2nd round:
Kuantum Metroloji

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Quantum metrology uses quantum effects, i.e., entanglement, to make more precise measurements.

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More information = A high sensitivity of measurement.

(Quantum) Optical Coherence Tomography

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PHYSICAL REVIEW A, VOLUME 65, 053817

Quantum-optical coherence tomography with dispersion cancellation

Ayman F. Abouraddy, Magued B. Nasr, Bahaa E. A. Saleh, Alexander V. Sergienko, and Malvin C. Teich*
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(Received 27 November 2001; published 8 May 2002)

(Quantum) Optical Coherence Tomography

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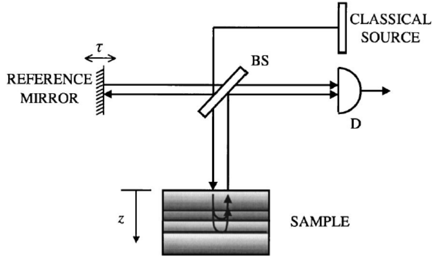

FIG. 1. Setup for optical coherence tomography (OCT). BS stands for beam splitter, D is a detector, and τ is a temporal delay introduced by moving the reference mirror.

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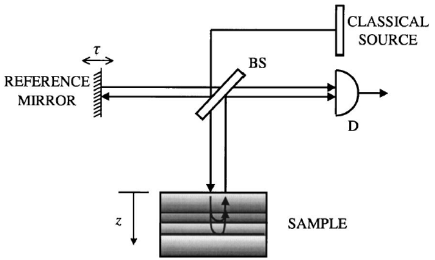

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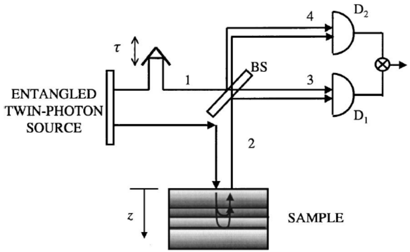

FIG. 2. Setup for quantum-optical coherence tomography (QOCT). BS stands for beam splitter and τ is a temporal delay. D_1 and D_2 are single-photon-counting detectors that feed a coincidence circuit.

REVIEW ARTICLES | FOCUS

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nature photonics

Advances in quantum metrology

Vittorio Giovannetti[1*], Seth Lloyd[2] and Lorenzo Maccone[3]

The statistical error in any estimation can be reduced by repeating the measurement and averaging the results. The central limit theorem implies that the reduction is proportional to the square root of the number of repetitions. Quantum metrology is the use of quantum techniques such as entanglement to yield higher statistical precision than purely classical approaches. In this Review, we analyse some of the most promising recent developments of this research field and point out some of the new experiments. We then look at one of the major new trends of the field: analyses of the effects of noise and experimental imperfections.

REVIEW

Quantum-Enhanced Measurements: Beating the Standard Quantum Limit

Vittorio Giovannetti,[1] Seth Lloyd,[2]* Lorenzo Maccone[3]

Quantum mechanics, through the Heisenberg uncertainty principle, imposes limits on the precision of measurement. Conventional measurement techniques typically fail to reach these limits. Conventional bounds to the precision of measurements such as the shot noise limit or the standard quantum limit are not as fundamental as the Heisenberg limits and can be beaten using quantum strategies that employ "quantum tricks" such as squeezing and entanglement.

Measurement is a physical process, and the accuracy to which measurements can be performed is governed by the laws of physics. In particular, the behavior of systems at small scales is governed by the laws of quantum mechanics, which place limits on the accuracy to which measurements can be performed. These limits to accuracy take two forms. First, the Heisenberg uncertainty relation (*1*) imposes an intrinsic uncertainty on the values of measurement results of complementary observables such as position and momentum, or the different components of the angular momentum of a rotating object (Fig. 1). Second, every measurement apparatus is itself a quantum system: As a result, the uncertainty relations together with other quantum constraints on the speed of evolution [such as the Margolus-Levitin theorem (*2*)] impose limits on how accurately we can measure quantities, given the amount of physical resources, such as energy, at hand to perform the measurement.

One important consequence of the physical nature of measurement is the so-called quantum back action: The extraction of information from a system can give rise to a feedback effect in which the system configuration after the measurement is determined by the measurement outcome. For example, the most extreme case (the so-called von Neumann or projective measurement) produces a complete determination of the post-measurement state. When performing successive measurements, quantum back action can be detrimental, because earlier measurements can negatively influence successive ones. A common strategy to get around the negative effect of back action

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Characterizing Nonclassical Correlations via Local Quantum Uncertainty

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(Received 14 December 2012; revised manuscript received 1 April 2013; published 13 June 2013)

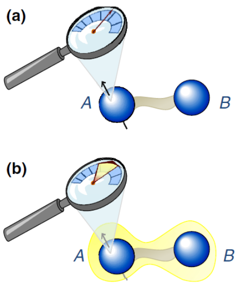


FIG. 1 (color online). Quantum correlations trigger local quantum uncertainty. Let us consider a bipartite state ρ. An observer on subsystem A is equipped with a *quantum meter*, a measurement device whose error bar shows the quantum uncertainty only. (Note that, in order to access such a quantity, the measurement of other observables that are defined on the full bipartite system may be required, in a procedure similar to state tomography) (a) If ρ is uncorrelated or contains only classical correlations [darker (brown) inner shade], i.e., ρ is of the form $\rho = \sum_i p_i |i\rangle\langle i|_A \otimes \sigma_{iB}$ (with $\{|i\rangle\}$ an orthonormal basis for A) [8–10], the observer can measure at least one observable on A without any intrinsic quantum uncertainty. (b) If ρ contains a nonzero amount of quantum correlations [lighter (yellow) outer shade], as quantified by entanglement for pure states [5] and quantum discord in general [10], any local measurement on A is affected by quantum uncertainty. The minimum quantum uncertainty associated to a single measurement on subsystem A can be used to quantify discord in the state ρ, as perceived by the observer on A. In this Letter, we adopt the Wigner-Yanase skew information [16] to measure the quantum uncertainty on local observables.

