QUANTUM RUN-AND-TUMBLE MEASUREMENT ENGINE

Léa Bresque[1,*], Debraj Das[1,2], Édgar Roldán[1]

[1]ICTP – The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, 34151 Trieste, Italy
[2]SISSA – International School for Advanced Studies, Via Bonomea 265, 34136 Trieste, Italy
[*]lea.bresque@protonmail.com

ABSTRACT

We introduce a single-qubit quantum measurement engine powered by backaction energy input. This engine utilizes the fundamental principles of quantum measurement and feedback to harness work from the single-qubit system. To reduce the energetic costs associated with information processing, we introduce a lazy feedback mechanism [1]. The lazy feedback step stochastically utilizes measurement outcomes, prescribed by a designated *laziness* probability. As a result, we show that the cumulative work extracted over successive cycles of the engine exhibits a second-order Markov process, analogous to a classical run-and-tumble process with transient anomalous diffusion. We derive exact analytical expressions for finite-time moments of the extracted work and key statistical measures, including first-passage-time distributions. Furthermore, we obtain the optimal laziness probability that maximizes the mean power extracted per cycle from the quantum engine. All analytical results on the extracted work are readily applicable to the run-and-tumble process, for which obtaining first-passage-time distributions is highly nontrivial. Our work thus highlights hitherto-unexplored links between quantum engine and active matter.

Keywords: Quantum measurement engine, Run-and-Tumble dynamics, Nonequilibrium work statistics, Quantum thermodynamics, Active matter
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REFERENCES

[1] Léa Bresque, Debraj Das, Édgar Roldán, *Run-and-tumble exact work statistics in a lazy quantum measurement engine: stochastic information processing*, Phys. Rev. Lett. **134** (2025), 200402.