

COMPUTATIONAL IMAGING FOR DEFENCE APPLICATIONS: UNCONVENTIONAL METHODS FOR PSF ENGINEERING AND ESTIMATION

MAHENDRA PRATAP SINGH



DEPARTMENT OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY DELHI

MAY 2026

© Indian Institute of Technology Delhi (IITD), New Delhi, 2026

Computational Imaging for Defence Applications: Unconventional Methods for PSF Engineering and Estimation

by

Mahendra Pratap Singh

Department of Physics

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



Indian Institute of Technology Delhi

MAY 2026

Dedicated to
The Creator, The Mentor and The Curator

Certificate

This is to certify that the thesis entitled "**Computational Imaging for Defence Applications: Unconventional Methods for PSF Engineering and Estimation**", submitted by **Mahendra Pratap Singh** to the Department of Physics, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**. This thesis is a bonafide record of the research carried out by him under my guidance and supervision. In my opinion the thesis has reached the standards fulfilling the requirements for the submission relating to the degree.

The results contained in this thesis have not been submitted in part or in full to any other Institute or University for the award of any degree or diploma to the best of our knowledge.

Prof. Kedar Khare

Department of Physics,

Indian Institute of Technology Delhi.

Date:

Acknowledgements

The journey of Ph.D. has been a great learning experience and a lot of people supported me during this period. I take this opportunity to thank all of them for their kind support. First of all, I express my sincere gratitude to my thesis supervisor Prof. Kedar Khare for giving me the opportunity to work on this research problem. Starting from the problem formulation to the completion of thesis, I have gained a lot of insight through the discussions with him. His great analysis capability and problem-solving approach have been the inspiration and motivation for me throughout the research work. I would like to thank him for his invaluable guidance, constant encouragement, and insightful feedback. His expertise, patience, and dedication greatly contributed to the successful completion of this thesis. I am deeply thankful for the time and effort invested by him mentoring me. It has been an excellent learning experience under his supervision. I would also like to thank Prof. Anurag Sharma, Prof. P. Senthilkumaran, Prof. Gufran Sayeed Khan and Prof. Bhaskar Kanseri for their valuable suggestions and guidance. I also thank them and my supervisor for valuable suggestions and feedback during the various reviews during the course of thesis work. I would also like to thank Prof. Ratnamala Chatterjee and Prof. H. C. Gupta for providing me with insightful lectures during Ph.D. coursework.

I am thankful to my organisation, DRDO(Defence research and Development organisation) for allowing me to do this research work. I am highly thankful to Dr. Ajay Kumar, Director IRDE for his constant motivation and encouragement for research work. I would like to thank Dr. Lalit Mohan Pant for providing facilities and support for performing the experiments at optical fabrication and testing lab. I am also grateful to my colleagues at optical fabrication and testing lab at IRDE for their help during the experiments. I am thankful to my colleague Dr. Neeraj Pandey for the invaluable discussions on various topics related to computational imaging and experimental design. I pay special thanks to Sh. Bikram Poddar for his help to set up experiments at optical testing lab. I am thankful to all my friends who have been source of motivation and were helpful to me at many occasions.

I pay sincere gratitude to my respected parents Sh. Krishna Raj Singh and Smt. Krishna Singh for their blessings and support. I would also like to thank my wife 'Neerja', my sweet daughter 'Sanskriti' and adorable son 'Avyaan' for their love and

support during the Ph.D. work. This journey would not have been possible without their support. They have been a great influence of my life; and their constant encouragement and patience have let me pursue my dream.

