Enhancing Sensitivity in Quantum Optomechanical Systems Through Quantum Control

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Ultra-high-precision sensors are essential in research areas including earthquake detection, medical imaging, autonomous vehicle navigation, and the Laser Interferometer Gravitational-Wave Observatory (LIGO). Observing weak gravitational waves has been a significant challenge for many years, and they have only been detected recently due to developments in quantum sensing technologies. In the case of LIGO, a weak gravitational wave interacts with a massive oscillator coupled to a movable mirror, whose movement is then detected through the phase shift of the interference in the optical cavity. This research project aims to develop a quantum optomechanical system that is essential for high-precision measurements. Our model consists of an optical cavity, a mechanical oscillator, and a noisy environment designed to examine the impact of environmental noise on the performance of our optomechanical sensor. In our numerical simulation, we use the quantum-state diffusion method to develop a set of coupled differential equations that model the noise. The major results of our model include a longer coherent time, and wider power spectral density leading to increased sensitivity to weaker signals. We additionally observed stronger feedback on signals than the Markovian process. Our findings have significant implications for designing the control strategies and improving the sensitivity of open quantum systems, with further applications in quantum computing and information storage.

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