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Quantum Bomb Detection Using The Zeno Effect

ABSTRACT

A peculiar feature of quantum mechanics is the so called ‘Zeno effect’[1]. Essentially, the effect allows you to slow down the time evolution of a quantum system by making measurements on it often enough and fast enough. Another counterintuitive phenomenon is the ‘interaction free measurement’, which allows the presence of an object to be detected without any interaction between it and the measuring device. One of the most dramatic illustrations of these two effects has been shown (by both theory and experiment) in what is called ‘quantum bomb detection’. The idea is that an ultrasensitive bomb which explodes on even the slightest interaction, can still be detected with a probability not possible in classical physics. This can be done via an interaction free measurement. Remarkably. the quantum zeno effect allows us to increase the probability of live bomb detection to arbitrary precision.

We simulate this process using a quantum circuit implemented with a python-based library: pyQuil.

METHOD

Experimental realizations of quantum bomb detection involve quantum optics with Mach-Zehnder interferometers. In our case, we simulate a quantum circuit analogue of the optics experiment using the circuit in Fig 1.

1. In the circuit, a qubit is acted on by rotation gates incrementally for N stages. This corresponds in the optical scenario to rotating the polarization of a single photon by some angle θ.
2. To model the presence of a bomb in the interaction-free device, we take another qubit initially in the $|0\rangle$ state which represents an absent bomb, *Prob (presence) = 0*. By rotating this qubit towards the state $|1\rangle$, we can model an increasing probability for the bomb’s presence until at the end of N stages, the bomb qubit is $|1\rangle$, which means *Prob (presence) = 1*.
3. To check for its presence, and henceforth an explosion, we perform a post-selection measurement on an additional qubit, the ancilla. This essentially introduces the Zeno effect in our circuit which restricts the evolution of the first qubit to $|1\rangle$.
4. Here, we measure the probability of effectiveness of Zeno effect in restricting the evolution while spanning over for given range of N passes *∊ [2, 4, 8, 16, 32, 64, 128, 256]*, and the corresponding probability of the presence of a live bomb.

RESULTS

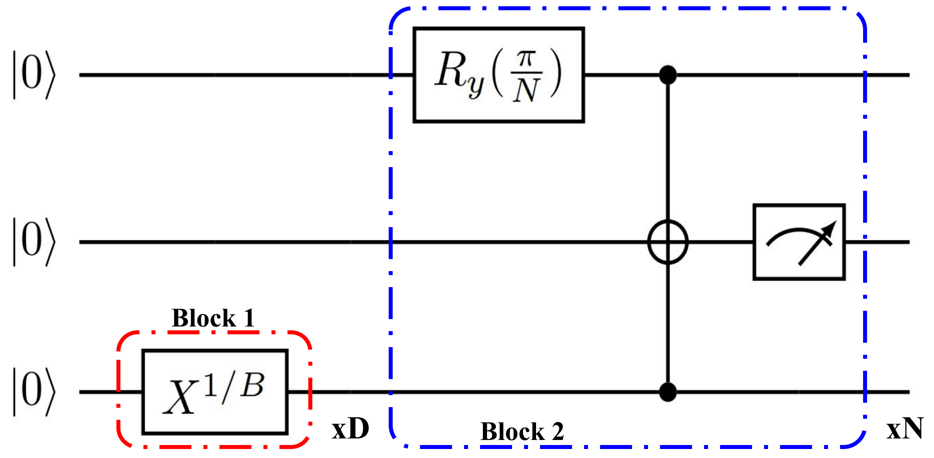

Fig 1. Block-1 consists of Bth root of pauli X gates repeated D times. This controls the probability of the presence of live bomb. Block-2 consists of a Ry gate applied on the qubit [0], followed by a toffoli gate with qubit 1 as the target and qubits 0, 2 as the control. Post-selection measurement $|0\rangle\langle 0|$ is performed at the end of every N iteration. These partial measurements make the system vulnerable to Zeno effect.

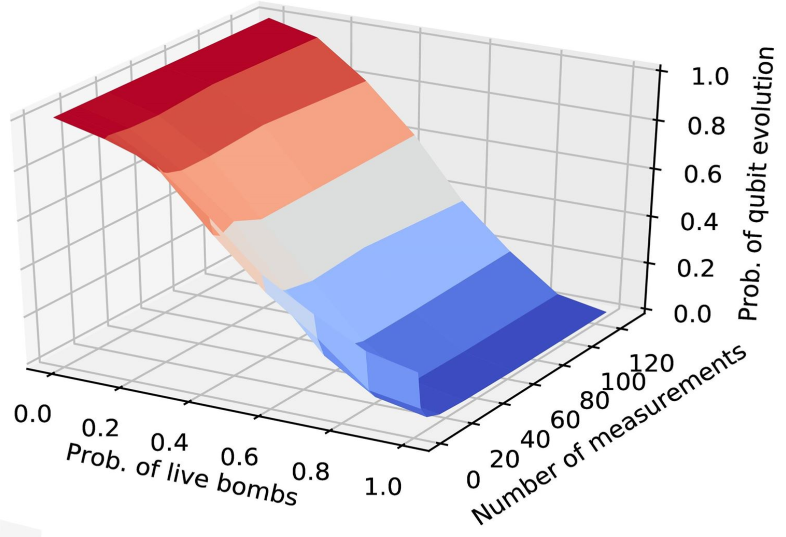

Fig 2. Results from the pyQuil simulation of the quantum circuit without qubit decoherence effects.

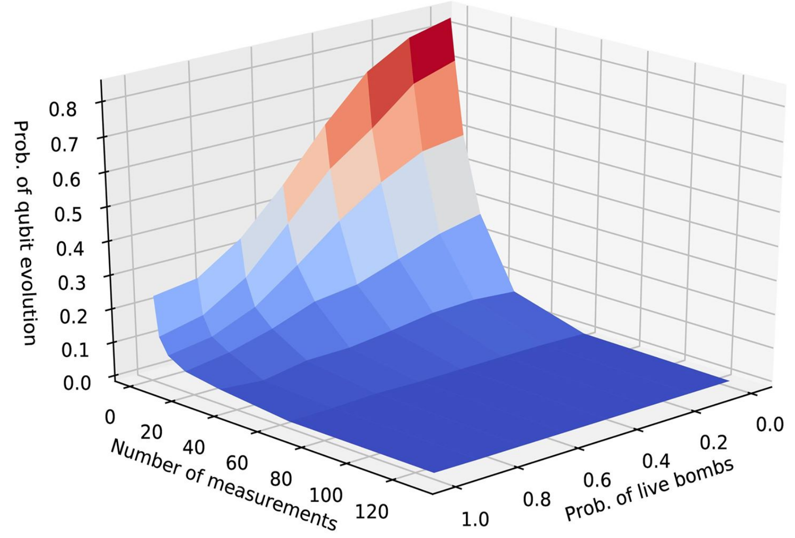

Fig 3. Results from the pyQuil simulation of the circuit by including qubit decoherence effects. Specifications: T_1=30ms, T_2=30ms, fQX = 0.9, fCZ = 0.9.

References

[1] Kwiat,P. G., White, A. G., Mitchell, J. R., Nairz, O., Weihs, G., Weinfurter, H. & Zeilinger, A. High-Efficiency Quantum Interrogation Measurements via the Quantum Zeno Effect *Physical Review Letters* **83**, 4725 - 4728 1999.

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