Experimental demonstrations of coherence de Broglie wavelength for superresolution sensing

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High-precision measurement has been a longstanding objective across many areas of science and technology, including spectroscopy, imaging, sensing, and metrology. In conventional optical systems, the resolution limit is ultimately constrained by the diffraction limit of the probe light [1], while measurement sensitivity is limited by photon shot noise, commonly referred to as the shot-noise limit (SNL) [2]. Overcoming these constraints has been a major goal of quantum sensing and metrology [3]. Quantum metrology utilizes distinctly quantum features of light—such as squeezing and entanglement—to improve measurement capabilities beyond classical bounds. Although maximally path-entangled N00N states have demonstrated quantum sensing up to the Heisenberg limit for the photonic de Broglie wavelength, whose corresponding sensitivity and resolution are inversely proportional to the photon number N, the scalability of N is strictly limited, resulting in a practically unacceptable level of replacing classical counterparts [3,4]. Thus, generating and controlling high-photon-number entangled states has been the most important technical issue. Even in this case, their performance is highly susceptible to losses and environmental decoherence, which quickly diminish the quantum effect. These limitations significantly hinder the implementation of PBW-based quantum sensing [3]. Recently a coherence approach in the name of coherence de Broglie wavelength (CBW) has been proposed for the same superresolution as PBW using classical optics [5]. Unlike N00N-based PBW, which relies on multiphoton entanglement, CBW originates from deterministic higher-order coherence of a probe field propagating through cascaded Mach-Zenhder interferometers (MZIs). This coherence-driven mechanism yields an effective wavelength scaling proportional to 1/N, analogous to PBW, but without requiring the generation of fragile entangled states. Moreover, CBW-based schemes are inherently resilient to photon loss. The CBW scalability relies on the number of MZIs. Although CBW does not surpass the SNL in sensitivity, theoretical analyses indicate that it can still improve phase estimation compared to conventional interferometric techniques, while preserving superresolution capabilities with nearly perfect fringe visibility [6]. These characteristics point to CBW as a viable and scalable alternative for superresolution sensing and metrology without the demanding resource requirements of entanglement-based approaches. Here, we experimentally demonstrate CBW up to third order (N = 3) in both single-photon and continuous-wave regimes. The measured interference fringes exhibit the expected wavelength reduction proportional to 1/N, while maintaining near-unity visibility across different orders. Moreover, the observations confirm a high degree of robustness against photon loss, highlighting a key advantage over PBW-based quantum sensing. These findings provide direct experimental support for the CBW framework and establish coherence-based interferometry as a promising route toward practical and scalable superresolution sensing and metrology. Acknowledgment: This work was supported by MSIT under IITP 2026-2021-01810, supervised by the IITP. References 1. Hell, S. W. Nanoscopy with focused light (Nobel lecture). Angew. Chem. Int. Ed. 54, 8054-8066 (2015). 2. Kay, S. Fundamentals of statistical signal processing: Estimation theory (Prentice Hall, New Jersey 1993). 3. Pezze, L. et al., Quantum metrology with nonclassical states of atomic ensemble. Rev. Mod. Phys. 90, 035005 (2018). 4. Wang, X.-L. et al. 18-qubit entanglement with six photons' three degree of freedom. Phys. Rev. Lett. 120, 260502 (2018). 5. Ham, B. S. Deterministic control of photonic de Broglie waves using coherence optics. Sci. Rep. 10, 12899 (2020). 6. Ham, B. S. A quantum mechanical analysis of the coherence de Broglie wavelength for superresolution and enhanced sensitivity in a coupled interferometer scheme arXiv:2602.20410 (2026).