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Feedback control and the Second Law of thermodynamics in a ratchet physical system

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We simulate a realization of Maxwell's demon based on the experimental setup developed in \textit{Bayesian Information Engine that Optimally Exploits Noisy Measurements}, in which a heavy bead, immersed in water at room temperature, is trapped by an optical tweezer and lifted through rapid feedback control without net work expenditure. This system functions as an information engine, harnessing favorable thermal fluctuations to increase the bead's gravitational potential energy while keeping the trap's potential energy unchanged. Our simulations successfully reproduce key experimental findings regarding the engine's performance across a range of noisy measurements and verify the Generalized Jarzynski Inequality. In contrast to previous works that employ a Langevin dynamics approach, we implement a molecular dynamics algorithm to model the system. Our results confirm that the Generalized Jarzynski Inequality holds for all tested cases, by a significant margin. This study contributes to the theoretical understanding of the thermodynamics of mesoscopic systems under feedback control and further reinforces the fundamental connection between information and thermodynamics.

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