Kazan Federal University

Zavoiskii Physical-Technical Institute, FRC Kazan Scientific Center of RAS

International Conference "Magnetic Resonance - Current State and Future Perspectives" and satellite XXI International Youth Scientific School "Actual problems of magnetic resonance and its application"

devoted to the 75-th anniversary of the discovery of Electron Paramagnetic Resonance by E.K. Zavoiskii

Book of
ABSTRACTS

September 23-27, 2019 Kazan, Russia

Associative Memory on Qutrits by means of Quantum Annealing

V.E. Zobov, I.S. Pichkovskiy

Kirensky Institute of Physics, Federal Research Center KSC SB RAS, Krasnoyarsk, Russia

e-mail: rsa@iph.krasn.ru

At the present stage of development of information technologies, quantum properties of many-body systems open up new possibilities of artificial neural networks [1], including the associative memory [2 - 5]. Quantum superposition of states can be used to store patterns [2 - 5]. As a neuron, a qubit is usually considered - a quantum system with two states. However, in this role a system with three states — qutrit can be used. Among the advantages of qutrits over qubits it expect a faster growth of the Hilbert space, and hence the size of the computational basis with the addition of new elements. This circumstance may be important for increasing the memory capacity. As qutrits, it is suggested to use objects with spin $S=1$, for example, NV centers in diamond [6]. In this case, there is a large difference in the frequency of transitions between different energy levels, which makes it possible to control the state of the system with the help of transition-selective microwave pulses.

In this work, we consider the associative memory on the qutrits represented by the spins with $S=1$. As a computational basis, we use a basis $|m_1, m_2, ..., m_n\rangle$ of the eigenfunctions of the operators S_i^z of the projections of the spins on the *Z* axis. Each of the projections m_i can take one of three values: 1, 0, -1. To keep in memory *p* elements represented by *p* quantum vectors $|\psi_\mu\rangle = |m_1^\mu, m_2^\mu, ..., m_n^\mu\rangle$, where $\mu = 1, 2, ..., p$, we chose the projection method of memorization [2, 3], in which the recording is performed through the memory Hamiltonian $H_{mem} = -\sum_{\mu=1}^{p} |\psi_\mu\rangle\langle\psi_\mu|$. This choice is due to the need to operate with a state with a zero spin projection, the interaction of which with the magnetic field vanishes. The recording and recall of the patterns are carried out by adiabatic variation of the Hamiltonian over time (by quantum annealing) [2 - 5]:

$$H(t) = (1 - t/T)H_0 + (t/T)(1 - t/T)H_{help} + (t/T)(H_{mem} + \Gamma H_{prob}),$$

where $H_0 = -h\sum_{i=1}^{n} S_i^x$ is the initial Hamiltonian, $H_{prob} = -|\psi_{prob}\rangle\langle\psi_{prob}|$ is a probe Hamiltonian of hint, Γ is a small coefficient. H_{help} is an auxiliary Hamiltonian with off-diagonal projectors which we have proposed to equalize the probabilities of finding the system in different states of superposition. We performed simulations on two and three qutrits and shown an increase in the memory capacity after replacing qubits with qutrits. As a result, we demonstrated the possibility of realizing associative memory on qutrits and pattern recognition by means of quantum annealing.

[1] V. Dunjko and H. J. Briegel, Reports on Progress in Physics **81**, 074001 (2018).
[2] R. Neigovzen, J.L. Neves, R. Sollacher, and S.J. Glaser, Phys. Rev. A **79,** 042321 (2009).
[3] H. Seddiqi and T.S. Humble, Front. Phys. **2**, 79 (2014).
[4] S. Santra, O. Shehab, and R. Balu, Phys. Rev. A **96**, 062330 (2017).
[5] C. Dlaska, L.M. Sieberer, and W. Lechner, Phys. Rev. A **99**, 032342 (2019).
[6] M.F. O'Keeffe, L. Horesh, D.A. Braje, and I.L. Chuang, New J. Phys. **21,** 023015 (2019).