Washington University in St. Louis
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TOOLKIT TO EFFICIENTLY DESIGN EXACT PULSE CODE SEQUENCES FOR MRI, NMR OR QUANTUM COMPUTING

Li, Jr-Shin

Markiewicz, Gregory

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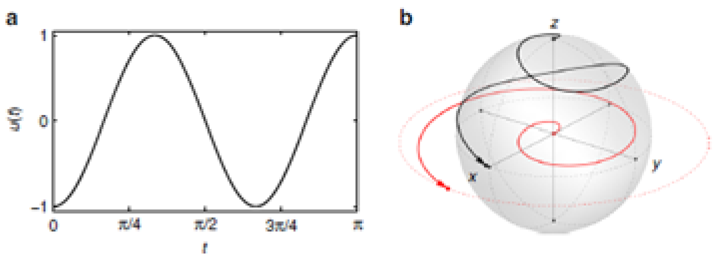
Technology Description

Engineers in Prof. Jr-Shin Li's laboratory have developed a computationally efficient analytical technique to design exact RF pulse code sequences which optimize quantum applications such as MRI for medical diagnosis, NMR spectroscopy for uncovering protein structures or quantum computing for information processing.

Accurate and high-fidelity broadband pulses are necessary for exploiting quantum properties in a variety of fields but they are difficult to design due to the complexity of quantum spin dynamics. In the past, these pulses have been discovered by approximation and testing which is slow and highly customized. This new technology simplifies the pulse design process by providing a specific mathematical formula with an exact result to excite a population of nuclear spins over a wide band of frequencies. This computational toolkit is based on the revelation that complex, non-linear spin systems can be mapped to linear harmonic oscillator spring systems to obtain simple analytical expressions for NMR and other pulses. After this mapping, the results can be numerically optimized to satisfy designated experimental requirements. Overall, this approach could push past limitations of current numerical methods to provide analytical quantum pulses which enable ultrafast all optical signal processing devices, control of logical qubits, or high resolution MRI/NMR imaging.



Exact excitation of single spins. *The minimum-energy control steering the spring (a) with the corresponding trajectories (b) of the spring (red) and spin (black).*

Stage of Research

Proof of concept: The inventors have performed simulations to demonstrate that the projection from nonlinear (spin) to linear (spring) is valid. They were able derive analytic broadband 90° and 180° (p and p /2) pulses used commonly in NMR by designing controls that steer a spring between specific states. This work strongly suggest that the framework can be generalized to design pulses that employ two controls simultaneously and also that achieve arbitrary flip angles.

Applications

- **Analytical pulse design** with end user applications such as:
  - MRI
  - NMR spectrometry
  - quantum computing
  - all-optical signal processing

Key Advantages

- **Computationally efficient, exact solutions -** pulse code sequences can be:
  - computed with minimal computational effort
  - solved exactly or quickly asymptotically approximated
  - designed to satisfy parameters such as RF amplitude or total energy of the pulse
- **High resolution images –** pulse code sequences designed by this method provide better signal-to-noise ratio to enhance images in a diverse range of applications

Publications

- Li, J. S., Ruths, J., & Glaser, S. J. (2017). Exact broadband excitation of two-level systems by mapping spins to springs. *Nature communications*, 8(1), 446.
- Decade of work pays off. *theSource* Sept. 5, 2017.

Patents: Methods of constructing and designing rf pulses and exciting or inverting two-level systems (U.S. Patent No. 10,956,827)

Website: Li Lab