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UW students have turned Schrödinger's cat on its head

Students at the Faculty of Physics of the University of Warsaw (UW) and researchers from the QOT Centre for Quantum Optical Technologies have developed an innovative method that allows the fractional Fourier Transform of optical pulses to be performed using quantum memory. This achievement is unique on the global scale, as the team was the first to present an experimental implementation of the said transformation in this type of system. The results of the research were published in the prestigious journal Physical Review Letters. In their work, the students tested the implementation of the fractional Fourier Transform using a double optical pulse, also known as a "Schrödinger's cat" state.

The spectrum of the pulse, and temporal distribution

Waves, such as light, have their own characteristic properties - pulse duration and frequency (corresponding, in the case of light, to its color). It turns out that these characteristics are related to each other through an operation called the Fourier Transform, which makes it possible to switch from describing a wave in time to describing its spectrum in frequencies.

The fractional Fourier Transform is a generalization of the Fourier Transform that allows a partial transition from a description of a wave in time to a description in frequency. Intuitively, it can be understood as a rotation of a distribution (for example, the chronocyclic Wigner function) of the considered signal by a certain angle in the time-frequency domain. It turns out that transforms of this type are exceptionally useful in the design of special spectral-temporal filters to eliminate noise and enable the creation of algorithms that make it possible to use the quantum nature of light to distinguish pulses of different frequencies more precisely than traditional methods. This is especially important in spectroscopy, which helps study the chemical properties of matter, and telecommunications, which requires the transmission and processing of information with high precision and speed.

Lenses, and the Fourier Transform?

An ordinary glass lens is capable of focusing a monochromatic beam of light falling on it to almost a single point (focus). Changing the angle of incidence of light on the lens results in a change in the position of the focus. This allows us to convert angles of incidence into positions, obtaining the analogy of the Fourier Transform, in the space of directions and positions. A classical spectrometer based on a diffraction grating uses this effect to convert

the wavelength information of light into positions, allowing us to distinguish between spectral lines.

Time and frequency lenses

Similarly to the glass lens, time and frequency lenses allow the conversion of a pulse's duration into its spectral distribution, or effectively, perform a Fourier transform in time and frequency space. The right selection of powers of such lenses makes it possible to perform a fractional Fourier Transform. In the case of optical pulses, the action of time and frequency lenses corresponds to applying quadratic phases to the signal.

To process the signal, the researchers used a quantum memory - or more precisely a memory equipped with quantum light processing capabilities - based on a cloud of rubidium atoms placed in a magneto-optical trap. The atoms were cooled to a temperature of tens of millions of degrees above absolute zero. The memory was placed in a changing magnetic field, allowing components of different frequencies to be stored in different parts of the cloud. The pulse was subjected to a time lens during writing and reading, and a frequency lens acted on it during storage.

The device developed at the UW allows the implementation of such lenses over a very wide range of parameters and in a programmable way. A double pulses is very prone to decoherence, hence it is often compared to the famous Schrödinger cat - a macroscopic superposition of being dead and alive, almost impossible to achieve experimentally. Still, the team was able to implement faithful operations on those fragile dual-pulse states.

The publication was the result of work in the Quantum Optical Devices Laboratory and Quantum Memory Laboratory in the "Quantum Optical Technologies" center with the participation of two master's students: Stanisław Kurzyna and Marcin Jastrzębski, two undergraduate students Bartosz Niewelt and Jan Nowosielski, Dr. Mateusz Mazelanik, and lab heads Dr. Michał Parniak and Prof. Wojciech Wasilewski. For the described results, Bartosz Niewelt was also awarded a presentation grant award during the recent DAMOP conference in Spokane, WA.

Before direct application in telecommunications, the method must first be mapped to other wavelengths and parameter ranges. Fractional Fourier transform, however, could prove crucial for optical receivers in state-of-the-art networks, including optical satellite links. A quantum light processor developed at the UW makes it possible to find and test such new protocols in an efficient way.

The "Quantum Optical Technologies" (MAB/2018/4) project is carried out within the International Research Agendas programme of the Foundation for Polish Science co-financed by the European Union under the European Regional Development Fund. The UW's Center for Quantum Optical Technologies (hosted in CeNT - the Centre of New Technologies) is a research unit seeking practical applications of the latest discoveries in quantum optics.

Faculty of Physics of the University of Warsaw

Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics, the Department of Mathematical Methods and the Astronomical Observatory. The research covers almost all areas of modern physics, on scales from quantum to cosmological. The Faculty's research

and teaching staff consists of over 200 academic teachers, 88 of whom are professors. About 1,100 students and over 170 doctoral students study at the Faculty of Physics at the University of Warsaw.

SCIENTIFIC PUBLICATION:

Niewelt, B., Jastrzębski, M., Kurzyna, S., Nowosielski, J., Wasilewski, W., Mazelanik, M., and Parniak, M. Experimental Implementation of the Optical Fractional Fourier Transform in the Time-Frequency Domain. Phys. Rev. Lett., 130, 240801 (2023).

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RELATED WEBSITES WWW:

<https://www.fuw.edu.pl>

Website of the Faculty of Physics, University of Warsaw, Poland

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Press service of the Faculty of Physics of the University of Warsaw, Poland

<http://qodl.cent.uw.edu.pl/>

Webpage of the Quantum Optical Devices Lab

<http://qot.uw.edu.pl/>

Webpage of the QOT Centre for Quantum Optical Technologies, University of Warsaw

GRAPHIC MATERIALS:

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https://www.fuw.edu.pl/tl_files/press/images/2023/FUW230629b_fot01.jpg

Students in the laboratory presenting rotation of Schrödinger cat states. No actual cats were hurt during the project. (Photo: S. Kurzyna and B. Niewelt, source: University of Warsaw)