Also in this issue: HRL's New Podcast & Leadership Development Program

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HRL HORIZONS

A publication from HRL Laboratories, LLC

Navigate Without GPS With HRL's MEMS

Enabling Prediction of likelihood of Large Disasters

Using Biomimicry and Memristors to Build a Brain

About HRL

HRL is the largest employer in Malibu, California with over 500 employees on our campus overlooking the Pacific from the Santa Monica Mountains. Although all HRL scientists and engineers are U.S. persons, 43% were born in other countries. Among them, 99% hold advanced degrees and 82% have doctorate degrees. Our diversity is a strength that enriches our organizational growth and development and ensures a breadth of perspectives from around the world with wide-ranging technical knowledge. Since 1960, HRL scientists and engineers have led pioneering research and provided real-world technology solutions for defense and industry. We are recognized for our leadership in physical and computer sciences, engineering research, and significant contribution to national defense.

HRL HORIZONS STAFF

Creative Director
Michele Durant

Technology Writer
Shaun A. Mason

Contributing Writers
Parney Albright
Leslie Momoda
Geoff McKnight

Photos
Bryan Ferguson
Julian Grijalva
Geoff Ramos
Getty Images

HRL HORIZONS Online
Bryan J. Ferguson

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CONTENT

HRL Laboratories, LLC, Malibu, California (www.hrl.com) is a corporate research-and-development laboratory owned by The Boeing Company and General Motors specializing in research into sensors and electronics, information systems and sciences, materials and microsystems, and microfabrication technology. HRL provides custom research and development and performs additional R&D contract services for its LLC member companies, the U.S. government, and other commercial companies.

A WORD FROM

Frank Brady

Director,
Human Resources

Besides commitment to its LLC partners and Malibu neighbors, HRL Laboratories recognizes that its employees are its most important asset. Our people give us the competitive advantage needed for success in the 21st century, and our goal is to provide them an environment that enables individual performance that fulfills each employee's full potential.

HRL encourages collaboration and teamwork within our extremely diverse workforce. We leverage our diversity to our greatest benefit, emphasizing our place in the scientific world as a facility where new things happen daily, and we are not afraid to try to do the impossible. Our compensation and reward systems are linked to individual and team performance and are aligned with our short- and long-term business goals.

We enhance individual and organizational performance through continuous learning. Our performance management system is based on candid and honest feedback to all employees, which promotes the fullest application of each employee's knowledge, skills, and abilities.

HRL's positive work environment motivates employees, buttressing morale with leading-edge equipment, training, and competitive benefits.

Our vision is to be a premier destination for our nation's very best scientists and engineers. In this issue of *HRL Horizons*, you'll see the technology innovation and challenges that keep our staff engaged and motivated. You will also see the types of individualized programs that provide a first-class work environment for our employees and enable HRL staff members to be good stewards of our resources and good neighbors in our community.

PODCAST

Examining The History of the Future

HRL's' history is long and storied and the technology developed on site after the facility opened in 1960 had a dramatic effect on the future from that time until the present day. We now live in that historical future, with lasers, satellite communication, laptop computers, smartphones, artificial intelligence, and myriad other technologies that were born or enjoyed major advances at the legendary hilltop laboratory in Malibu.

This concept was the impetus for a podcast created and distributed by HRL Laboratories' Multimedia and PR department, aptly titled *HRL's History of the Future.* The idea was to create a science-related interview program that explored HRL's legacy and investigated its possible effects on technology to come by talking to scientists past and present who spent time at HRL, built careers here, or studied the results of HRL research.

Podcast guests also include outside scientists whose research ties in with HRL's mission, or is of potential interest to HRL's audience.

"Our intention with the podcast was to talk to experts from different eras about the many scientific milestones reached here throughout our history, now spanning portions of two different centuries," said HRL CEO and President Parney Albright. "We've had a good response from emeritus researchers and current HRL employees who are happy to talk to us for an hour about their work and how it has influenced daily human life."

HRL's History of the Future is a public-facing representation of advanced science, but is tailored for a lay audience, to bring the average person inside the environs of a high-level research and development laboratory with terms and concepts they can understand without having an advanced degree.