Mahendra Pratap Singh

Abstract

Optical imaging systems are now embedded in various defense platforms and find a variety of applications like surveillance and target detection or tracking. The optical systems are designed such that the properties of different wavelength bands are utilized intelligently for strategic advantages in all-weather and illumination conditions. Some of the key requirements in deployable systems are necessity to have smaller form factor, minimal weight, cost and high performance with respect to field of view (FOV), depth of focus, resolution, athermalization, and noise robust performance. Traditional optical imaging systems are unable to meet these contrasting requirements due to the inherent trade-offs in the design process that aims to achieve optimal raw image quality. Traditional design in such scenarios may result in bulky designs, complex folded systems that are difficult to assemble with impractical tolerances. The computational imaging model offers potential solutions to the traditional design roadblocks by combining optical encoding with algorithmic decoding of raw data. This thesis explores new approaches to PSF engineering and PSF measurement for improving the performance of imaging systems keeping in view the on-field deployment constraints.

This thesis addresses three specific problems of interest for enhancing the performance of defense imaging systems. The first problem is simultaneous athermalization and/or depth-of-focus improvement with a compact single lens design that has a generalized cubic phase function imprinted on the back surface of an aspheric lens designed with Germanium and suited to LWIR (8-12 μm) band. The system design is enabled by advanced manufacturing and is shown to have nearly invariant PSF over full field of view as well as over temperature range of -20°C to $+60^\circ\text{C}$. This wavefront coding approach allows for a compact single lens design with significantly reduced weight for ease of deployment.

In the second topic, we introduce the concept of vortex phase diversity. Here, it is shown that two images recorded with open aperture and charge-1 vortex aperture incoherent imaging systems can be combined via the generalized Wiener filter to obtain high contrast imaging performance without increasing system aperture. The novelty here is that the two generalized Wiener filters have nearly opposing polarity and thus offer a STED (Stimulated Emission Depletion) Microscopy-like advantage where an

effective computational PSF with a narrowed down central lobe and corresponding OTF better than diffraction-limited OTF is achievable.

The third problem relates to accurate in-situ PSF estimation of on-field deployed systems that may be affected by outdoor environmental conditions such as variations in temperature (compared to that in controlled laboratory environment), humidity, mechanical shocks, etc. The accurate knowledge of PSF is essential for computational imaging systems for de-convolution. It is often not possible to bring a deployed system back to laboratory for testing. Also standard interferometer setups cannot be transported to field for testing purpose. To address this problem, we record large number of white noise frames shown to an imaging system and average their squared Fourier magnitudes to get an estimate of the two-dimensional system MTF. This MTF data is used along with the complexity-guided phase retrieval algorithm which is able to provide system PSF even when PSF is asymmetric.

Overall the thesis explores novel computational imaging solutions that may be deployed in real-world applications after some development efforts. We believe that the solutions discussed here have interesting implications for defense imaging systems for which this effort was undertaken, as well as for other spin-off imaging modalities like microscopy or commercial digital photography.

सारांश

ऑप्टिकल इमेजिंग सिस्टम आजकल विभिन्न रक्षा प्लेटफार्मों में एम्बेड किए जा रहे हैं और निगरानी और लक्ष्य की पहचान या ट्रैकिंग जैसी विभिन्न अनुप्रयोगों में पाए जाते हैं। ऑप्टिकल सिस्टम इस तरह डिज़ाइन किए जाते हैं कि विभिन्न तरंग दैर्घ्य बैंड की विशेषताओं का सूझबूझ से उपयोग सभी मौसम और प्रकाशन स्थितियों में रणनीतिक लाभ के लिए किया जा सके। डिप्लॉय किए जा सकने वाले सिस्टम की कुछ प्रमुख आवश्यकताएँ में छोटी फॉर्म फैक्टर, न्यूनतम वजन, लागत और दृश्य क्षेत्र (FOV) के संदर्भ में उच्च प्रदर्शन, फोकस की गहराई, विभेदन क्षमता, एथरमलाइजेशन और नॉइज़-रोबस्ट प्रदर्शन की आवश्यकता हैं। पारंपरिक ऑप्टिकल इमेजिंग सिस्टम इन विपरीत आवश्यकताओं को पूरा करने में असमर्थ हैं क्योंकि डिज़ाइन प्रक्रिया में अंतर्निहित ट्रेड-ऑफ्स होते हैं जो इष्टतम रॉ इमेज गुणवत्ता प्राप्त करने का प्रयास करते हैं। ऐसे परिदृश्यों में पारंपरिक डिज़ाइन का परिणाम भारी डिज़ाइन, जटिल फोल्डेड सिस्टम हो सकता है जिन्हें असेंबल करना कठिन होता है और जिनकी उपेक्ष्य त्रुटि व्यावहारिक नहीं होती। कम्प्यूटेशनल इमेजिंग मॉडल कच्चे डेटा के ऑप्टिकल एन्कोडिंग के साथ एल्गोरिथम डिकोडिंग के संयोजन द्वारा पारंपरिक डिज़ाइन बाधाओं के लिए संभावित समाधान प्रदान करता है। यह थीसिस ऑन-फील्ड तैनाती बाधाओं को ध्यान में रखते हुए इमेजिंग सिस्टम के प्रदर्शन में सुधार के लिए पीएसएफ इंजीनियरिंग और पीएसएफ माप के लिए नए दृष्टिकोणों की पड़ताल करती है।