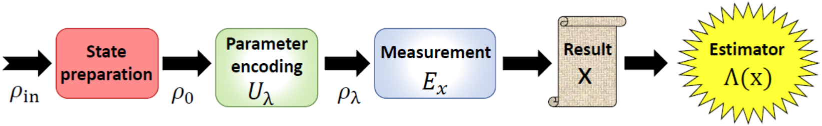
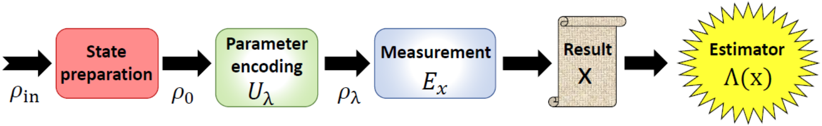


FIG. 1. **Conceptual scheme of a parameter estimation.** An initial probe is prepared (red box) in a state ρ_0 (eventually, from an initial state ρ_{in}). Then, it interacts with the unknown parameter λ through an evolution U_λ (green box). The state ρ_λ encoding the information on λ is measured by a POVM E_x (blue box) generating outcome x. Based on the outcomes x, a suitable estimator provides an estimate $\Lambda(x)$ of the parameter λ.



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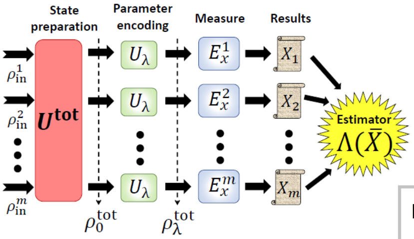

FIG. 2. **Conceptual scheme of a parallel parameter estimation.** The measurements here considered are separable. Indeed, empolying entanglement in the measurement process does not allow to obtain better performances than the optimal separable strategy. Conversely, state preparation can lead to quantum enhancement by exploiting entanglement between probes[9].

Photonic Quantum Metrology

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Resource Theory of Superposition

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(Received 10 April 2017; revised manuscript received 26 June 2017; published 5 December 2017)

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Resource Theory of Superposition

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Resource theory of superposition: State transformations

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Channel Discrimination Task—a branch of quantum metrology

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"Assume we have two players, say Alice and Bob. Alice performs a selective quantum operation (which is known to Bob) with outcomes $n = 0, 1, \ldots, d < \infty$ on a state she received from Bob. If the result is $n = 0$, they start a new turn and Bob has to hand in a new state. In case the result was $n \neq 0$ she returns the post-measurement state to Bob, who is allowed to apply an arbitrary quantum operation on it. Then he has two choices: he either tells Alice his guess about the outcome n or he asks for a new turn. He has lost immediately if he gives a wrong answer and he wins if his answer is correct." (PRL 119, 230401 (2017)).

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Identify outcomes $n = 1, \ldots, d$ with the free Kraus operators

$$K_n = \sqrt{\frac{p}{d}} \sum_{j=1}^{d} e^{\frac{2\pi i j n}{d}} |c_j\rangle\langle c_j^{\perp}| \quad \left[p \in (0, 1],\ \sum_n K_n^{\dagger} K_n = p \sum_j |c_j^{\perp}\rangle\langle c_j^{\perp}| \leq \mathbb{I} \right]$$

1st case: Bob can hand in only free states—superposition-free states: $\rho_f = \sum_j |c_j\rangle\langle c_j|$

$$\left[K_n = \sqrt{\frac{p}{d}} \sum_{j=1}^{d} e^{\frac{2\pi i j n}{d}} |c_j\rangle\langle c_j^{\perp}|\right] \quad \rho_n = \frac{K_n \rho_f K_n^\dagger}{\mathrm{tr}(K_n \rho_f K_n^\dagger)} = \rho_f \quad \left[p_n = \mathrm{tr}(K_n \rho_f K_n^\dagger) = p/d\right]$$

The best choice is to make a random guess; since $p \leq 1$, Bob will lose with certainty for d against infinity.

2nd case: Bob can hand in only resource states—superposition states: $|\psi\rangle = \frac{1}{N}\sum_j |c_j\rangle$

$$|\psi_n\rangle = \frac{1}{N}\sum_k e^{\frac{2\pi i k n}{d}} |c_k\rangle$$

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These states are linearly independent. Since the free states ($|c_k\rangle$) are linearly independent,

$$\sum_n x_n|\psi_n\rangle = 0 \Rightarrow \sum_n x_n e^{\frac{2\pi ikn}{d}} = 0 \;\forall k$$

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Since $u_n^\dagger u_m = \delta_{nm} d$, the only solution is $x_n = 0$ for all n. Thus Bob can do unambiguous state discrimination on the states $\{|\psi_n\rangle\}$ and will, after enough repetitions, win with certainty (PRL 119, 230401 (2017)).

Kaynaklar

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