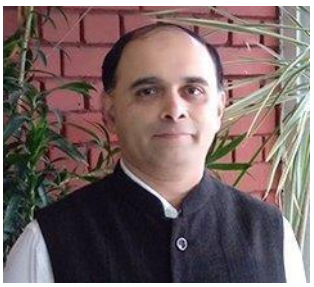
Executive Summary



Kedar Khare
Professor, Optics and Photonics Centre, IIT Delhi
(joint appointment with Department of Physics, IIT Delhi)

1. Title of the Project:

   Lens-less Computational Microscopy: Concepts, Devices and Bio-Medical Applications

2. Date of Start of the Project:

   1-October-2022

3. Aims and Objectives:

   Year 1: Algorithm design for lens-less imaging and simulation tests.

   Year 2: First system setup with associated algorithm, comparison with standard microscopes.

   Year 3: Demonstration of cell imaging with developed system, specify system parameters.

   Years 4, 5: Point-of-care device prototype and application development in collaboration with Bio-Medical science researchers. Investigate important newer possibilities for achieving super-resolution imaging in the lens-less microscopy platform.

4. Significant achievements (not more than 500 words to include List of patents, publications, prototype, deployment etc)

During the second year of the Fellowship, the following significant contributions have been made:

(1) Key conceptual result on use of vortex illumination for phase retrieval problem has been proved. A full patent on this idea is filed and a proof has been published in an article in the *Journal of Optical Society of America: A* (2024). With the new understanding of the phase retrieval problem, we observe that the problem has become nearly deterministic. This step is critical to building a microscope instrument based on the conceptual idea.

Initial experimental results have shown promising convergence of iterative phase retrieval algorithm.

(2) A new idea on high contrast computational imaging using vortex phase diversity has been proved and published in *Journal of Physics B: Atomic, Molecular and Optical Physics* (2024). This experiment shows narrowing of effective point-spread-function (PSF) of an ordinary brightfield microscope system. Previously, such enhanced PSF has required complex nanostructured gratings. Our work however shows that this enhancement is achievable with bulk optics-based measurements combined with algorithms. The concept has interesting similarities to STED advantage of super-resolution microscopy – we however achieve it without the need of fluorescence. We are in the process of testing and incorporating this idea into a device/product prototype system.

(3) Inspired by the results of extended field-of-view (FOV) imaging system demonstrated by us during the last year, we have now proposed a new information measure for computational imaging in general. We obtained an important result which shows that the enhancement of space-bandwidth product in all computational imaging systems occurs by exploiting the bit depth dimension of the sensors. This result allows us to predict or assess the enhanced performance of computational imaging systems in general by means of a novel power-law relation that we have established.

(4) A new result regarding phase tomography with axial structured illumination has been demonstrated. This problem has implications for making compact leaner optical diffraction tomography systems.

(5) A proposal based on the seed ideas initiated through the first two years of Fellowship have been approved under the National Quantum Mission. A significant effort on quantum enhanced imaging and microscopy is expected in coming years.

Publications during 1 October 2023 – 30 September 2024

Journal publications:

1. MP Singh, N Pandey, K Khare, "High contrast computational imaging with vortex phase diversity", J. Physics B: Atomic, Molecular and Optical Physics DOI 10.1088/1361-6455/ad8499 (2024).

2. Esha Baidya Kayal, Shuvadeep Ganguly, Devasenathipathy Kandasamy, Kedar Khare, Raju Sharma, Sameer Bakhshi, Amit Mehndiratta, "Reproducibility of spatial penalty-based methodologies for intravoxel incoherent motion analysis with diffusion MRI", Scientific Reports 14, 22811 (2024).

3. Deepanshu Yadav, Reena Parihar, Suraj Goel, B Om Subham, Kedar Khare, Vivek Venkataraman, Amol Choudhary, “Integrated photonic waveguides for on-chip SBS with OAM modes”, Optics Communications 565, 130660 (2024).

4. S Tayal, S Kuila, K Khare, DS Mehta, “Optimization-based approach for high-fidelity phase retrieval from sparse interferometric data: implications for industry and biological research”, Applied Optics 63, 6026-6035 (2024).

5. M Kularia, M Banerjee, K Khare, “Twin-stagnation-free phase retrieval with vortex phase illumination”, JOSA A 41, 1166-1174 (2024).

6. A Singh, M Gupta, H Rastogi, K Khare, PK Chowdhury, “Deeper Insights into Mixed Crowding through Enzyme Activity, Dynamics, and Crowder Diffusion”, J. Phys. Chem B 128, 5293-5309 (2024).

7. N Pandey, MP Singh, K Khare, “Design and development of a prism–mirror module for single-shot phase retrieval of a microlens”, Journal of Optics 53, 1120-1128 (2024).

8. N Goyal, K Khare, “Carrier-frequency estimation for digital holograms of phase objects”, Applied Optics 63, B42-B48 (2024).

9. Esha Baidya Kayal, Devasenathipathy Kandasamy, Richa Yadav, Kedar Khare, Sameer Bakhshi, Raju Sharma, Amit Mehndiratta, “Radiologists' rating for comparative qualitative assessment of intravoxel incoherent motion using novel analysis methods”, Journal of Computer Assisted Tomography 48, 263-272 (2024).

10. P Lochab, B Kumar, DP Ghai, P Senthilkumaran, K Khare, “Real time characterization of atmospheric turbulence using speckle texture”, Journal of Optics 26, 015602 (2023).

Patents (granted/filed during the past one year):

1. K. Khare, et al, COHERENT DIFFRACTION IMAGING SYSTEM EMPLOYING VORTEX PHASE ILLUMINATION FOR PRODUCING REAL-TIME IMAGES AND METHOD THEREOF, Patent number 202311070570 (2023). (Filed)

2. K. Khare et al, SYSTEM AND METHOD FOR ACHIEVING ULTRA-HIGH DEPTH OF FIELD IMAGING, Patent number 201811016990, (Granted, June 2024)

5. **Concluding remarks**

The proposed work through Abdul Kalam National Innovation Fellowship has progressed as per the proposed timeline. New conceptual ideas have been established that are key to proposed device realization. New approved funding for quantum enhanced imaging through National Quantum Mission will further accelerate the current activities towards device development. Overall, the Fellowship support has proved to be fruitful for taking the PI’s research and development work in the proposed topical areas forward in a significant manner.