Abstract: We introduce hypercube states, a new class of quantum states. These feature with sub-Planck scale resolution allowing increased sensitivity to small phase space perturbations. We investigate their sensitivity in a variety of realistic circumstances.

1. Main Text

Quantum-enhanced sensors have the potential to break classical sensitivity limits and transform the landscape of sensing technology [1]. A good sensor should have the ability to distinguish its initial state from that after the application of a small disturbance. This desirable property is closely related to the size of the smallest features in the quantum state’s phase space representation [2]. Roughly speaking, two quantum states with smallest features occupying an area on the order of $\delta$, can become maximally distinguishable for displacements on the order of $\sqrt{\delta}$. Similarly, the rate of change in distinguishability in response to a displacement—a measure of the sensor’s sensitivity—is a function of the size of the state’s phase-space features. Quantum mechanics generally limits the size of these features to be at least on the order of $\hbar$, which is variously known as the shot-noise or standard quantum limit depending on the area of physics in which it arises. Yet, quantum theory also provides a way around this limit, and states such as the Schrödinger-cat state [3]—and the more-recently introduced compass state [2, 4]—show features at a scale below $\hbar$.

Here we introduce new class of non-classical states that we call hypercube states. These states have an link to geometry in that they are obtained as Petrie-polygon orthographic projections of $n$-cubes [5], into phase space, where the polygon vertices correspond to the location of coherent states, and interference fringes are observed between every pair of vertices.

Our class of states in particular includes the Schrödinger-cat state and the compass state as the lowest-order special cases, and all hypercube states exhibit sub-Planck phase-space features that decrease in size with the order of the state, making them an attractive resource for quantum metrology. We introduce a method for creation of hypercube states using multiple applications of a recently developed optomechanical technique [6] that is applicable to a wide range of state-of-the-art experiments. We analyse hypercube states in different regimes of temperature and interaction strength, determining the distance between the coherent states at the vertices of the hypercubes.

Specifically, we show that hypercube states become progressively more sensitive as their order increases and that this sensitivity is robust to variations in temperature and/or interaction strength of the state. Finally, we use the introduced method to experimentally observe the signature of the second, third and fourth order hypercube states that survives in the high temperature regime.

References

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