For people with an interest in science, the podcast is compelling and informative. It can also serve as an introduction to the real world of research and development for students who have an interest in a career in science, but don't have personal access to a professional.

"We're continuing to improve the podcast and seek out exciting guests," Albright said. "We'd like for people to hear our podcast as an audio gateway to an amazing world of history as well as questions and discoveries that have and will change all our lives for the better." ■

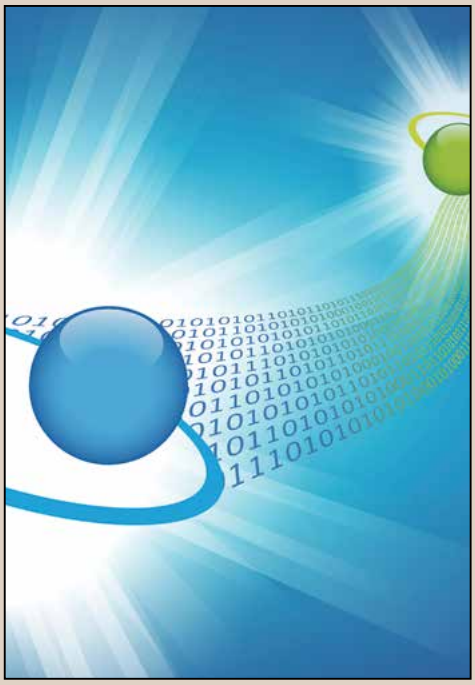
***HRL's History of the Future* is available on iTunes and Libsys.com**

HIGHLIGHTS

A look at the year's biggest achievements and news to date

Radio Frequency Switch Enables Faster Video and Audio 5G Streaming
HRL Laboratories researchers achieved a major advancement over existing technology in radio frequency (RF) switches that will vastly accelerate data streaming for smartphones and other devices that use 5G wireless networks. The new switch enables faster audio and video with a more reliable signal with wider band width and extremely low-loss and high isolation for increased speed and clarity well into the millimeter-wave (mmW) frequency range. It is the first antimony-telluride phase-change-material-based RF switch and turns on and off by changing its material phase from metallic to insulator. These qualities make it an excellent mmW switch technology for the huge data streaming demands of 5G wireless networks. During testing the switch set an impressive world record of 10 million reliable switching cycles without failure, a dramatic improvement over the previous record set by a PCM-based switch.

Cybersecurity Experts at HRL Laboratories Take Aim at Personal Data of Social Engineering Attackers
The goal of a new program being developed by HRL computer scientists is to turn the tables on cyberattackers who use social engineering to obtain private information from unsuspecting victims. These hackers do not break into computer systems surreptitiously, but research a potential victim's social media presence, gathering information they use to approach with what looks like a legitimate social connection. The HRL defense system--Continuously Habituating Elicitation Strategies for Social Engineering Attacks or CHESS--aims to exploit attackers' methods by drawing them in with automated responses to their behavior. Then the system seeks to gather as much personal information on an attacker as possible, including identifying individual bad actors and any agencies that might be behind them.



A Step Toward Revolutionary Computing by Improving Topological Material
HRL hopes to advance the vast potential of two-dimensional topological materials for quantum computation with the project Suppressing Trivial Edge Conductance in 2D Topological Materials. The HRL team aims to provide a novel building block for quantum computation that does not need quantum correction to mitigate noise. Imagine the topological material as a doughnut with a qubit—the basic information unit of quantum computation—encoded in the hole. Environmental disturbances are squeezing, pressing, or deforming the doughnut, but the doughnut's identity—the hole storing quantum information—remains consistent, even if the doughnut changes drastically to the shape of a mug with a handle. The beauty of topological encoding is that the qubit stays safe and does not change with deformation. With these topological qubits, quantum computation could be accomplished with far fewer total qubits than are needed in other approaches that require extra qubits for quantum error correction.