यह थीसिस रक्षा इमेजिंग सिस्टम के प्रदर्शन को बढ़ाने के लिए तीन विशिष्ट रुचि की समस्याओं को संबोधित करती है। पहली समस्या एक कॉम्पैक्ट सिंगल लेंस डिज़ाइन के साथ एक साथ एथर्मलाइजेशन और/या डेप्थ-ऑफ-फोकस सुधार है, जिसमें जर्मेनियम के साथ डिज़ाइन किए गए एस्फेरिक लेंस की पिछली सतह पर एक सामान्यीकृत क्यूबिक फेज़ फ़ंक्शन अंकित होता है और LWIR (8-12 μm) बैंड के अनुकूल होता है। सिस्टम डिज़ाइन उन्नत विनिर्माण द्वारा सक्षम है और पूर्ण दृश्य क्षेत्र के साथ-साथ -20 डिग्री सेल्सियस से +60 डिग्री सेल्सियस के तापमान सीमा पर लगभग अपरिवर्तनीय पीएसएफ दिखाया गया है। यह वेवफ्रंट कोडिंग दृष्टिकोण तैनाती में आसानी के लिए काफी कम वजन के साथ एक कॉम्पैक्ट सिंगल लेंस डिज़ाइन की अनुमति देता है।

दूसरे विषय में, हम वॉर्टेक्स फेज़ विविधता की अवधारणा का परिचय देते हैं। यहां, यह दिखाया गया है कि खुले एपर्चर और चार्ज -1 वॉर्टेक्स एपर्चर असंगत इमेजिंग सिस्टम के साथ रिकॉर्ड की गई दो छवियों को सिस्टम एपर्चर को बढ़ाए बिना उच्च विपरीत इमेजिंग प्रदर्शन प्राप्त करने के लिए सामान्यीकृत वीनर फ़िल्टर के माध्यम से जोड़ा जा सकता है। यहां नवीनता यह है कि दो सामान्यीकृत वीनर फ़िल्टर में लगभग ध्रुवीयता का विरोध होता है और इस प्रकार एक एसटीईडी (उत्तेजित उत्सर्जन कमी) माइक्रोस्कोपी जैसा लाभ प्रदान करता है जहां एक संकुचित केंद्रीय लोब के साथ एक प्रभावी कम्प्यूटेशनल पीएसएफ और विवर्तन-सीमित ओटीएफ से बेहतर ओटीएफ प्राप्त करने योग्य है।

