Rotation Angular Measurement beyond Quantum Noise Limit with an Orbital Angular Position Squeezed State

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Abstract: The rotation angular measurement beyond the quantum noise limit based on orbital angular position squeezed beam was demonstrated. An improvement of a factor of 1.4 was achieved over the quantum noise limited coherent state.
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In addition to the spin angular momentum (SAM), optical beams carry another angular momentum, orbital angular momentum (OAM), which is associated with helical phase fronts [1]. Due to its complex spatial phase structure and theoretically uncapped number of quanta of OAM, the optical beams with OAM has advantages in the measurement of spatial rotation angle. Recently increasing attentions has been focused on the quantum-enhanced effect for precision measurement with the help of ‘‘quantum tricks’’ such as squeezing and entanglement [2-5]. It can offer enhanced precision of a measurement beyond quantum noise limit (QNL), even beat the ultimate precision “Heisenberg limit”. The squeezed state has been a powerful quantum source to improve the precision of measurements since it was proposed.

When a probe light in HG_{10} mode experiences a rotation with a small angle θ (θ <<1) in the transverse plane around the propagation direction z, as shown in fig. 1(a). In this case, we deduced the commutation relation $[\hat{\theta}, O_3] = 2i$ and uncertainty relation $\Delta\theta * \Delta O_3 \geq 1$ between the continuous variable orbital angular position (OAP) and orbital angular momentum (OAM). Based on the relations, we defined a new type of squeezed state, called “OAP” squeezed state, which is squeezed in the plane perpendicular to axis O_3 [6-7]. It can be produced by combining a bright coherent state in HG_{10} mode and a vacuum squeezing state in HG_{01} mode. For more understanding on the OAP squeezed state, we describe the state on an equivalent Poincare sphere as shown in fig. 1(b) [8]. With the OAP squeezed state enhancing the precision of rotation angle measurement beyond QNL, the uncertainty Δθ in the estimation of the rotation angle is given by $\Delta\theta = \frac{1}{\sqrt{N}} e^{-r}$, where *r* is the factor of the squeezing, *N* is photon number of probe beam.

In the experiment, the squeezed light of HG_{01} mode was generated using optical parametric oscillator (OPO) with a type II phase matching KTP as its non-linear medium [9]. The dark squeezed HG_{01} mode was chosen to transform to OAP squeezed state by coupling with a bright coherent HG_{10} mode in a beam splitter.

The signal light carried with rotation angle information is then analyzed by balance homodyne detection scheme with a bright coherent light of HG_{01} mode as its local oscillator whose spatial distribution was orthogonal with the coherent HG_{10} light, which was shown in fig.2 (a). A broadband reduction from 100 kHz to 900 kHz with a noise floor of 3.0±0.03 dB relative to the shot-noise-level was obtained when OAP-squeezed light as the probe beam. A clearly peak corresponding to the rotation modulation signal was observed whose center frequency was 600 kHz. An improvement of a factor of 1.4 was achieved over the quantum noise limited coherent state, which shown in fig. 2(b). A 3.89 *urad* of rotation angular displacement was obtained at the signal-to-noise ration equaling to 1 with the OAP squeezed state.

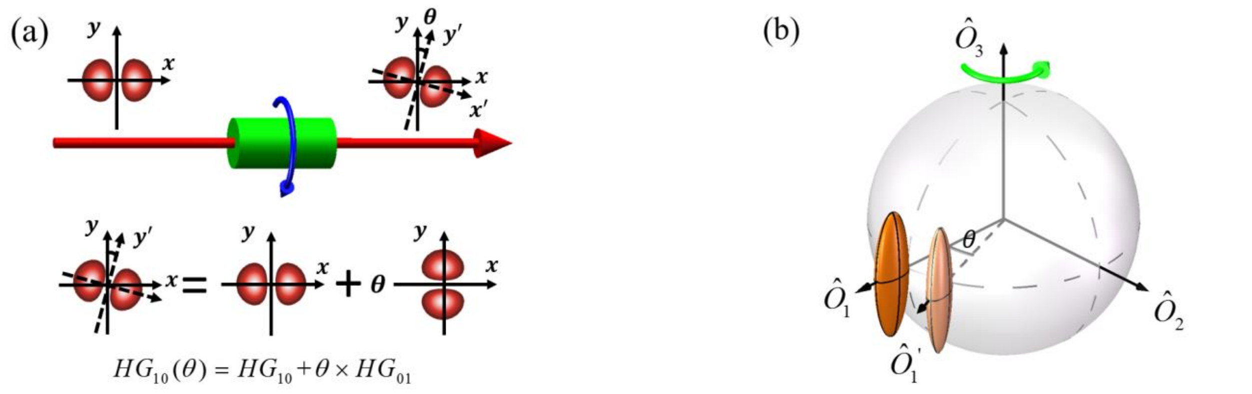

Fig. 1. Rotation definition. (a)Representation of a rotational HG10 mode in the transverse plane, and the rotation angle information is carried by its orthogonal mode component. (b) Representation of rotational OAP squeezed beam on the quantum Poincaré sphere, the rotation angle information is carried by the variances the Stokes parameter $\Delta\hat{O}_2$.

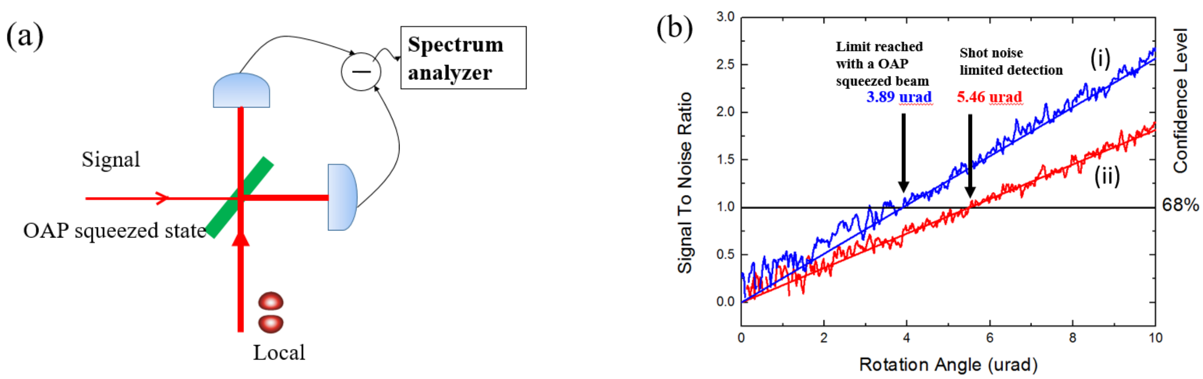

Fig.2. (a) Balance homodyne detection scheme. (b) Signal to noise versus increasing rotation angle at 600 kHz

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