NO SATELLITE? **NO PROBLEM!**

HRL Laboratories develops MEMS inertial sensors and frequency sources that enable position, navigation, and timing **WITHOUT GPS**

by Shaun A. Mason

Global Positioning

The first use of satellites for navigation was done with the first satellite, Sputnik, launched by the Soviet Union in 1957. William Guier and George Weiffenbach, physicists at Johns Hopkins University's Applied Physics Laboratory (APL), tuned in Sputnik's radio signals and discovered they were able to track the satellite by measuring how the Doppler effect shifted the signals as Sputnik orbited. Deputy Lab Director Frank McClure then asked Guier and Weiffenbach to investigate the inverse problem of finding the receiver's location on Earth based on the known location of the transmitting satellite. The success of that work led to APL teaming with DARPA predecessor ARPA to develop the TRANSIT system for locating US submarines that carried the first submarine-launched ballistic missle, the Polaris.

The Global Positioning System, or GPS, that we now access daily on our smartphones was originally launched by the US Department of Defense in 1973 and became fully operational in 1995. Owned by the US government, the GPS satellite network encircles the Earth and is maintained by the United States Air Force. Anyone can access GPS signals without needing to transmit any data to the satellites. A receiver must have an unobstructed line of sight to at least four GPS satellites at once for radio signals to determine position on the surface of the Earth. The exact time of that position is measured against synchronized atomic clocks aboard the satellites, whose time information is transmitted along with GPS signals. However, these signals are not particularly strong and are easily obstructed by buildings and other structures or terrain. GPS radio signals cannot be received underground or underwater—such as in subways, caves, or submarines.

The US Department of Defense has long had a goal of developing a system to maintain position, navigation, and timing without GPS in signal-denied areas and improve GPS positioning accuracy. Scientists at HRL Laboratories have been working with the Defense Advanced Research Project Agency (DARPA) to solve non-satellite navigation using equipment compact enough to equip nearly any vehicle or be carried in a small pack.

MEMS Gyroscopes and Accelerometers

Microelectromechanical systems (MEMS) are microscopic devices and structures that function with parts that move or vibrate. That movement is how MEMS differ from electronics, such as transistors, which have fixed structures that guide the paths of moving electrons. Like electronics, MEMS are made with microfabrication techniques. These include dry etching, a method of strategically removing layers of material to create the MEMS device on a compact disk-like substrate called a wafer. This enables the

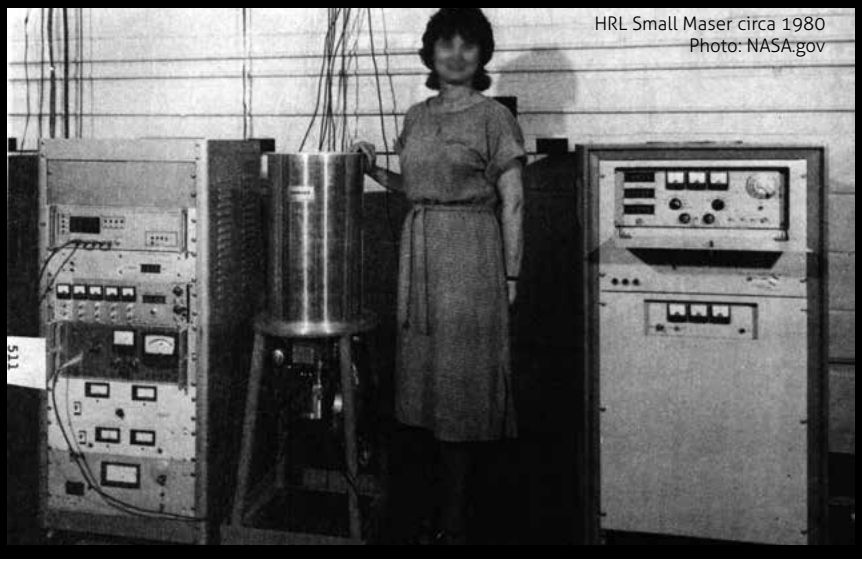
Cold Atom Source Key to Portable Atomic Clocks

The most precise measurements of time are made using atomic clock systems. The consistency and accuracy of these amazing instruments is based on the simple fact that an atom used to keep time is the same in any clock. The two basic types of atomic clocks are those that operate at room temperature and those that use atoms cooled down to just above absolute zero, with atoms virtually standing still. Room temperature atomic clocks have been miniaturized, but cold-atom atomic clocks are much more accurate because less atom movement means less noise. Miniaturization of cold atom clocks is a prominent goal, but they present many more difficulties. HRL researchers have now taken a big step toward solving many of those problems by developing a small, low-power source for cold atoms. The device uses four lasers and a magnetic field to catch atoms zipping around in a chamber and hold them virtually still long enough to make ten-second measurements.