तीसरी समस्या ऑन-फील्ड डिप्लॉय किए गए सिस्टम की सटीक इन-सिटु PSF अनुमान से संबंधित है, जो बाहरी पर्यावरणीय परिस्थितियों जैसे तापमान में परिवर्तन (नियंत्रित प्रयोगशाला पर्यावरण की तुलना में), आर्द्रता, यांत्रिक झटके आदि से प्रभावित हो सकते हैं। PSF का सटीक ज्ञान कम्प्यूटेशनल इमेजिंग सिस्टम के लिए डी-कन्वोल्यूशन के लिए आवश्यक है। अक्सर किसी डिप्लॉय किए गए सिस्टम को परीक्षण के लिए प्रयोगशाला में वापस लाना संभव नहीं होता। इसके अलावा, मानक इंटरफेरोमीटर सेटअप को परीक्षण के उद्देश्य से फील्ड में ले जाना संभव नहीं है। इस समस्या को हल करने के लिए, हम एक इमेजिंग सिस्टम को दिखाए जाने वाले बड़ी संख्या में व्हाइट नॉइज़ फ्रेम रिकॉर्ड करते हैं और दो-आयामी सिस्टम MTF का अनुमान प्राप्त करने के लिए उनके वर्गीकृत फोरियर मानों का औसत निकालते हैं। इस MTF डेटा का उपयोग जटिलता-निर्देशित फेज़ पुनर्प्राप्ति (Complexity guided phase retrieval) एल्गोरिदम के साथ किया जाता है, जो सिस्टम PSF प्रदान करने में सक्षम है, भले ही PSF असममित हो। कुल मिलाकर यह थीसिस नए कम्प्यूटेशनल इमेजिंग समाधानों की खोज करती है जिन्हें कुछ विकास प्रयासों के बाद वास्तविक दुनिया के अनुप्रयोगों में लागू किया जा सकता है। हमें विश्वास है कि यहां चर्चा किए गए समाधान, रक्षा इमेजिंग सिस्टम के लिए के लिए रोचक प्रभाव हैं जिनके लिए यह प्रयास किया गया था, साथ ही अन्य स्पिन-ऑफ इमेजिंग विधाओं जैसे माइक्रोस्कोपी या व्यावसायिक डिजिटल फोटोग्राफी के लिए भी ये उपयोगी हैं।

Contents

Certificate

Acknowledgements

Abstract

Contents

List of Figures

List of Tables

Abbreviations

1	Introduction	1
1.1	Optical Imaging	3
1.1.1	Coherent Optical Imaging	6
1.1.2	Incoherent Optical Imaging	8
1.1.3	Optical Imaging System Design and Constraints	9
1.1.4	Image restoration	12
1.1.4.1	Linear Shift invariant optical systems	13
1.1.4.2	Image deconvolution methods	15
1.2	Challenges of optical imaging for defence applications	20
1.3	Computational imaging using PSF engineering	22
1.3.1	Practical aspects of computational imaging systems	27
1.3.2	Advances in optical fabrication	28
1.3.3	Advances in sensor technology and algorithms	30
1.4	Motivation	33
1.5	Thesis overview	35

2	Design of Single Lens Wavefront coded Infrared Camera	37
2.1	Introduction	37
2.2	Principle of wavefront coding and analysis of aberration compensation properties of extended depth of focus phase mask	40
2.3	Performance analysis of single lens design	48
2.3.1	Tolerance analysis and fabrication considerations	53
2.4	Image simulation with designed lens	54
2.5	Fabrication, testing and evaluation of single lens	60
2.6	Conclusion	67
3	High Contrast Computational Imaging using Vortex Phase Diversity	69
3.1	Introduction	69
3.2	PSF Diversity and generalized Wiener filtering	72
3.2.1	Simulation of vortex phase diversity imaging	77
3.3	Experimental illustration of vortex phase diversity imaging	77
3.4	Thermal imaging using vortex phase diversity	84
3.5	Conclusion	86
4	On-field PSF recovery using random noise targets	87
4.1	Introduction	87
4.2	Theory of PSF estimation from random noise targets	89
4.3	PSF estimation using complexity guided phase retrieval	95
4.4	Simulation results for PSF estimation using random Targets	97
4.5	Experimental results and discussion	100
4.6	Conclusion	103
5	Conclusions and Future Scope	105
5.1	Conclusions of the thesis work	105
A	Generalized Wiener Filtering	109
B	Zernike Polynomials	111
	Bibliography	115
	List of Publications	131
	Curriculum Vitae	133

