TU Delft researchers realize quantum teleportation onto mechanical motion of silicon beams

Quantum technology typically employs qubits (quantum bits) consisting of, for example, single electrons, photons, or atoms. A group of TU Delft researchers has now demonstrated the ability to teleport an arbitrary qubit state from a single photon onto an optomechanical device – consisting of a mechanical structure comprising billions of atoms. Their breakthrough research, now published in Nature Photonics, enables real-world applications such as quantum internet repeater nodes while also allowing quantum mechanics itself to be studied in new ways.

Quantum optomechanics
The field of quantum optomechanics uses optical means to control mechanical motion in the quantum regime. The first quantum effects in microscale mechanical devices were demonstrated about ten years ago. Focussed efforts have since resulted in entangled states between optomechanical devices as well as demonstrations of an optomechanical quantum memory. Now, the group of Simon Gröblacher, of the Kavli Institute of Nanoscience and the Department of Quantum Nanoscience at Delft University of Technology, in collaboration with researchers from the University of Campinas in Brazil, has shown the first successful teleportation of an arbitrary optical qubit state onto a micromechanical quantum memory.

Repeater nodes for a quantum internet
Quantum teleportation – the faithful transfer of an unknown input quantum state onto a remote quantum system – is a key component of long-distance quantum communication protocols needed to build a quantum internet. Just like the regular internet, distribution of quantum information between quantum devices anywhere in the world will require a network of repeater nodes. Each node will temporarily store the quantum information in a memory before teleporting it to a subsequent node, ultimately establishing long-distance quantum communication.

Two micromechanical resonators sharing a single quantum state
In their experiment, the researchers create a polarisation-encoded photonic qubit in an arbitrary quantum state. They then transport this photon over tens of meters of optical fibre and teleport it onto their quantum memory comprised of two massive, mechanical silicon resonators – each about 10 micrometres in size and consisting of tens of billions of atoms. The quantum information was stored in the single-excitation subspace of the two resonators. To test the reliability of the process, the researchers further demonstrated that they could faithfully retrieve this teleported state from the memory.

Telecom wavelengths
Although quantum teleportation has already been demonstrated in various quantum systems, the use of optomechanical devices is a breakthrough because they can be designed to operate at any optical wavelength, including the low-loss infrared telecom fibre wavelengths. 'It is this wavelength that results in the lowest transmission loss, allowing the longest distance between repeater nodes,' Gröblacher says. 'This milestone was possible due to the quality and flexibility of our nanofabricated optomechanical systems, which,

unlike most other quantum systems, allow for independently engineered optical properties. A future quantum internet will undoubtedly make use of the existing telecom network at this wavelength.'

All the building blocks

In principle, quantum teleportation can be done over arbitrary distances. By teleporting a photonic quantum state over tens of meters of optical fibre onto a quantum memory, the researchers have demonstrated the requirement for a fully functional optomechanical quantum repeater node. Gröblacher: 'We now have to further improve the performance to the level required for a system that can be deployed in a real-world application, such as increasing the repetition rates, fidelities and the success-rate of the qubit teleportation and storage.' According to Thiago Alegre, researcher at the University of Campinas and collaborator on this project, one route will be to design optomechanical systems that are resilient to parasitic optical absorption. 'This can be realized due to the flexibility of these nanofabricated devices.'

A hybrid approach

The current research is a big step towards Gröblacher's vision of a future hybrid quantum internet. 'We are working towards a heterogeneous network where you have various physical systems communicating and performing different functionalities,' he says. 'You may have optomechanical quantum repeater nodes connected to a quantum computer or memory consisting of superconducting qubits or spin quantum systems, respectively. All of these will have to be compatible with one another and operate at the same wavelength in order to faithfully transfer quantum information.'

Quantum-to-classical transition

Besides enabling building blocks for novel quantum technologies, the ability to teleport an arbitrary qubit state onto massive, mechanical oscillators can also be used for testing quantum physics itself at a fundamental level. Whereas very small systems typically behave according to the laws of quantum mechanics, large systems are governed by the classical laws of physics. 'Experiments have excluded certain theories describing decoherence mechanisms leading to the quantum-to-classical transition, but we are far away from a definitive answer,' Gröblacher says. 'As it is relatively easy to scale our optomechanical systems and to use teleportation to create interesting quantum states, this is an important step in understanding this boundary.'

Article

N. Fiaschi, B. Hensen, A. Wallucks, R. Benevides, J. Li, T.P. M. Alegre, and S. Gröblacher, *Optomechanical quantum teleportation*, Nature Photon. (2021)
https://www.nature.com/articles/s41566-021-00866-z

More Information

For more information please contact:

Prof. Simon Gröblacher
Department of Quantum Nanoscience
Kavli Institute of Nanoscience

Delft University of Technology
Lorentzweg 1, 2628CJ Delft
T +31 15 2786124
s.groeblacher@tudelft.nl