A clock that measures time based on the frequency of a vibrating piece of silicon might not be measuring vibrations with the same frequency as a different clock with a different piece of silicon. Atomic clocks measure time based on changes in the state of electrons around an atom (rubidium for instance) and all rubidium atoms have the same frequency. An atomic clock has many components to measure that frequency, and it is the atom's consistency that guarantees the same time between clocks wherever they are. Measurements at such small levels also are incomparably precise. Atomic time-keeping precision combined with MEMS sensors could make possible inertial measurement units that navigate extremely accurately for long periods without global positioning systems.

The difficulty so far has been the size of atomic clocks. They have existed for decades, but some look like refrigerators. Some clocks are now the size of a toaster oven and accuracy varies depending on size, larger being most accurate. The ideal is an atomic clock package that fits in a pocket, such as the MEMS devices in a smartphone.

"MEMS sensors available commercially right now are okay for devices like smartphones," said HRL researcher Christopher Roper. "With a bit more advancement they will work for automotive uses. If we advance them a lot more they will be good for short-term GPS-denied navigation, but to navigate for really long stretches without GPS, we'll need to combine them with small atomic clocks."



HRL Small Maser circa 1980
Photo: NASA.gov

fabrication of many MEMS devices simultaneously on one wafer, which are then cut into individual chips, making them economical for production at the industrial level. MEMS are common in our smartphones, computers, and tablets, so their fabrication is a well-known technique done in the type of cleanroom used to fabricate semiconductor chips.

Two types of MEMS sensors in a smartphone are gyroscopes and accelerometers, which determine the phone's attitude (or orientation) and position in three-dimensional space by sensing rotation rates and accelerations, respectively. Although these MEMS sensors work well enough to keep a phone's screen upright, for instance, they are not able to independently achieve the same accuracy of position, navigation, and timing enabled by GPS.

HRL researchers now fabricate MEMS gyroscopes and accelerometers on a chip that are up to the task done by devices many orders of magnitude larger. These extremely sensitive MEMS sensors are integrated into a device called an inertial measurement unit, or IMU. Position, navigation, and timing on par with GPS are achieved by the IMU, regardless of satellite reception.

A body moving through space has six degrees of freedom, three fundamental translation directions—vertical, longitudinal, and lateral, or x, y, and z axes—and three fundamental rotational directions—pitch, roll, and yaw. Therefore, the IMU needs at least three accelerometers and three gyroscopes because the key to IMU function is accurate information about those six directions simultaneously.

"Basically, we're trying to enable people to determine exactly where they are and keep that information available to them constantly, without GPS," said HRL researcher Logan Sorenson. "We're using inertial navigation combined with gyro-compassing to find north. That is unique to our MEMS gyroscopes, in that we can use our IMU as a compass as well as a position finder."

To put this technical achievement in perspective, the Earth rotates at a rate that is imperceptible to the humans on it—360 degrees in 24 hours or 15 degrees per hour. For their compass function, HRL gyroscopes must be designed well enough to sense forces generated by 1/1500th of Earth's rotation rate.

Gyroscopes require a moving element and most traditional full-sized gyroscopes have a rotor that spins quickly to create the gyroscopic effect needed for sensing. For HRL's MEMS gyroscope, the chip contains a tiny vibrating spring that supplies the movement needed for a gyroscopic effect.

Although the MEMS IMU is small compared to other navigation devices, the physics involved require it to be of a certain size. A navigation-grade IMU will not fit in a watch or phone, for example, but it can be installed in any vehicle, mounted on a helmet, or carried in a pack.

"We're demonstrating our ability to navigate inertial space without GPS, but in the field there will be no silver bullet. First responders will be using all available systems working together. There are situations in which the IMU will offer advantages when combined with other sensors such as lidar that might be working at a slower rate."