List of Figures

1.1	4-F imaging system	6
1.2	Coherent imaging system	7
1.3	Incoherent imaging system	8
1.4	Example of image deconvolution: a) Input image b) Image blurred by optical system c) Image deconvolution by inverse filtering d) By Wiener filtering	16
2.1	(a)Layout of two lens system with separate phase mask(cubic), (b) layout of single lens system with phase mask(generalized cubic) on second surface.	43
2.2	(a) Correlation of MTF of phase mask with increasing value of aberrations in waves, (b) Profile of Cubic phase mask in form of fringe pattern, (c) Phase map of cubic phase mask (in waves $\lambda=10\mu\text{m}$).	44
2.3	Astigmatism profile (a) Saggital direction(b) 45-degree to saggital direction.	46
2.4	(a) Generalized cubic phase mask contour in form of fringes (b)Phase map of generalized cubic phase mask(waves $\lambda=10\mu\text{m}$).	46
2.5	Correlation of MTF in presence of generalized cubic phase mask with increasing value of aberrations.	47
2.6	Zernike coefficients for initial design with spherical aberration minimized using lens bending.	49
2.7	Zernike coefficients after selective minimization and optimization of zernike terms.	49
2.8	(a) On -axis MTF with variation of temperature (b) MTF with variation of field angle at temperature of 20°C	50
2.9	a) MTF with variation of field angle at 20 °C b) MTF with variation of field angle at -20 °C c) MTF with variation of field angle at 60 °C d) MTF with defocus at 5 lp/mm	51
2.10	Image simulation of single lens without the proposed phase mask a)image at focus T=20 °C b) image with defocus at T=-20 °C c) image with defocus at T=60 °C	55
2.11	Simulated image record with generalized cubic phase plate on second surface of the lens a)at defocus at T=20 °C, b) T=-20 °C, c)at T=60 °C	55

2.12	Recovered image using on axis PSF a) at focus $T=20\text{ }^{\circ}\text{C}$ b) $T=-20\text{ }^{\circ}\text{C}$ c) at $T=60\text{ }^{\circ}\text{C}$	56
2.13	Profile error of aspheric surface	60
2.14	(a) Fabricated Single lens (b) Profile error map of freeform surface (c) CGH used for testing	60
2.15	(a) Fabricated lens (b) Lens in Mechanical housing (c) Lens integrated with detector and processing electronics	61
2.16	Experimental images of resolution target using conventional LWIR Camera a) on axis image b) off-axis image at 4° horizontal c) off-axis image at 3° vertical and d) off-axis image at $4^{\circ}\times 3^{\circ}$	61
2.17	Wavefront coded images of resolution target using Single lens LWIR Camera a) on axis image b) off-axis image at 4° horizontal c) off-axis image at 3° vertical and d) off-axis image at $4^{\circ}\times 3^{\circ}$	62
2.18	Recovered images of resolution target using Single lens LWIR Camera a) on axis image b) off-axis image at 4° horizontal c) off-axis image at 3° vertical and d) off-axis image at $4^{\circ}\times 3^{\circ}$	63
2.19	Wavefront coded and recovered images of resolution target at different temperatures using Single lens LWIR Camera a) Wavefront coded at $T=20\text{ }^{\circ}\text{C}$ b) Wavefront coded at $T=40\text{ }^{\circ}\text{C}$ c) Wavefront coded at $T=60\text{ }^{\circ}\text{C}$ d) Recovered image at $T=20\text{ }^{\circ}\text{C}$ e) Recovered image at $T=40\text{ }^{\circ}\text{C}$ f) Recovered image at $T=60\text{ }^{\circ}\text{C}$	63
2.20	Wavefront coded images of resolution target at different target to background temperature difference a) Wavefront coded at $\Delta T=5^{\circ}\text{C}$ b) Wavefront coded at $\Delta T=1^{\circ}\text{C}$ c) Wavefront coded at $\Delta T=0.5^{\circ}\text{C}$ d) Wavefront coded at $\Delta T=0.1^{\circ}\text{C}$	64
2.21	Recovered images of resolution target at different target to background temperature difference a) Recovered image at $\Delta T=5^{\circ}\text{C}$ b) Recovered image at $\Delta T=1^{\circ}\text{C}$ c) Recovered image at $\Delta T=0.5^{\circ}\text{C}$ d) Recovered image at $\Delta T=0.1^{\circ}\text{C}$	65
2.22	Experimental images of resolution target at different target to background temperature difference using conventional LWIR Camera a) Image at $\Delta T=5^{\circ}\text{C}$ b) Image at $\Delta T=1^{\circ}\text{C}$ c) Image at $\Delta T=0.5^{\circ}\text{C}$ d) Image at $\Delta T=0.1^{\circ}\text{C}$	65
2.23	Experimental images for comparison of conventional IR imaging with wavefront coded single lens (a) Conventional IR image with focus at far end of scene (b) Conventional IR image with focus at near end of scene (c) Image with wavefront coded single lens (d) Recovered image with enhanced depth of field	66
3.1	(a), (b) OTF magnitudes for open circular aperture and vortex phase aperture, respectively. (c) Central line profiles of the OTF magnitudes shown in (a) and (b).	74

