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RESEARCH ARTICLE

Online optimization for optical readout of a single electron spin in diamond

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Supporting Information

I. HOOKE-JEEVES ALGORITHM

The pattern search method was proposed by Hooke and Jeeves in 1961, so it is called Hooke-Jeeves method. In a geometric sense, the basic idea of this method is to look for "valleys" with smaller functional values, trying to make the sequence generated by iteration close to the minimum point along the "valley" trend. Starting from the initial base point, the algorithm has two types of movement, namely detection movement and pattern movement. The detection movement is performed along n coordinate axes in turn to determine the new base point and the direction conducive to the decline of the function value. And, the model movement is carried out in the direction of the connection of adjacent two basis points, trying to follow the "valley" to make the function value decrease faster. The calculation steps of the Hooke-jeeves method are also summarized in the Table I.

TABLE I. Computational steps of the Hooke-Jeeves algorithm.

Hooke-Jeeves algorithm
0. Start from the initial point $\boldsymbol{u}^0 = [u_1, u_2, ..., u_n]^0$ and $f(\boldsymbol{u}^0)$
$\boldsymbol{y}^0 = \boldsymbol{u}^0, k = 0$
1. While the acceleration factor $\alpha <$ allowable error ε
2. for $1 \leq i \leq n$
3. if $f(\boldsymbol{y}^{i-1} + \alpha * \boldsymbol{e}_i) > f(\boldsymbol{u}^k)$
4. $\boldsymbol{y}^i = \boldsymbol{y}^{i-1} + \alpha * \boldsymbol{e}_i$
5. else if $f(\boldsymbol{y}^{i-1} - \alpha * \boldsymbol{e}_i) > f(\boldsymbol{u}^k)$
6. $\boldsymbol{y}^i = \boldsymbol{y}^{i-1} - \alpha * \boldsymbol{e}_i$
7. else $\boldsymbol{y}^i = \boldsymbol{y}^{i-1}$
8. if $f(\boldsymbol{y}^n) > f(\boldsymbol{u}^k)$
9. $\boldsymbol{u}^{k+1} = \boldsymbol{y}^n, \boldsymbol{y}^0 = \boldsymbol{u}^k + \alpha(\boldsymbol{u}^{k+1} - \boldsymbol{u}^k)$
10. else $\varepsilon = \beta\varepsilon, \boldsymbol{y}^0 = \boldsymbol{u}^{k+1} = \boldsymbol{u}^k$
11. $k = k + 1$

II. SIMULATION RESULTS FOR OTHER NV CENTERS

Our simulations rely on QuTip, an open-source library for simulating the dynamics of quantum systems, in which we demonstrate our method on three different NV centers. Their transition rates are shown in Table II, which come from literatures [1, 2]. The simulation results of NV1 are shown in the main text. Fig. 1 and Fig. 2 in the supplementary information show the simulation results of NV2 and NV3, respectively. A random starting parameters (duration and pumping rate) for readout optimization for NV2 and NV3 is chosen to be (720 ns, 0.05 GHz) and (100 ns, 0.14 GHz), respectively. As shown in Fig. 1 and Fig. 2, the optimal SNR achievable with traditional scheme in NV2 and NV3 is 263.3 and 300.9, respectively. The searched optimal parameters (see Fig. 1(f) and Fig. 2(f)) induce a final SNR of 403.2 in NV2 and 440.7 in NV3, which are 53.1% and 46.4% higher than using the constant waveform (the traditional scheme), respectively.

TABLE II. Transition Rates(ns^{-1}) in Simulation.

Sample	k_{31}, k_{42}	k_{35}	k_{45}	k_{51}	k_{52}
NV1	0.0677	0.0067	0.0507	0.0007	0.0006
NV2	0.0691	0.0052	0.0486	0.0015	0.0014
NV3	0.4396	0.0314	0.1884	0.020724	0.013816

