R&D 100 Award Finalists Support Laboratory Missions

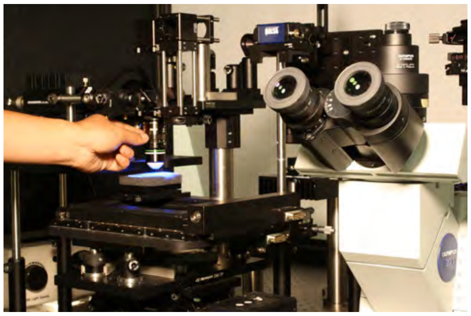
LAWRENCE Livermore is home to researchers from diverse disciplines, including physical and life sciences and engineering, who push the state of the art in their respective fields to support the Laboratory's many missions. This year, three notable Livermore teams were chosen as finalists and runners-up in *R&D Magazine*'s annual competition that recognizes top scientific and engineering products and technologies with commercial potential.

Each of these teams innovated existing technologies to create novel tools. Previous research into microelectromechanical systems- (MEMS-) based adaptive optics (AO) led to development of an advanced confocal microscope for viewing detailed cellular-level structures. Another technology builds on radio-frequency identification (RFID) to produce a system for faster, more efficient tracking of emergency equipment in harsh environments. Finally, researchers in the National Ignition Facility (NIF) improved x-ray framing camera technology to deliver a diagnostic that achieves unprecedented temporal resolution for laser experiments.

A Clearer View of Living Structures

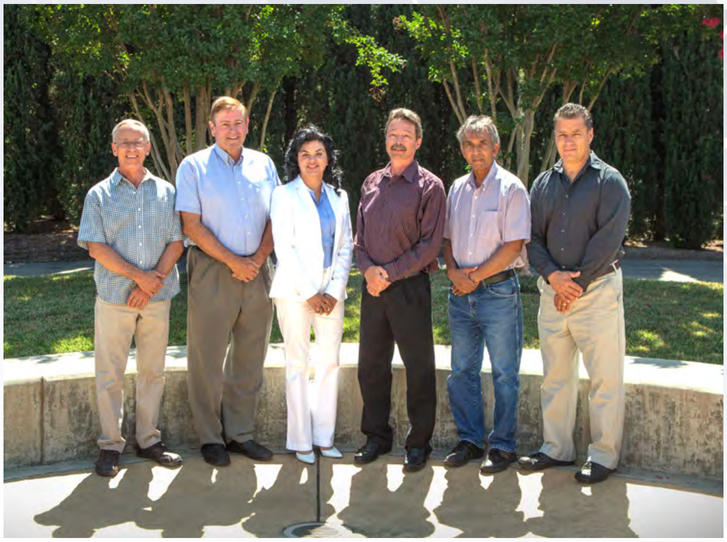
Since its invention in the late 16th century, the microscope has been an important tool for observing and analyzing biological structures, but each type has some limitations. For example, compound and dissection microscopes offer different degrees of magnification but with similar resolution. Scanning electron and transmission electron microscopes provide higher resolution, but the samples have to be specially prepared using electrically conductive material and must be mounted on metal grids and observed in a vacuum, which prevents observation of a living specimen. The confocal microscope was a major advance over existing technologies for analyzing live tissue, enabling three-dimensional (3D) image reconstruction of a thick sample. However, optical aberrations created by the sample's inhomogeneous refractive index still limit the instrument's overall resolution.

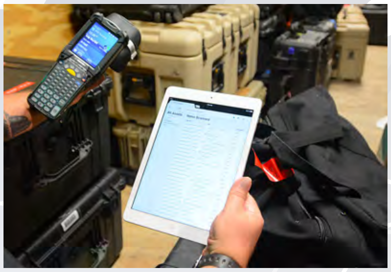
Developed in collaboration with academic and industrial partners, Livermore's innovative MEMS-based AO Confocal Microscope (MAOCM) leverages the latest advances in MEMS and AO technology to enable high-resolution, 3D views of complex living tissues at the cellular level. The instrument uses the same AO principles employed in the world's largest telescopes to provide clearer images of distant astronomical objects. An AO deformable mirror integrated into the device provides real-time correction of aberrations in both the illumination and imaging light paths to remove image distortions, thus enabling high-resolution, 3D live images to be viewed immediately by scientists or clinicians. AO compensates for optical aberrations by controlling the phase of the light waves, or wavefronts, that distort the light and degrade the final image. MAOCM automatically measures the optical aberrations in the light path with a wavefront sensor and then rapidly compensates for these aberrations with a wavefront corrector.