3.2	(a), (b) Real parts of the generalized Wiener filters $W_1(f_x, f_y)$ and $W_2(f_x, f_y)$ for the open and vortex apertures. (c) Central profiles of the filters. (d) OTF magnitudes for the open aperture, vortex aperture, and the computationally synthesized effective PSF, showing enhanced high spatial frequency response.	75
3.3	(a) Open-aperture PSF, (b) vortex-aperture PSF, and (c) effective PSF obtained using generalized Wiener filtering. (d) Central profiles of the PSFs. Red dotted lines indicate the first zero of the central lobe.	76
3.4	(a) "Boat" test object, (b),(c) blurred and noise added versions of the test object with open aperture and vortex aperture PSFs respectively; (d) Recovery of test object using generalized Wiener filter. The insets in (b), (c) show the PSFs used for blurring the test object in (a). All pictures are shown with equal median pixel value to maintain similar background brightness.	78
3.5	(a), (b) Recoveries of the blurred images in Fig. 3.4(b), (c) using individual Wiener filters corresponding to the open aperture and vortex aperture PSFs respectively. The recoveries show faint ghosting artefacts near sharp edges.	79
3.6	(a), (b), (c): Zoomed portions of Wiener recoveries in Fig. 3.5 (a), (b) and Fig. 3.4(d) respectively. The individual Wiener filter recoveries in (a), (b) show faint ghosting artifacts near sharp features that are missing in the generalized Wiener filter recovery in (c).	79
3.7	Schematic experimental setup. A red LED (center wavelength 635 nm) with a diffuser is used to provide nearly uniform spatially incoherent illumination. MO: 10X/0.25NA infinity corrected microscope objective lens (Make: Nikon); charge-1 vortex phase plate designed for 633 nm (Make: Holo-or) is placed in the Fourier plane of the system for recording one of the two images; $f = 200$ mm tube lens suitable for the Nikon objective; array sensor (Make: IDS, part number uEye 30370).	80
3.8	Generalized Wiener filter experimental illustration with cell sample: (a) image record with open aperture, (b) image record with vortex aperture, (c) generalized Wiener filter reconstruction using (a), (b); (d) image in (c) after five TV reduction iterations. The images shown are grey-scale and shown with a false "hot" colour map.	81
3.9	Generalized Wiener filter experimental illustration with part of USAF chart: (a) image record with open aperture, (b) image record with vortex aperture, (c) generalized Wiener filter reconstruction using (a), (b); (d) image in (c) after five TV reduction iterations.	82
3.10	Profile plots of (a) cell sample and (b) USAF chart object for open aperture image record and generalized Wiener filter recovery without and with TV denoising along dotted lines in Fig. 3.8 (a), (c), (d) and Fig. 3.9 (a), (c), (d) respectively.	83

