Optical micro-oscillator could lead to next-generation timing, navigation and sensing applications

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The micro-oscillator functions analogously to the gears of a clock pendulum. Credit: Nicoletta Barolini

A team of engineering researchers from UCLA and OEWaves has developed an optical micro-oscillator, a key time-keeping component of clocks that could vastly improve the accuracy of time-keeping, which is essential for use in spacecraft, automobile sensing or satellite communications.

An optical oscillator is similar to a pendulum in a grandfather clock, only instead of a swinging motion to keep time, its "tick" is the laser's very high frequency, or cycles per second. This "optical pendulum" is a laser light confined in a very quiet resonator that allows for the light to bounce back and forth without losing its energy. This class of optical oscillators is extremely accurate. However, they are large stand-alone devices, about the size of a home kitchen oven, and must be kept in completely stable laboratory conditions.

The new oscillator has laboratory-like stability, and is small and lightweight enough to be potentially incorporated into satellites, in cars for super-accurate navigation, for ultra-high precision measurement, or even an everyday device like a smartphone. The improvement is orders of magnitude better compared to the best currently available outside a lab, which are quartz crystal oscillators in luxury wrist watches, computers and smartphones. The new device also takes advantage of a phenomenon discovered in St. Paul's Cathedral in London.

The researchers suggest this could be used in miniaturized atomic clocks for spacecraft and satellites, for which precise timing is important to navigation. It could be used for precision distance and rotation sensing for cars and other vehicles and in high-resolution optical spectroscopy, which is used to image molecular and atomic structures.

"Any fluctuations in temperature or pressure can change the size of the oscillators, and therefore changes how far the laser light travels, and thus, the accuracy of the oscillation," said Chee Wei Wong, professor of electrical engineering at the UCLA Henry Samueli School of Engineering and Applied Science and the principal investigator on the research.

Think of when a doorframe expands or contracts because of changes in temperature. At the tiny scales of optical oscillators, even the smallest change in size can affect its accuracy.

The research team's new oscillator is accurate and stable. The light oscillation frequency doesn't change more than 0.1 parts per billion. At the same time, they shrank the oscillator's size down to only 1 cubic centimeter in volume.

"The miniature stabilized laser demonstrated in this work is a key step in reducing the size, weight and power of optical clocks, and to make possible their availability outside the laboratory and for field applications," said Lute Maleki, CEO of OEwaves.

The research team's optical oscillator is three to five times more stable than existing devices in not being affected during extreme changes in temperature and pressure. Based on experimental results, the researchers also suggest its stability could be as much as 60 times better.

"Usually, even tiny variations of the atmospheric temperature or pressure introduce measurement uncertainty by an order of magnitude larger than the observed effects," said Jinkang Lim, a UCLA postdoctoral researcher in the Mesoscopic Optics and Quantum Electronics Laboratory and the lead author on the study. "We carefully designed our resonator and isolated it from the ambient fluctuations. Then we observed the minute changes and saw it remained stable, even with environmental changes.

"This tiny oscillator could lead to measurement and navigation devices in the field, where temperature and pressure are not controlled and change dramatically," Lim added. "This new micro-oscillator could retain its accuracy, even with unfriendly environmental conditions."

The optical micro-oscillator, works at this level of accuracy because it confines the laser light inside itself by using what's known as "whispering gallery-mode" resonance, so named because of similarities to how a someone can whisper something against the walls in the dome of London's St. Paul's Cathedral, where this phenomenon was first reported, that will be completely audible on the opposite side. The phenomenon is also in New York City's Grand Central Station. In this case, the laser light wave propagates along the specially-designed interior of the micro-resonator. Additionally, the frequency remains stable as the micro-resonator resists changes from temperature and pressure. Finally, the light oscillations themselves are very distinct, rather than "fuzzy."

More information: Jinkang Lim et al. Chasing the thermodynamical noise limit in whispering-gallery-mode resonators for ultrastable laser frequency stabilization, *Nature Communications* (2017). DOI: 10.1038/s41467-017-00021-9

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