(above) The Microelectromechanical Systems- (MEMS-) Based Adaptive-Optics Confocal Microscope (MAOCM) combines adaptive optics and confocal microscopy to produce high-resolution, three-dimensional images of living tissue at the cellular level. (right) Livermore codevelopers of MAOCM: (from left) Diana Chen and Scott Olivier.

Biologists from the University of California at Santa Cruz used MAOCM to image in vivo fly embryos. MAOCM's penetration depth was tested by performing AO correction from the top surface of a sample to a depth of 100 micrometers. Prior to wavefront correction, cell centrosomes could only be observed down to 60 micrometers. After correction, they could be observed to 95 micrometers. The size of the point-spread function, which





(left) Development team for the Smart Real-Time Inventory System Based on Long-Range, Battery-Free, Radio Frequency Harsh Environment Tag (HET) system: (from left) Del Ekels, Rick Twogood, Faranak Nekoogar, Dave Weirup, Farid Dowla, and Don Mendonsa. (Not pictured: Jimmie Jessup.) (above) The HET system enables first responders to quickly and more efficiently track inventories of emergency equipment while working in harsh environments.

defines image resolution, showed an approximate eight times improvement over a conventional confocal microscope. The Strehl ratio, which measures the image quality, calculated more than 20 times improvement.

Purchased as a lower cost add-on or as a complete system, the MAOCM instrument enables unprecedented visualization of cellular content and cell–cell interactions in deep tissue for fundamental scientific research and clinical processes. Chen says, “This technology will enable earlier detection of diseases and provide more effective monitoring of disease progression and treatment.”

Inventory Tracking for First Responders

When it comes to responding to a critical situation, emergency response teams require quick, efficient methods for tracking extensive equipment inventories. Manual systems can be slow and unreliable, prone to errors, omissions, and outdated information. Inventory systems that use RFID enable faster, more reliable tracking, but these systems typically have short lifetimes, maintenance issues, limited detection ranges, and poor performance in harsh environments. Thus, they are unsuitable for first responder purposes.

Researchers at Lawrence Livermore and Dirac Solutions, Inc., developed the Smart Real-Time Inventory System Based on Long-Range, Battery-Free, Radio Frequency Harsh Environment Tag (HET) system to remedy these issues. The automated inventory tracking system uses novel passive RF tags, specialized portal or handheld readers, and a customized, cloud-based database to provide time-sensitive and real-time inventory or personnel tracking in environments that are hostile to RF signals.

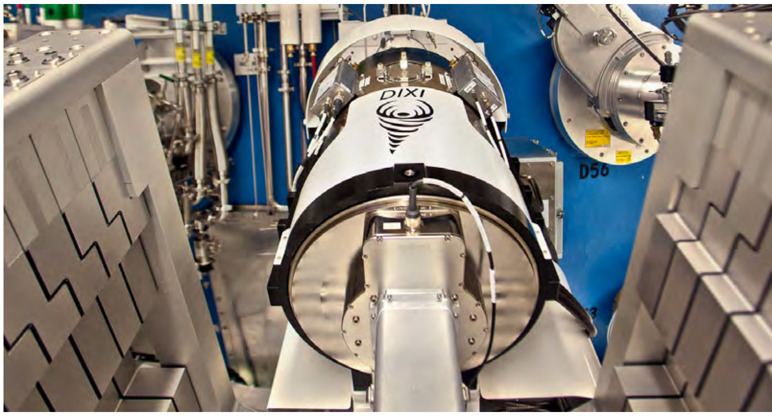
The RF tags used in the HET system are battery-free, so they have an indefinite lifetime. These tags can be placed into inventory items or carried in clothing for personnel tracking. Much like a mirror reflects light, the tags—which range in size from a postage stamp to a standard printed photo—receive their energy from radio waves transmitted either from a stationary reader antenna or from a handheld reader. The larger the tag, the greater the reading distance, up to approximately 60 meters for a 10-by-15-centimeter tag. HET multistatic, distributed reader antennas focus low-power RF signals onto confined monitoring areas to provide complete coverage of the tags. Multiple reader antennas are used to coherently focus the electromagnetic beam from various directions to see objects in cluttered and obscured environments. A smart, multilayered, cloud-based database allows real-time inventory data to be available from both handheld and portal readers.

