Enhancement of measurement accuracy via squeezed light input

Y. Takahashi and N. Yamamoto

Department of Applied Physics and Physico-Informatics, Keio University, Hiyoshi 3-14-1, Kohoku, Yokohama, Japan
takahashiyuya@z3.keio.jp, yamamoto@appi.keio.ac.jp

When we aim to extract information from a system, we have to be careful in choosing a suitable “probe” input signal. In the case of classical deterministic systems, the outputs are also deterministic, which means that it may contain the information in very accessible manner. However, a quantum system is essentially stochastic, thus the corresponding output has to be noisy. The quantum filtering theory was established for this purpose; that is, it provides a scheme to produce the ”best” estimation of the physical quantities of the system from the noisy output data.

Mainly for the reason of implementability, a Gaussian coherent light field is usually employed as an input. As mentioned above, the output has inevitable stochastic fluctuation that causes measurement error. The fluctuation is due to the "uncertainty principle", which means that the product of fluctuations of the position and momentum components (i.e., quadratures) of the input is bounded from below and cannot be zero. To decrease the estimation error, we employ a ”squeezed light field” for input; this is a quantum light field whose single component in quadrature is squeezed while the other component is anti-squeezed with keeping the uncertainty principle. We can then decrease the estimation error of the quadrature component under measurement by applying a squeezed input whose fluctuation of the same component is squeezed. This means that the squeezed input enhances the measurement accuracy.

Now let us consider a nano-mechanical oscillator with squeezed light input [1] shown in Fig. 1. \( \hat{x} := [\hat{q}, \hat{p}]^{\top} \) denotes a vector including the position and momentum components of the oscillator. The position \( \hat{q} \) is indirectly measured through the probe field. We analytically obtain the stationary solution of the estimation errors of \( \hat{q} \) and \( \hat{p} \), and they are shown in Fig. 2. Apparently, the bigger the squeezing level of the input is, the smaller the estimation error of \( \hat{q} \) becomes. In contrast, the right one shows that the estimation error of \( \hat{p} \) becomes bigger with increasing the squeezing level.

![Schematic of the nano-mechanical oscillator subjected to the squeezed light input.](image1.png)

Figure 1: Schematic of the nano-mechanical oscillator subjected to the squeezed light input.

![Estimation error vs the squeezing level; the left and right figures the case of \( \hat{q} \) and \( \hat{p} \), respectively.](image2.png)

Figure 2: Estimation error vs the squeezing level; the left and right figures the case of \( \hat{q} \) and \( \hat{p} \), respectively.