Quantum sensing using laser-cooled atoms shows promise for Army navigation, detection

U.S. Army

ADELPHI, Md. (March 20, 2013) -- U.S. Army Research Laboratory scientists in the Sensors and Electron Devices Directorate are currently exploring the field of quantum sensing and are discovering ways in which the Army can benefit from innovations that were once thought impossible.

According to Qudsia Quraishi, Ph.D., a physicist in the Sensors and Electron Devices Directorate, or SEDD, who is working at the forefront of quantum sensing research at ARL, classical physics can limit the performance of precision sensing technologies such as time-keeping, imaging and navigation.

"Precision imaging is typically limited by the diffraction limit of light," said Quraishi. "Precision navigation for vehicles or planes has limits ranging from thermal fluctuations to say, GPS-denied environments, and conventional inertial navigation systems have essentially reached a performance plateau," Quraishi said.

Quraishi said that next generation systems for precision sensing involve quantum sensors, which are based on laser cooled atoms, and could potentially offer tremendous gains in performance.

Laser cooled atoms are small yet coherent, meaning that one can measure a change in gravity or magnetic field, are extremely precise, and are highly sensitive.

In addition, quantum sensors rely upon a phenomenon not seen in conventional sensors, which is known as entanglement.

"Entanglement is a quantum phenomenon that links one quantum system to another in such a way that a measurement of one system affects the results of the other system, even if these systems are physically separated," Quraishi said.

"These two quantum systems go through slightly different environments and interfering them with one another gives information about the environment of one path verses the other. Such atom interferometers can in theory provide orders of magnitude better performance than conventional technologies," Quraishi said.

An atom interferometer is an interferometer based on exploiting the wave character of atoms, which is a quantum phenomenon.

One established method for navigation is a Sagnac interferometer, which uses coherent light, such as that emitted by a laser. A beam of light is split and the two beams then follow a trajectory in opposite directions to provide the reference for an inertial guidance system.

In the Army's case, quantum sensors based on atomic systems are a major development that can benefit Soldiers because the use of atoms in an interferometer leads to more accurate navigation and environmental sensing.

The specific areas within quantum sensing that ARL scientists are exploring include gyroscopes, magnetometry, gravity gradiometry, next generation compact sensors and atomtronics.

Gyroscopes measure changes in rotation of a body and atom-base gyros can be useful in applications such as precision navigation and seismic detection. Importantly, atom-based navigation would not require GPS signals and hence could be used in GPS-denied environments.

Magnetometry is the measurement of magnetic fields, and when it comes to magnetometry and quantum sensing, laser cooled atoms can precisely measure magnetic fields, useful for biomagnetic imaging and studies of condensed matter systems.

Gravity gradiometry is the study and measurement of variations in the acceleration due to gravity. Gravity gradiometers that are based on laser cooled atoms are able to more accurately and precisely detect changes in gravity that can be useful for detection of underground bunkers or natural resources and for geophysics, for example.

Another application of these quantum sensors is in the measurement of time.

Atomic clocks have revolutionized time keeping. In fact, they have gained global attention especially since the 2012 Nobel Prize for Physics was awarded to David Wineland and Serge Haroche for their work on quantum systems that has helped to lay the foundation for quantum devices, including quantum computers, and the next generation of atomic clocks.

Wineland in particular has used cooled ions to develop optical atomic clocks that are the most accurate clocks in the world.

Scientists are working to make it possible for Soldiers to carry miniature atomic clocks that will assist with time synchronization and position of tactical operations, such as directing missiles after they have been launched in GPS-denied environments.

"However, quantum sensors typically involve large experimental setups and sensitive, costly equipment that requires a dedicated team to operate," Quraishi said.

The first step on the path to a field-ready device is an integrated and compact setup, and atom-chips are an excellent platform for compact sensors.

Atoms confined on atom-chips are a robust and cost-effective system. Modern approaches to quantum sensors now include smaller, integrated devices like the atom-chip setup at ARL.

ARL scientists' work involves demonstrating quantum sensing in this small-scale platform, which includes atom-chips, and focuses on quantum sensing for a long-term vision of devices that can be placed in vehicles or carried by individual Soldiers.

The first and only cold atom setup for ARL, which has seen great interest from major universities all over the world, is located at ARL's Adelphi Laboratory Center, where all ARL exploration of quantum sensing is currently done in-house by physicists in the Cold Atom Optics Group, including Quraishi.

Though atom-chips are an attractive platform, additional work needs to be done to execute the long-term program vision, as the size and complexity of the system often directly corresponds to its measurement sensitivity.

"The first goal would be to create a table top compact sensor that could be used for Army installations or in tanks and planes, and the long-term goal would be for Soldiers to be able to carry compact sensors in their backpacks for precise navigation in GPS-denied environments," Quraishi said.

ARL scientists are also exploring the field of atomtronics, and according to Quraishi, atomtronics is basically taking what you can do with electronics and doing them with atoms.

Atomtronic devices are still in their infancy, but could be used in future applications such as ultra-cold atomtronic circuits to be used with quantum computers.

Ultra-cold atomtronic circuits would allow for the more coherent, quick and secure exchange and flow of information.

Just like with the classic computer though, scientists cannot imagine all of the possibilities of the quantum computer, which is still very much in its infancy as well.

There is much to be explored on what Quraishi calls the "quantum horizon," and those explorations could be vital to our Soldiers on the battlefield and have the potential to forever change the way they execute their missions.

The experiments with cold atoms at ARL are led by Patricia Lee, Ph.D., of SEDD. She is supported by Quraishi, SEDD post-docs Violeta Prieto, Ph.D., Jason Alexander, Ph.D., Dan Stack, Ph.D, and SEDD undergraduate students Matt Bahnsen and Ian Grissom.