Search and Rescue in Any Conditions

First responders such as firefighters, police officers, and disaster rescue crews often are working in difficult conditions that block or obscure GPS signals. The ability of rescuers to enter a smoke-filled or collapsed building, know where they are at all times, and find their way out safely with rescued victims means life or death to all involved. HRL's MEMS inertial measurement unit (IMU) technology can give search and rescue crews an unprecedented tool in the many situations they face in which satellite reception is obstructed. Underground, underwater, and remote rescue situations could have vastly more desirable outcomes if the position, navigation, and timing of rescuers are never in question regardless of the condition of a satellite signal.

"We're demonstrating our ability to navigate inertial space without GPS, but in the field there will be no silver bullet. First responders will be using all available systems working together. There are situations in which the IMU will offer advantages when combined with other sensors such as lidar that might be working at a slower rate," according to HRL researcher Logan Sorenson. "Also, it is still difficult for an object to measure its own starting position. GPS works because you know absolutely where the satellites are and they've been measured according to certain reference points on the Earth. From that knowledge we can figure out exactly where we are. By combining GPS with inertial sensors and a starting point, you can always know where you are, how fast you're going, and your attitude in three dimensions. This constant flow of positional information could greatly enhance search and rescue operations anywhere on Earth in any conditions."

HRL LABORATORIES MEMS TEAM (L to R): Kevin Holabird, Brian Cline, Raviv Perahia, Robert McElwain, Fred Stratton, Bruce Holden, Hung Nguyen, Matt Pelliccione, David Chang, Logan Sorenson, Margie Cline, Richard Joyce, Deb Kirby, Lian-xin Coco Huang, Makena White, Tracy Boden, Randy Kubena.

HRL researcher Coco Huang explained, "The biggest spinning gyroscopes are very accurate, but are huge. The challenge has been to build smaller gyros, but in the past reducing size always sacrificed performance. We are breaking the barrier of smaller size and precision. By building the gyroscope and accelerometer in the same package, our ultimate goal is to integrate three gyros and three accelerometers in a single cube. That would give us the GPS-level navigation performance we envision, without a GPS signal, in an IMU about the size of a baseball."

Because the IMU detects motion and not gravitation or weight, it will work just as well in space as on Earth. It could conceivably guide spacecraft deprived of radio telemetry from Earth due to interference or distance.

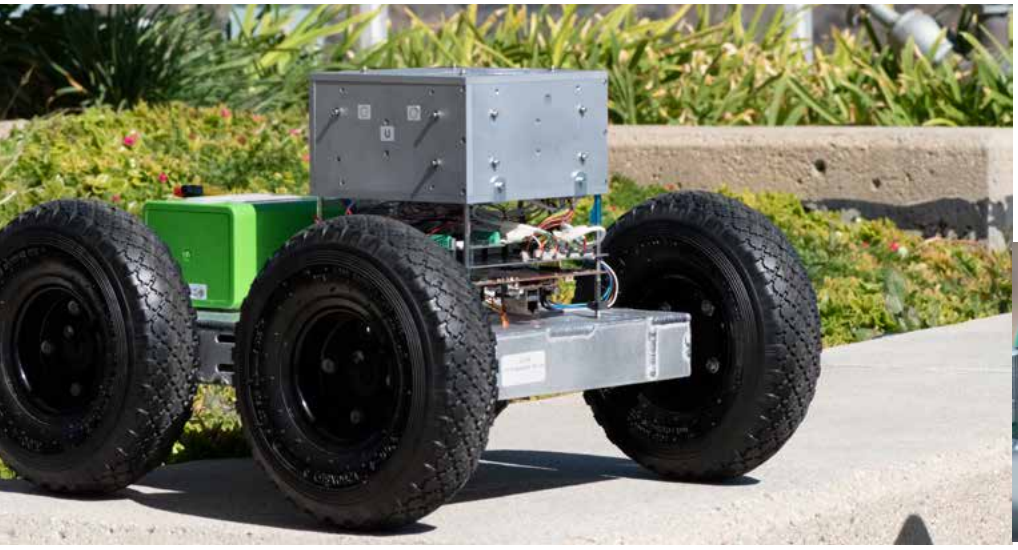
Quality factor is an important metric of performance for gyroscopes and is an indicator of how long the structure will resonate, like a bell. The higher the quality factor, the more accurate the gyroscope, and the more precise the navigation.

