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Fifteen Lincoln Laboratory Technologies Receive 2024 R&D 100 Awards

The innovations map the ocean floor and the brain, prevent heat stroke and cognitive injury, expand AI processing and quantum system capabilities, and introduce new fabrication approaches.

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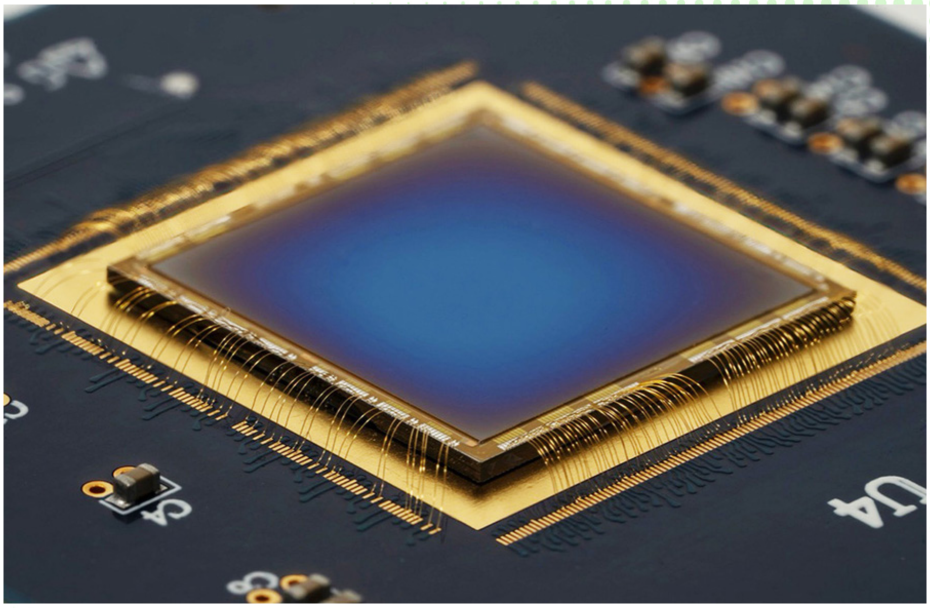
Fifteen technologies developed either wholly or in part by MIT Lincoln Laboratory have been named recipients of 2024 R&D 100 Awards. The awards are given by R&D World, an online publication that serves research scientists and engineers worldwide. Dubbed the "Oscars of Innovation," the awards recognize the 100 most significant technologies transitioned to use or introduced into the marketplace in the past year. An independent panel of expert judges selects the winners.

"The R&D 100 Awards are a significant recognition of the laboratory's technical capabilities and its role in transitioning technology for real-world impact," says Melissa Choi, director of Lincoln Laboratory. "It is exciting to see so many projects selected for this honor, and we are proud of everyone whose creativity, curiosity, and technical excellence made these and many other Lincoln Laboratory innovations possible."

The awarded technologies have a wide range of applications. A handful of them are poised to prevent human harm — for example, by monitoring for heat stroke or cognitive injury. Others present new processes for 3D printing glass, fabricating silicon imaging sensors, and interconnecting integrated circuits. Some technologies take on long-held challenges, such as mapping the human brain and the ocean floor. Together, the winners exemplify the creativity and breadth of Lincoln Laboratory innovation. Since 2010, the laboratory has received 101 R&D 100 Awards. This year's R&D 100 Award–winning technologies are described below.



This packaged research device was created with Lincoln Laboratory's engineered substrates. These new engineered substrates, and related fabrication process, dramatically reduces the time and cost of developing advanced silicon imaging sensors. Credits:Photo: Glen Cooper

Protecting human health and safety

The Neuron Tracing and Active Learning Environment (NeuroTrALE) software uses artificial intelligence techniques to create high-resolution maps, or atlases, of the brain's network of neurons from high-dimensional biomedical data. NeuroTrALE addresses a major challenge in AI-assisted brain mapping: a lack of labeled data for training AI systems to build atlases essential for study of the brain's neural structures and mechanisms. The software is the first end-to-end system to perform processing and annotation of dense microscopy data; generate segmentations of neurons; and enable experts to review, correct, and edit NeuroTrALE's annotations from a web browser. This award is shared with the lab of Kwanghun (KC) Chung, associate professor in MIT's Department of Chemical Engineering, Institute for Medical Engineering and Science, and Picower Institute for Learning and Memory.

