Overcoming the quantum sensing barrier: New protocol counteracts the limitation of decoherence

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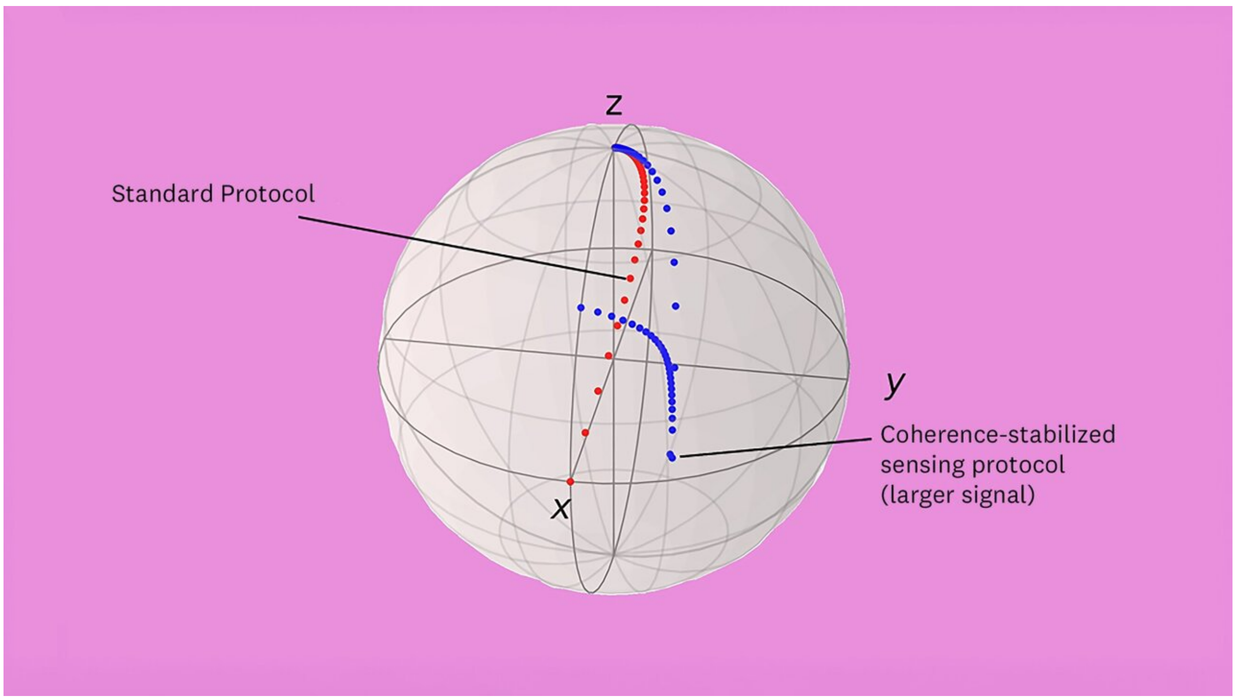

The qubit state decays toward the "north pole" of the sphere due to decoherence. Using the study's coherence-stabilized sensing protocol, the researchers temporarily counteracted the decay, leading to a larger sensing signal (y component) in the study's protocol (blue) than the standard protocol (red). Credit: Eli Levenson-Falk/USC

Researchers have demonstrated a new quantum sensing technique that widely surpasses conventional methods, potentially accelerating advances in fields ranging from medical imaging to foundational physics research, as shown in a study published in Nature Communications.

For decades, the performance of quantum sensors has been limited by decoherence, which is unpredictable behavior caused by environmental noise.

"Decoherence causes the state of a quantum system to become randomly scrambled, erasing any quantum sensing signal," said Eli Levenson-Falk, senior author of the study, associate professor of physics and astronomy at the USC Dornsife College of Letters, Arts and Sciences and associate professor of electrical and computer engineering at the USC Viterbi School of Engineering.

Quantum sensing is the use of quantum systems (such as atoms, light particles or qubits) as sensors to measure physical quantities (such as brain activity, ultra-precise clocks or gravity anomalies) with extreme precision, often surpassing the limits of classical sensors. Sensing devices utilize quantum properties (like superposition, entanglement and coherence) to detect tiny signals that would otherwise be drowned out by noise.

"Think of it as trying to hear a faint whisper in a noisy space," said Malida Hecht, doctoral student in physics at USC Dornsife and lead author of the study. "Quantum sensing devices detect things that are too small or faint for normal measuring tools to notice."

Counteracting decoherence with a new coherence-stabilized protocol

In the new study, the research team temporarily counteracted the longstanding problem of decoherence by using a new pre-determined coherence-stabilized protocol on their experiment's qubit, stabilizing one key property of the quantum state.

The study's protocol was based on theory derived by co-authors Daniel Lidar (Viterbi Professor of Engineering and professor of chemistry and physics and astronomy at USC) and Kumar Saurav (doctoral student in electrical engineering at USC Viterbi).

This experiment significantly improved the measurement of small frequency shifts in quantum systems. Levenson-Falk said the study's coherence-stabilized sensing protocol allows the sensing signal, which takes the form of a change in the quantum state, to grow larger than it would with the standard protocol sensing measurement.

This stabilization could prove crucial for applications where detecting subtle signals is essential. "The larger signal is easier to detect, giving improved sensitivity," Levenson-Falk said.

"Our study gives the best sensitivity for detecting a qubit's frequency to date. Most importantly, our protocol requires no feedback and no extra control or measurement resources, making it immediately applicable across various quantum computing and quantum sensor technologies."

165% improvement in sensing ability

The researchers demonstrated their protocol on a superconducting qubit, achieving up to 1.65 times better efficacy per measurement compared to the standard protocol known as Ramsey interferometry. Theoretical analysis indicated potential improvements of up to 1.96 times in some systems.

Levenson-Falk said his experimental demonstration of sensing with a stabilized state shows that there are ways to improve quantum sensors without resorting to complicated techniques like real-time feedback or entangling many sensors.

"It also shows that we have not yet extracted all the possible information from these types of measurements. Even better sensing protocols are out there, and we could use them to make immediate real-world impacts."

More information: Beating the Ramsey limit on sensing with deterministic qubit control, *Nature Communications* (2025). DOI: 10.1038/s41467-025-58947-4.
www.nature.com/articles/s41467-025-58947-4

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