"We've iterated through many designs to optimize the IMU, using advanced finite element analysis software to fine tune it," Huang said. "We have been able to at least double the quality factor from the state of the art."

Another HRL technology called a cold-atom source is being developed to make much smaller and more accurate atomic clocks. Combining the IMU with such an atomic clock could improve the inertial measurement and timing even more to enable better communication with synchronized vehicles or spacecraft, and even better satellite-free navigation

Rover Test

The HRL team is also putting IMUs through their paces in a small remotely operated rover vehicle that has no cameras or other visual guidance. To guide the rover they designed a custom IMU from the best available commercial MEMS sensors—three gyroscopes and three accelerometers—and fed



THE ROVER BOT A remotely operated vehicle serves as the test bed for HRL MEMS inertial sensors.

the resulting sensor data streams into an experimental Inertial Navigation System, or INS, that used HRL navigation algorithms and performed better than the capability of the commercial sensors by themselves. This rover platform will become the test bed for benchmarking HRL's MEMS inertial sensors when they are ready to be integrated in an IMU.

"We were able to drive the test vehicle inside the building without GPS as well as plotting out a map along the way to know exactly where the vehicle was," Sorenson said. "Our navigational algorithms are the core of the system. A robotic platform in the field, such as a self-driving car, would incorporate radars, lidars, cameras, infrared sensors, etc., to fully enhance the vehicle's safe operation and navigation. However, this rover experiment proved that under visually restrictive conditions, the IMU could continue to navigate a vehicle without visual sensors or a GPS signal."

"This was also a demonstration of the integration of gyroscopes and accelerometers," Huang said. "The rover project helped us complete an integrated platform for the IMU. Building the navigation system on the rover platform and simultaneously building the inertial sensor makes the eventual integration of the two easier."

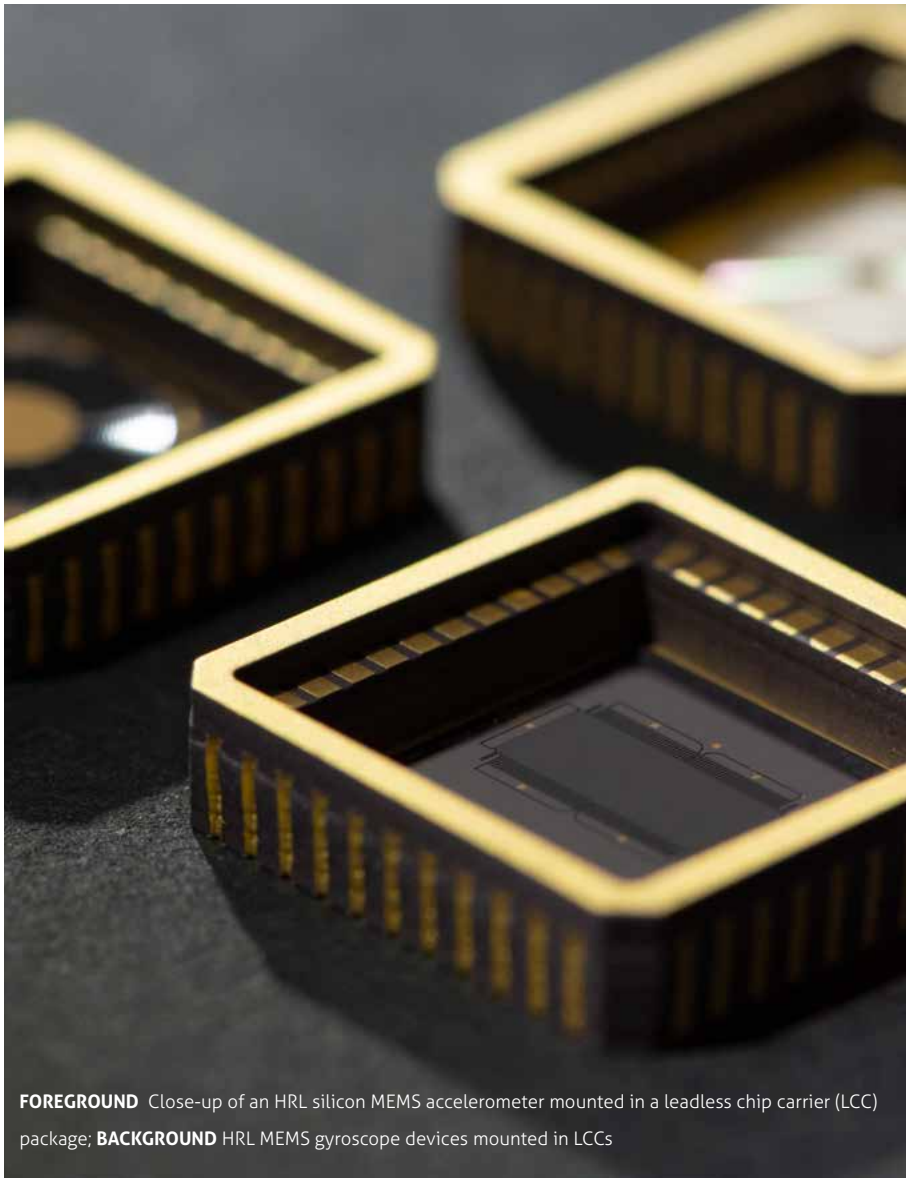
In the best case, the IMU will always work with GPS. Because the GPS signal will give one location and the IMU location might be slightly different, the HRL algorithms calculate a total fused solution that is more accurate than either solution alone, thus enhancing GPS positioning. This capability also could lessen the need for more visual sensors, which in turn would lessen the price and complexity of an autonomous vehicle.