3.11	Experimental results of thermal imaging using vortex phase diversity (a) Image recorded by LWIR camera (b) spatial frequency spectrum of the image (c) Image recorded with vortex phase in pupil (d) spatial fre- quency spectrum of the image (e) Recovered image using vortex phase diversity and (f) spatial frequency spectrum of recovered image	85
4.1	Simulation of PSF recovery from random noise patterns with circular aperture (a) PSF, (b) MTF (c) Input noise frame (d) Output from imaging system	98
4.2	Simulation of PSF recovery from random noise patterns with circular aperture (a) recovered PSF, (b) Recovered MTF (c) Mean square error with iterations (d) Error map between original and recovered MTF data	98
4.3	Simulation of PSF recovery from random noise patterns with coma aberration (a) MTF due to coma (b) PSF of coma aberration (c)Recovered MTF (d) Recovered PSF	99
4.4	Simulation of PSF recovery from random noise patterns with coma aberration (a) Error map between original and recovered MTF data (b) Simulated Phase of OTF (c)Recovered phase (d) Mean square error with iterations	99
4.5	Experimental set up	101
4.6	Experimental results of PSF recovery of optical system with cubic phase plate in pupil (a) MTF obtained from noise targets (b) Recovered PSF using phase retrieval (c)Recovered MTF (d) Recovered Phase	102

List of Tables

2.1	Specifications of the optical system	43
2.2	Tolerance analysis data	53
2.3	Image quality metrics for simulated images shown in Fig. 2.10	58
2.4	Image quality metrics for reconstructed images shown in Fig. 2.12	58

Abbreviations

AFM	A tomic F orce M icroscope
BD	B lind D econvolution
CCD	C harge C oupled D evice
CCOS	C omputer C ontrolled O ptical S urfacing
CGH	C omputer G enerated H ologram
CGPR	C omplexity G uided P hase R etrieval
CMM	C o-ordinate M easuring M achine
CMOS	C omplimentary M etal O xide S emiconductor
CNC	C omputer N umerical C ontrol
CNN	C onvolutional N eural N etwork
DH-PSF	D ouble H elix- P oint S pread F unction
DOE	D iffractive O ptical E lement
EBL	E lectron B eam L ithography
FFT	F ast F ourier T ransform
FOV	F ield O f V iew
FTS	F ast T ool S ervo
HIO	H ybrid I nput O utput
IBF	I on B eam F iguring
IR	I nfra R ed
LSI	L inear S hift I nvariant
LWIR	L ong W ave I nfra R ed
MCT	M ercury C admium T elluride
MRF	M agneto R heological F inishing
MTF	M odulation T ransfer F unction
NA	N umerical A perture
OTF	O ptical T ransfer F unction

PGM	P recision G lass M oulding
PSF	P oint S pread F unction
PSNR	P eak S ignal- to- N oise R atio
SIM	S tructured I llumination M icroscopy
SLM	S patial L ight M odulator
SMLM	S ingle M olecule L ocalization M icroscopy
SNR	S ignal- to- N oise R atio
SPAD	S ingle P hoton A vlanche D iode
SPDT	S ingle P oint D iamond T urning
SSIM	S tructural S imilarity I ndex M easure
STED	S timulated E mission D epletion M icroscopy
STS	S low T ool S ervo
SWaP	S ize W eight and P ower
T2SL	T ype I I S uper L attice
TV	T otal V ariation