Many military and law enforcement personnel are routinely exposed to low-level blasts in training settings. Often, these blasts don't cause immediate diagnosable injury, but exposure over time has been linked to anxiety, depression, and other cognitive conditions. The Electrooculography and Balance Blast Overpressure Monitoring (EYEBOOM) is a wearable system developed to monitor individuals' blast exposure and notify them if they are at an increased risk of harm. It uses two body-worn sensors, one to capture continuous eye and body movements and another to measure blast energy. An algorithm analyzes these data to detect subtle changes in physiology, which, when combined with cumulative blast exposure, can be predictive of cognitive injury. Today, the system is in use by select U.S. Special Forces units. The laboratory co-developed EYEBOOM with Creare LLC and Lifelens LLC.

Tunable knitted stem cell scaffolds: The development of artificial-tissue constructs that mimic the natural stretchability and toughness of living tissue is in high demand for regenerative medicine applications. A team from Lincoln Laboratory and the MIT Department of Mechanical Engineering developed new forms of biocompatible fabrics that mimic the mechanical properties of native tissues while nurturing growing stem cells. These wearable stem-cell scaffolds can expedite the regeneration of skin, muscle, and other soft tissues to reduce recovery time and limit complications from severe burns, lacerations, and other bodily wounds.

Mixture deconvolution pipeline for forensic investigative genetic genealogy: A rapidly growing field of forensic science is investigative genetic genealogy, wherein investigators submit a DNA profile to commercial genealogy databases to identify a missing person or criminal suspect. Lincoln Laboratory's software invention addresses a large unmet need in this field: the ability to deconvolve, or unravel, mixed DNA profiles of multiple unknown persons to enable database searching. The software pipeline estimates the number of contributors in a DNA mixture, the percentage of DNA present from each contributor, and the sex of each contributor; then, it deconvolves the different DNA profiles in the mixture to isolate two contributors, without needing to match them to a reference profile of a known contributor, as required by previous software.

Each year, hundreds of people die or suffer serious injuries from heat stroke, especially personnel in high-risk outdoor occupations such as military, construction, or first response. The Heat Injury Prevention System (HIPS) provides accurate, early warning of heat stroke several minutes in advance of visible symptoms. The system collects data from a sensor worn on a chest strap and employs algorithms for estimating body temperature, gait instability, and adaptive physiological strain index. The system then provides an individual's heat-injury prediction on a mobile app. The affordability, accuracy, and user-acceptability of HIPS have led to its integration into operational environments for the military.

Observing the world

More than 80 percent of the ocean floor remains virtually unmapped and unexplored. Historically, deep sea maps have been generated either at low resolution from a large sonar array mounted on a ship, or at higher resolution with slow and expensive underwater vehicles. New autonomous sparse-aperture multibeam echo sounder technology uses a swarm of about 20 autonomous surface vehicles that work together as a single large sonar array to achieve the best of both worlds: mapping the deep seabed at 100 times the resolution of a ship-mounted sonar and 50 times the coverage rate of an underwater vehicle. New estimation algorithms and acoustic signal processing techniques enable this technology. The system holds potential for significantly improving humanitarian search-and-rescue capabilities and ocean and climate modeling. The R&D 100 Award is shared with the MIT Department of Mechanical Engineering.

FocusNet is a machine-learning architecture for analyzing airborne ground-mapping lidar data. Airborne lidar works by scanning the ground with a laser and creating a digital 3D representation of the area, called a point cloud. Humans or algorithms then analyze the point cloud to categorize scene features such as buildings or roads. In recent years, lidar technology has both improved and diversified, and methods to analyze the data have struggled to keep up. FocusNet fills this gap by using a convolutional neural network — an algorithm that finds patterns in images to recognize objects — to automatically categorize objects within the point cloud. It can achieve this object recognition across different types of lidar system data without needing to be retrained, representing a major advancement in understanding 3D lidar scenes.

Atmospheric observations collected from aircraft, such as temperature and wind, provide the highest-value inputs to weather forecasting models. However, these data collections are sparse and delayed, currently obtained through specialized systems installed on select aircraft. The Portable Aircraft Derived Weather Observation System (PADWOS) offers a way to significantly expand the quality and quantity of these data by leveraging Mode S Enhanced Surveillance (EHS) transponders, which are already installed on more than 95 percent of commercial aircraft and the majority of general aviation aircraft. From the ground, PADWOS interrogates Mode S EHS–equipped aircraft, collecting in milliseconds aircraft state data reported by the transponder to make wind and temperature estimates. The system holds promise for improving forecasts, monitoring climate, and supporting other weather applications.