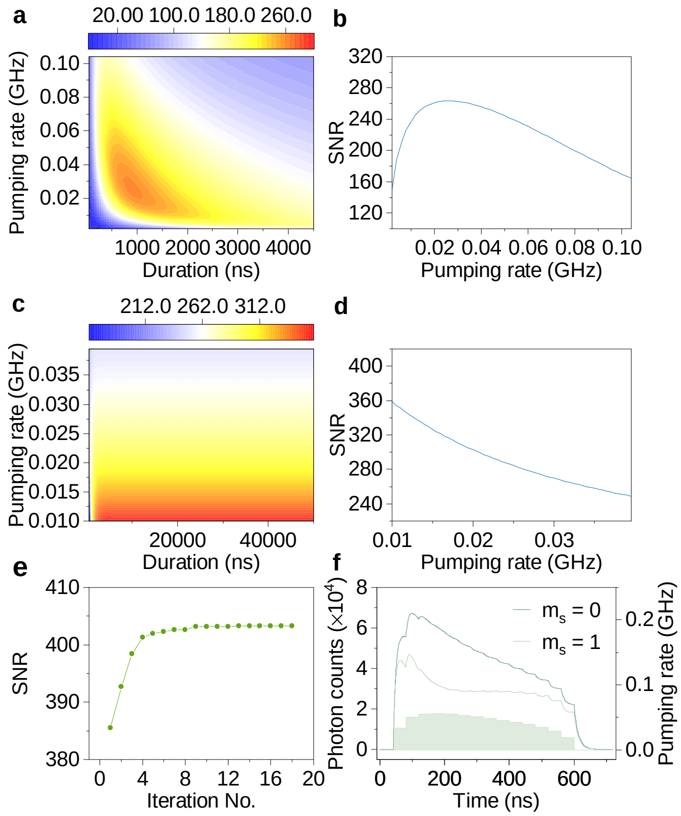

FIG. 1. Simulation results of NV2. (a) and (c) Theoretical SNR of the traditional scheme as a function of the pumping rate and duration for global optical pumping and initialization, respectively. (b) and (d) SNR of the traditional scheme as a function of pumping rate in simulations or power in experiments under optimal duration conditions for global optical pumping and initialization, respectively. (e) shows the optimization process for simulations. The dotted lines represent the optimal SNR achieved at each iteration. (f) plots the final optimal laser waveform (shaded area) and photon time traces of the $m_s = 0$ and $m_s = 1$ for simulations.

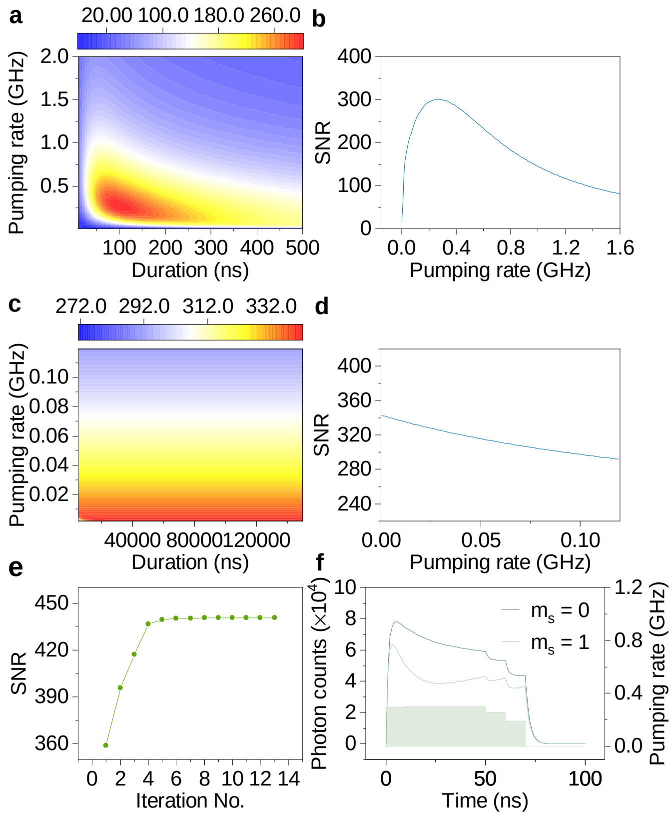

FIG. 2. Simulation results of NV3. (a) and (c) Theoretical SNR of the traditional scheme as a function of the pumping rate and duration for global optical pumping and initialization, respectively. (b) and (d) SNR of the traditional scheme as a function of pumping rate in simulations or power in experiments under optimal duration conditions for global optical pumping and initialization, respectively. (e) shows the optimization process for simulations. The dotted lines represent the optimal SNR achieved at each iteration. (f) plots the final optimal laser waveform (shaded area) and photon time traces of the $m_s = 0$ and $m_s = 1$ for simulations.

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