics and Aberration Exploitation				5a. CONTRACT NUMBER W911NF-10-1-0214	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 0H20BH	
				5d. PROJECT NUMBER	
6. AUTHORS C. Zhou, O. Cossairt, D. Miaou, S.K. Nayar				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES Columbia University 615 West 131st Street Room 254, MC 8725 New York, NY 10027 -7922				8. PERFORMING ORGANIZATION REPORT NUMBER	
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13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT The resolution of a camera system determines the fidelity of visual features in an image. Higher resolution implies greater fidelity, and thus greater accuracy when performing automated vision tasks such as object detection, recognition, and tracking. However the resolution of any camera is fundamentally limited by geometric aberrations. In the past it has generally been accepted that the resolution of lenses with geometric aberrations cannot be increased beyond a certain threshold. In this work we aim to overcome this limitation and demonstrate very high resolution imagery for aberrated lenses through the use of hybrid optical and image processing design.					
15. SUBJECT TERMS Gigapixel Computational Imaging, Computational Cameras, Spherical Optics					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Shree Nayar
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 212-939-7092

Report Title

Final Report: Imaging System Using Shared Optics and Aberration Exploitation

ABSTRACT

The resolution of a camera system determines the fidelity of visual features in an image. Higher resolution implies greater fidelity, and thus greater accuracy when performing automated vision tasks such as object detection, recognition, and tracking. However the resolution of any camera is fundamentally limited by geometric aberrations. In the past it has generally been accepted that the resolution of lenses with geometric aberrations cannot be increased beyond a certain threshold. In this work we aim to overcome this limitation and demonstrate very high resolution imagery for aberrated lenses through the use of hybrid optical and image processing design.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u>	<u>Paper</u>
05/15/2012 6.00	Oliver S. Cossairt, Daniel Miao, Shree K. Nayar. Scaling law for computational imaging using spherical optics, Journal of the Optical Society of America A, (11 2011): 0. doi: 10.1364/JOSAA.28.002540
05/15/2012 2.00	Changyin Zhou, S. K. Nayar. Computational Cameras: Convergence of Optics and Processing, IEEE Transactions on Image Processing, (12 2011): 0. doi: 10.1109/TIP.2011.2171700
TOTAL:	2

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u>	<u>Paper</u>
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TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

05/15/2012 4.00 Oliver S. Cossairt, Daniel Miao, Shree K. Nayar. Gigapixel Computational Imaging, 2011 IEEE International Conference on Computational Photography (ICCP). 08-APR-11, Pittsburgh, PA, USA. : ,

TOTAL: 1

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Shree Nayar, Elected to American Academy of Arts and Sciences, 2011.

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	Discipline
Oliver Cossairt	1.00	
Daniel Miao	1.00	
Changyin Zhou	1.00	
FTE Equivalent:	3.00	
Total Number:	3	

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Oliver Cossairt	1.00
FTE Equivalent:	1.00
Total Number:	1

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Shree K. Nayar	0.00	Yes
FTE Equivalent:	0.00	
Total Number:	1	

Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Daniel Miao

Total Number: 1

Names of personnel receiving PHDs

NAME

Oliver S. Cossairt

Total Number: 1

Names of other research staff

NAME

PERCENT SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

We have derived an analytic scaling law that shows that, for lenses with spherical aberrations, resolution can be increased beyond the aberration limit by applying a post-capture deblurring step. We have also shown that resolution can be further increased when image priors are introduced

In Year I, we developed our scaling law based on empirical evidence about the PSF properties of ball lenses. We used our scaling law to design and build a spherical lens imaging system with very high resolution (gigapixel). We demonstrated proof-of-concept operation by sequentially scanning a sensor to multiple locations behind the ball lens, producing several high quality gigapixel images. In Year II we further analyzed the properties of ball lenses, deriving analytic expressions for the PSF and MTF of ball lens systems, deriving a rigorous theoretical basis for our empirical observations in Year I. In addition, we studied the tradeoff between lens complexity and deblurring performance for monocentric ball lens systems. Our observations indicate that there is a law of diminishing returns when increasing the complexity of ball lenses by introducing the number of discrete optical elements (i.e. spherical shells manufactured from different materials). Future work will investigate if similar principles apply of general, non-monocentric imaging systems as well.

Technology Transfer