Advancing computing and communications

Quantum networking has the potential to revolutionize connectivity across the globe, unlocking unprecedented capabilities in computing, sensing, and communications. To realize this potential, entangled photons distributed across a quantum network must arrive and interact with other photons in precisely controlled ways. Lincoln Laboratory's precision photon synchronization system for quantum networking is the first to provide an efficient solution to synchronize space-to-ground quantum networking links to sub-picosecond precision. Unlike other technologies, the system performs free-space quantum entanglement distribution via a satellite, without needing to locate complex entanglement sources in space. These sources are instead located on the ground, providing an easily accessible test environment that can be upgraded as new quantum entanglement generation technologies emerge.

Superconductive many-state memory and comparison logic: Lincoln Laboratory developed circuits that natively store and compare greater than two discrete states, utilizing the quantized magnetic fields of superconductive materials. This property allows the creation of digital logic circuitry that goes beyond binary logic to ternary logic, improving memory throughput without significantly increasing the number of devices required or the surface area of the circuits. Comparing their superconducting ternary-logic memory to a conventional memory, the research team found that the ternary memory could pattern match across the entire digital Library of Congress nearly 30 times faster. The circuits represent fundamental building blocks for advanced, ultrahigh-speed and low-power digital logic.

The Megachip is an approach to interconnect many small, specialized chips (called chiplets) into a single-chip-like monolithic integrated circuit. Capable of incorporating billions of transistors, this interconnected structure extends device performance beyond the limits imposed by traditional wafer-level packaging. Megachips can address the increasing size and performance demands made on microelectronics used for AI processing and high-performance computing, and in mobile devices and servers.

An in-band full-duplex (IBDF) wireless system with advanced interference mitigation addresses the growing congestion of wireless networks. Previous IBFD systems have demonstrated the ability for a wireless device to transmit and receive on the same frequency at the same time by suppressing self-interference, effectively doubling the device's efficiency on the frequency spectrum. These systems, however, haven't addressed interference from external wireless sources on the same frequency. Lincoln Laboratory's technology, for the first time, allows IBFD to mitigate multiple interference sources, resulting in a wireless system that can increase the number of devices supported, their data rate, and their communications range. This IBFD system could enable future smart vehicles to simultaneously connect to wireless networks, share road information, and self-drive — a capability not possible today.

Fabricating with novel processes

Lincoln Laboratory developed a nanocomposite ink system for 3D printing functional materials. Deposition using an active-mixing nozzle allows the generation of graded structures that transition gradually from one material to another. This ability to control the electromagnetic and geometric properties of a material can enable smaller, lighter, and less-power-hungry RF components while accommodating large frequency bandwidths. Furthermore, introducing different particles into the ink in a modular fashion allows the absorption of a wide range of radiation types. This 3D-printed shielding is expected to be used for protecting electronics in small satellites. This award is shared with Professor Jennifer Lewis' research group at Harvard University.

The laboratory's engineered substrates for rapid advanced imaging sensor development dramatically reduce the time and cost of developing advanced silicon imaging sensors. These substrates prebuild most steps of the back-illumination process (a method to increase the amount of light that hits a pixel) directly into the starting wafer, before device fabrication begins. Then, a specialized process allows the detector substrate and readout circuits to be mated together and uniformly thinned to microns in thickness at the die level rather than at the wafer level. Both aspects can save a project millions of dollars in fabrication costs by enabling the production of small batches of detectors, instead of a full wafer run, while improving sensor noise and performance. This platform has allowed researchers to prototype new imaging sensor concepts — including detectors for future NASA autonomous lander missions — that would have taken years to develop in a traditional process.

Additive manufacturing, or 3D printing, holds promise for fabricating complex glass structures that would be unattainable with traditional glass manufacturing techniques. Lincoln Laboratory's low-temperature additive manufacturing of glass composites allows 3D printing of multimaterial glass items without the need for costly high-temperature processing. This low-temperature technique, which cures the glass at 250 degrees Celsius as compared to the standard 1,000 C, relies on simple components: a liquid silicate solution, a structural filler, a fumed nanoparticle, and an optional functional additive to produce glass with optical, electrical, or chemical properties. The technique could facilitate the widespread adoption of 3D printing for glass devices such as microfluidic systems, free-form optical lenses or fiber, and high-temperature electronic components.

The researchers behind each R&D 100 Award–winning technology will be honored at an awards gala on Nov. 21 in Palm Springs, California.

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