Currently, response teams manually check their equipment before and after responding to an event. According to Livermore’s Faranak Nekoogar, who helped develop the HET system, “Manual inventory can take hours to complete. With the HET system, RFID tags provide accurate, automatic inventory control that can be verified in seconds.” For routine inventory processing, operators can use handheld readers as they look through the equipment to detect individual tags and update the cloud database. During an emergency response situation, individual tagged items inside transportation cases can be quickly packed into a vehicle and then detected by portal readers, reporting the inventory in real time as the vehicle passes.

The HET system is the only passive RFID inventory system designed for emergency responders. The system has been deployed in nuclear emergency response centers, where it has already improved operational efficiency and reliability. In the future, the HET system may find application in inventory control for other government agencies, medical and fire emergency response teams, and personnel tracking during search-and-rescue missions.

World’s Fastest X-Ray Camera

NIF provides scientists with a platform to research nuclear weapons physics and to explore basic science, such as astrophysical phenomena, materials science, and nuclear science. To support these efforts, NIF requires advanced diagnostics to accurately record experimental results. One of these technologies, the Dilation X-Ray Imager (DIXI), records two-dimensional x-ray images



As the world's fastest two-dimensional framing camera, DIXI can produce images of an imploding target capsule with 10 times faster temporal resolution and in environments with 10 times higher neutron yields than its competitors.

with unprecedented temporal resolution—the timescale over which changes in size or position can be measured—making it the world's fastest x-ray framing camera. The instrument was developed by Livermore in collaboration with General Atomics and Kentech Instruments, Ltd.

DIXI leverages three established technologies to improve its functionality in a harsh environment as well as its temporal resolution. These components include a pulsed transmission photocathode that converts incoming x-ray signals into electrons, a magnetic field for guiding the electrons in the drift space, and a standard framing camera backend to amplify a section of the dilated electron signal and record the images. DIXI also employs additional shielding to protect the recording device from x-ray and neutron-induced background signals.

The instrument uses pulse dilation (or stretching of the electron signal) to achieve a temporal resolution 10 times faster than traditional x-ray framing cameras. A voltage ramp imparts a velocity gradient on the signal-bearing electrons that are generated when x rays hit the transmission photocathode. As the electron signal traverses a drift space, it is stretched out in time, resulting in a signal that is 50 times longer. The high temporal resolution is achieved by selecting only a small part of the stretched signal stream for amplification and detection. Imaging enhancements result in the capability to resolve changes as fast as 5 trillionths of a second, equivalent to 200 billion images per second.

In addition, DIXI can survive 10 times higher neutron backgrounds compared to existing technologies. A longitudinal magnetic field guides the electrons within the drift space, allowing the instrument to be tilted off-axis to the object being viewed, which in turn permits additional shielding.

Development team for the Dilation X-Ray Imager (DIXI): (from left) Joe Holder, Jacob Parker, Charles Brown, Jay Ayers, Perry Bell, David Bradley, Sabrina Nagel, Joseph Kilkenny, and Kenneth Piston. (Not pictured: Walter Ferguson and Brian Felker.)

"DIXI is well suited for detecting x-ray emissions produced by various mechanisms, including those from inertial confinement fusion implosions and laser–plasma interactions," says Livermore's Sabrina Nagel, who helped develop the instrument. "The imaging system's greater-than-50-times magnification allows resolution of the very small emissions from compressed NIF target capsules. This instrument has already captured details of NIF implosions never before seen with slower, traditional framing cameras."

The success of DIXI at NIF has already sparked interest in adapting its pulse-dilation technology to other applications such as time-resolved neutron spectra. The system is also transportable and has variable temporal resolution and record length, which makes it a desirable diagnostic for other high-power laser facilities and x-ray emitting machines.

DIXI, MAOCM, and the HET system are three examples of how Laboratory researchers push the boundaries of scientific innovation and build on past technologies to improve capabilities. As evidenced by these three innovations, Laboratory researchers continue to advance the state of the art in the areas of cell biology, emergency response, and laser diagnostics in support of Livermore's national security mission.

—Lanie L. Rivera

Key Words: adaptive optics (AO); Dilation X-ray Imager (DIXI); disease; emergency response; inventory; microelectromechanical systems (MEMS); MEMS-Based Adaptive Optics Confocal Microscope (MAOCM); National Ignition Facility (NIF); optics; pulse dilation; R&D 100 Award; radio frequency; Smart Real-Time Inventory System Based on Long-Range, Battery-Free, Radio Frequency Harsh Environment Tag (HET) system; x-ray framing camera.

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