*** 北米連携センター情報***

2014 年 11 月 13 日

●MITなど、携帯型原子時計への道開く新アプローチを開発

【MIT News Office, 2014/11/12】

MIT、ドレイパー研究所の共同研究グループは、ルービックキューブ程度の大きさで安定的かつ正確に動作する携帯型原子時計の実現につながる新たな原子時管理のアプローチを見出した。

この手法は「Physical Review A」誌で発表された。チップ・サイズの原子時計(CSAC) は商業提供されているものの、世界時間を定めるより大型の原子泉時計に比べると精度は低い。

しかし現在最も精度が高いセシウム原子泉時計は安定性を失わずに持ち運びできない。

そこで共同研究グループはこれまでセシウムの振動計測に使っていたマイクロ波の代わりに、空間的制御が容易で必要なスペースも小さくなるレーザーを利用。

レーザーを利用する場合、レーザー自体などが生み出す磁場の影響で原子の振動周波数が変動する「AC Strak シフト」という現象がしばしば発生し、これが精度の低下を招くことがあるが、今回のアプローチはレーザーを固定された周波数・強度で照射せず、ラマン高速断熱通過法 (Raman adiabatic rapid passage) によって、レーザーパルスの周波数・強度を変動させながら照射する方法を採ることで AC Stark シフトの発生頻度を従来レーザー・システムの 100 分の 1 に抑制することに成功した。

この研究はドレイパー研究所をスポンサーとして進められており、グループは現在、真空室や電子部品などシステムの構成要素のサイズ縮小に取り組んでいる。

記事入手元：
http://newsoffice.mit.edu/2014/portable-atomic-clocks-1112

（参考）本件報道記事

Atomic timekeeping, on the go

A new approach to atomic timekeeping may enable more stable and accurate portable atomic clocks.
New approach may enable more stable and accurate portable atomic clocks.

Jennifer Chu | MIT News Office
November 12, 2014

What time is it? The answer, no matter what your initial reference may be — a wristwatch, a smartphone, or an alarm clock — will always trace back to the atomic clock.

The international standard for time is set by atomic clocks — room-sized apparatuses that keep time by measuring the natural vibration of atoms in a vacuum. The frequency of atomic vibrations determines the length of one second — information that is beamed up to GPS satellites, which stream the data to ground receivers all over the world, synchronizing cellular and cable networks, power grids, and other distributed systems.

Now a group at MIT and Draper Laboratory has come up with a new approach to atomic timekeeping that may enable more stable and accurate portable atomic clocks, potentially the size of a Rubik's cube. The group has outlined its approach in the journal Physical Review A.

While chip-sized atomic clocks (CSACs) are commercially available, the researchers say these low-power devices — about the size of a matchbox — drift over time, and are less accurate than fountain clocks, the much larger atomic clocks that set the world's standard. However, while fountain clocks are the most precise timekeepers, they can't be made portable without losing stability.

"You could put one in a pickup truck or a trailer and drive it around with you, but I'm guessing it won't deal very well with the bumps on the road," says co-author Krish Kotru, a graduate student in MIT's Department of Aeronautics and Astronautics. "We have a path toward making a compact, robust clock that's better than CSACs by a couple of orders of magnitude, and more stable over longer periods of time."

Kotru says such portable, stable atomic clocks could be useful in environments where GPS signals can get lost, such as underwater or indoors, as well as in militarily "hostile environments," where signal jamming can block traditional navigation systems.

Co-authors of the paper include Justin Brown, David Butts, Joseph Kinast, and Richard Stoner of Draper Laboratory.

A shift in time

The team came up with the new atomic timekeeping approach by making several “tweaks” to the standard method.

The most accurate atomic clocks today use cesium atoms as a reference. Like all atoms, the cesium atom has a signature frequency, or resonance, at which it oscillates. Since the 1960s, one second has been defined as 9,192,631,770 oscillations of a cesium atom between two energy levels. To measure this frequency, fountain clocks toss small clouds of slow-moving cesium atoms a few feet high, much like a pulsed fountain, and measure their oscillations as they pass up, and then down, through a microwave beam.

Instead of a microwave beam, the group chose to probe the atom’s oscillations using laser beams, which are easier to control spatially and require less space — a quality that help in shrinking atomic clock apparatuses. While some atomic clocks also employ laser beams, they often suffer from an effect called “AC Stark shift,” in which exposure to an electric field, such as that produced by a laser, can shift an atom’s resonant frequency. This shift can throw off the accuracy of atomic clocks.

“That’s really bad, because we’re trusting the atomic reference,” Kotru says. “If that’s somehow perturbed, I don’t know if my low-quality wristwatch is wrong, or if the atoms are actually wrong.”

To avoid this problem, most standard fountain clocks use microwave beams instead of lasers. However, Kotru and his team looked for ways to use laser beams while avoiding AC Stark shift.

Keeping time, in miniature

In laser-based atomic clocks, the laser beam is delivered at a fixed frequency and intensity. Kotru’s team instead tried a more varied approach, called Raman adiabatic rapid passage, applying laser pulses of changing intensity and frequency — a technique that is also used in nuclear magnetic resonance spectroscopy to probe features in individual molecules.

“For our approach, we turn on the laser pulse and modulate its intensity, gradually turning it on and then off, and we take the frequency of the laser and sweep it over a narrow range,” Kotru explains. “Just by doing those two things, you become a lot less sensitive to these systematic effects like the Stark shift.”

In fact, the group found that the new timekeeping system suppressed the AC Stark shift by a factor of 100, compared with a conventional laser-based system. Unlike fountain clocks, which shoot atoms more than a meter upwards in order to measure a single second, the team’s apparatus measures time in intervals of 10 milliseconds — an approach that is less accurate than fountain clocks, but much more compact.

“That’s fine, because we’re not trying to make the world’s standard — we’re trying to make something that would fit in, say, a Rubik’s cube, and be stable over a day or a week,” Kotru says.

The stability and accuracy of the system, he says, should be comparable to that of microwave-based atomic clocks on today’s GPS satellites, which are bulky and expensive.

Going a step further, the team tested the system’s response to physical forces. “Let’s say one day we got it small enough so you could put it in your backpack, or in your vehicle,” Kotru says. “Having it be able to operate while you’re moving across the ground is important.”

Just short of physically shaking the system, the group “created a displacement between the atoms and the laser beam,” moving the laser beam from side to side as it probed the cloud of atoms. Even under such simulated shaking, the system was able to measure the atoms’ resonant frequency, with a high degree of sensitivity.

The team is now working to reduce the size of other components of the system, including the vacuum chamber and electronics.

“Additional miniaturization could ultimately result in a handheld device with stability orders of magnitude better than compact atomic clocks available today,” Kotru says. “Such a device would satisfy requirements for more technologically intensive applications, like the synchronization of telecommunications networks.”

This research was sponsored by Draper Laboratory.

以　上