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Atom interferometer charters Navy's inertial navigation path to reduce drift

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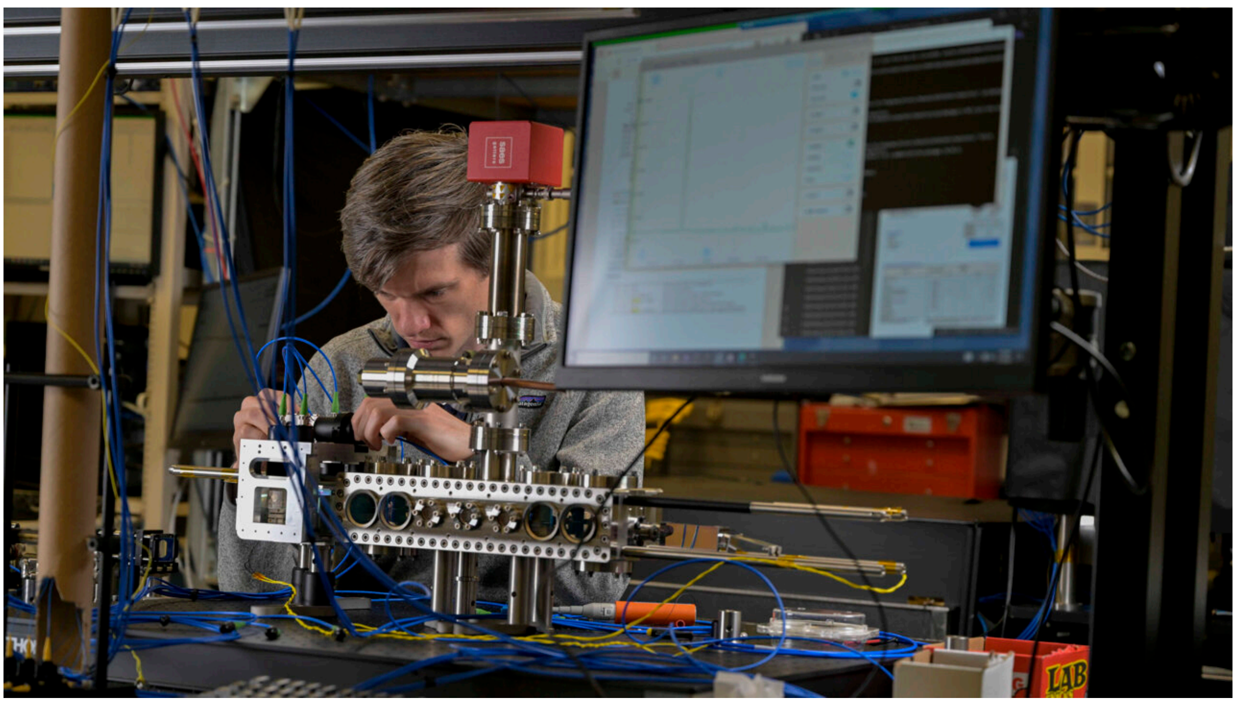

Jonathan Kwolek, Ph.D., a research physicist from the U.S. Naval Research Laboratory (NRL) Quantum Optics Section attaches fiber-optic cables to deliver light into the compact laser-delivery system, which is carefully aligned around a custom vacuum cell in the NRL Atom Interferometry Lab, Nov. 2, 2023. The apparatus will generate a cold, continuous atomic beam which will be delivered into the larger vacuum chamber to address Navy craft inertial navigation challenges. (U.S. Navy photo by Jonathan Steffen). Credit: (U.S. Navy /

Jonathan Steffen)

U.S. Naval Research Laboratory (NRL) researchers have developed a patent-pending Continuous 3D-Cooled Atom Beam Interferometer derived from a patented cold and continuous beam of atoms to explore atom-interferometry-based inertial measurement systems as a path to reduce drift in Naval navigation systems.

Inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and orientation of an object relative to a known starting point, orientation and velocity. Quantum inertial navigation is a new field of research and development that can increase inertial measurement accuracy by orders of magnitude.

"Our interferometer operates in a different regime than most other modern implementations of an atom interferometer," said Jonathan Kwolek, Ph.D., a research physicist from the NRL Quantum Optics Section within the Optical Sciences Division. "By operating with cold, continuous atoms, we have opened the door to a number of advantages as well as novel measurement techniques. Ultimately, we would like to use this technology to improve inertial navigation systems, thus reducing our reliance on GPS."

