Efficient Estimation of Multiple Temperatures via a Collisional Model

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Abstract: A quantum thermometric protocol for estimating multiple temperatures is presented. Our framework utilises the collisional model framework of repeated interaction of ancillas with multiple baths to estimate their temperatures with minimal error.

We present a quantum thermometric protocol [1] for the estimation of multiple temperatures within the collisional model framework [2]. Employing the formalism of multi-parameter quantum metrology [3], we develop a systematic strategy to estimate the temperatures of several thermal reservoirs with minimal estimation error. We prove a necessary and sufficient condition for the singularity of the Fisher information matrix for a bi-parametrized qubit state. By using controlled rotations of ancillary systems between successive interaction stages, we eliminate parameter interdependencies, thereby rendering the quantum Fisher information matrix (QFIM) non-singular. Remarkably, we demonstrate that precision enhancement in the joint estimation of multiple temperatures can be achieved even in the absence of correlations among the ancillas, surpassing the corresponding thermal Fisher information limits. Exploiting correlations within the ancillary system yields additional enhancement of Fisher information. Finally, we identify the dimensionality of the ancillary systems as a key factor governing the efficiency of multi-parameter temperature estimation.

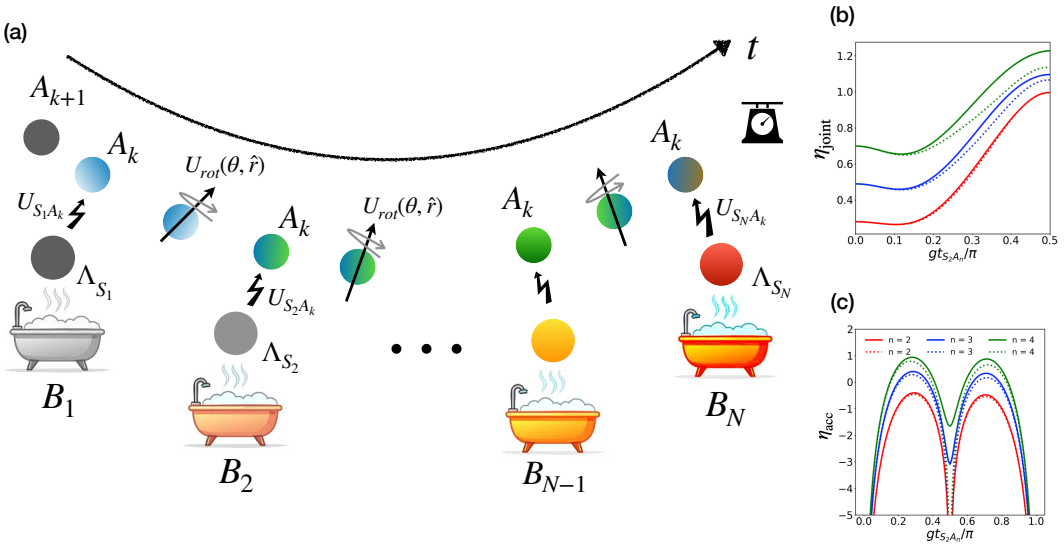

Fig. 1 The schematic representation of the protocol is given in (a). Two performance parameters $\eta_{joint} \geq 1$ and $\eta_{acc} \geq 0$ represents the protocol performing better than usual thermometry protocols is shown in (b) and (c).

In Fig. 1(a) a schematic representation of the multi-parameter temperature estimation protocol based on the collisional model is given. The information about the first bath B_1 is acquired by the $k-$th ancilla through its interaction with the probe system S_1. A controlled unitary rotation is subsequently applied to the ancilla A_k, after which it interacts with the next probe to extract information about the second bath B_2. This sequence is iteratively repeated for all N thermal reservoirs. Here $\eta_{\text{joint}} = \dfrac{\text{Tr}(\mathcal{F}_Q)}{\text{Tr}(\mathcal{F}_{\text{th}})}$ and $\eta_{\text{acc}} = \log\left[\dfrac{\det(\mathcal{F}_Q)}{\det(\mathcal{F}_{\text{th}})}\right]$, where $\mathcal{F}_Q$ and $\mathcal{F}_{th}$ represents QFIM of our protocol, and, thermal Fisher information, respectively.

Example References

[1] Srijon Ghosh, Sagnik Chakraborty, Rosario Lo Franco, arXiv preprint arXiv:2511.20448.
[2] F. Ciccarello, S. Lorenzo, V. Giovannetti, and G. M. Palma, Phys. Rep. 954, 1 (2022),
[3] M. Szczykulska, T. Baumgratz, and A. Datta, Adv. Phys.: X 1, 621 (2016).