Enabled by the unique properties of the atom source, the Continuous 3D-Cooled Atom Beam Interferometer exhibits promising measurement characteristics like high measurement contrast, low noise, and improved handling of variations in the sensor's environment. This technology wields the potential to provide Navy the ability to operate in GPS-denied environments and overcome limitations to the accuracy of GPS.

Depending on the measurement platform, errors in the location estimation will accumulate and result in loss of accurate position information. Current commercially available inertial navigation systems, for example, can navigate with an error accumulation of roughly 1 nautical mile over 360 hours. NRL intends to develop new technologies to extend that time such that navigational drift does not limit mission duration.

"The field of inertial navigation aims to provide navigation information anywhere GPS is unavailable," said NRL Associate Director of Research for Systems Dr. Gerald Borsuk. "The advent of atom interferometry allows for a novel approach in inertial sensing, which has the potential to address some of the deficiencies in current state-of-the-art technologies."

GPS has become a backbone to the functionality of both our civilian and military world, providing high-accuracy distributed position and timing information anywhere in the world. However, there are certain battlespace environments in which GPS cannot function, such as underwater or in space, as well as an increasing threat to GPS availability in the form of jamming, spoofing, or anti-satellite warfare.

"In an ideal world, we hedge against loss of conventional navigation by making the best inertial navigators we can," Kwolek said. "This is to ensure that a loss of GPS doesn't allow our ships to become lost in the middle of enemy territory."

Why use atom interferometers?

Interferometers are devices that extract information from interference using coherent waves. This class of device is widely used for the precise measurements of displacements, refractive index changes and surface topologies. Inertial navigation is used in a wide range of applications including the navigation of aircraft, tactical and strategic missiles, spacecraft, submarines, and ships.

Atomic physics offers a unique toolkit for measuring with extreme precision. Atom interferometry is a method within atomic physics in which quantum interference of atomic matter waves is used to measure extremely precise changes in environmental conditions, such as fields or inertial forces.

"Performing atomic inertial measurements as opposed to a classical measurement gives different error dependencies," Kwolek said. "We predict that if done carefully, atomic interferometers will exhibit better long-term noise behavior and accuracy than current leading technologies. Translated to the world of inertial navigation, this means keeping your location fix for longer providing more operational flexibility."

Atom interferometers can also be used to discipline another sensor, much like how clocks are disciplined to GPS. This combination of an interferometer with a cosensor can enable interferometers to realize a benefit in a real-world measurement scenario.

"This is by no means a complete solution," Kwolek said. "There are tradeoffs to operating an atomic interferometer, for example, the enhanced sensitivity correlates to worse dynamic range. We are exploring multiple avenues to solving this problem including cosensor implementation or alternative cold-atom techniques."

This quantum optics research is sponsored by the NRL Base Program and the Office of Naval Research.

The National Defense Authorization Act for Fiscal Year 2024 states that quantum technology is approaching a tipping point that will determine how quickly it can make an impact. If the United States can stay on pace, many important outcomes for the Department of Defense (DOD) can be realized including robust position, navigation and timing for DOD freedom of operations with precision strike even with contests in spectrum, space, or cyber operations.

A Navy less reliant on GPS

NRL has delivered navigation solutions to the fleet since its inception but a breakthrough occurred in the 1960s with the invention of GPS.

NRL launched TIMATION I on May 31, 1967, and TIMATION II on August 30, 1969. TIMATION I demonstrated that a surface vessel could be positioned to within two-tenths of a nautical mile and an aircraft to within three-tenths of a nautical mile using range measurements from a time-synchronized satellite.

While initially designed for use by the military, GPS has been adapted for civilian navigation needs ranging from commercial aviation to portable handheld and wristwatch-type devices. Today, GPS is a constellation of 32 Earth-orbiting satellites providing precise navigation and timing data to military and civilian end-users around the globe. Despite decades of development of GPS, optimized inertial navigation systems afford the Navy the ability to mitigate risk against becoming completely reliant on GPS.

"In the modern era, NRL is one of several research organizations addressing naval inertial navigation challenges," said Adam Black, Ph.D., NRL Quantum Optics Section Head. "The lab is taking advantage of advanced atomic and optical techniques to invent new architectures for inertial measurement that promise accurate navigation of dynamic Navy platforms."

Provided by Naval Research Laboratory