Never be lost again?

The coming age of self-driving cars and other vehicles draws nearer with the cascade of new technologies for safe operation without a human driver. Giving a self-driving car the ability to navigate with remarkable humanlike precision with GPS, and continue to navigate accurately when deprived of GPS, moves us closer to the day when humans will travel in thinking vehicles that take orders, make decisions, and never get lost.

This age of autonomy will have spillover into everyday human life outside self-driving vehicles. As MEMS technology makes possible radically smaller and more accurate navigational equipment, a time can be foreseen in which a human being can go anywhere on land, in the air, underwater, and even in space, and never get lost.

The cultural implications of this technology cannot be fully known, but human history is rife with stories and experiences based on being lost—lost in the desert, lost at sea, lost in the woods, lost in the snow, lost in the dark. Human experience could be dramatically changed if everyone always knows exactly where they are at any time, and HRL scientists are at the forefront of achieving this goal. ■



FOREGROUND Close-up of an HRL silicon MEMS accelerometer mounted in a leadless chip carrier (LCC) package; **BACKGROUND** HRL MEMS gyroscope devices mounted in LCCs

> "We're trying to enable people to determine exactly where they are and keep that information available to them constantly, without GPS"

Self-Organized Criticality:
Enabling Prediction of Likelihood of Large Disasters

Statistical physics is a field in which probability theory and statistics are mathematical tools for solving physical problems that involve large populations and approximations. Recent research on one statistical physics property called self-organized criticality (SOC) may make it possible to calculate the likelihood of larger physical disasters such as power outages, earthquakes, or mudslides.

Self-organized criticality is a property of granular systems that have interactions between the components, such as sand piles. Sometimes there are events or fluctuations based on those interactions, such as avalanches in the sand. The Earth's tectonic plates are similar granular systems that exhibit SOC and fluctuate by moving against each other causing earthquakes. Power grids, another granular system with SOC, fluctuate in the form of outages.

HRL senior researcher Heiko Hoffmann has determined that in these interactive networks such as tectonic plates, SOC is affected by the topology of the network in which the critical event happens.

"Our work describes how network topology has been determined as a mechanism behind SOC, which itself describes events that have scale-free size distribution," Hoffmann said. "This wider understanding of how topology affects SOC could enable statistical prediction of the critical events likely within a given network. We discovered the mechanism, which also explains the link between network topology and self-organized criticality and the interactions between a system's elements."

Hoffmann said he first came across the phenomenon of self-organized criticality in 1999 while working on his master's thesis. He has worked to understand it better ever since.

"Scale-free events are all around us. A better understanding of their formation may enable us to better predict their probability and find mitigations to alter that probability to our advantage," he said.

In the case of earthquakes, tectonic plates are structures of many interacting components that exhibit SOC and have a few key characteristics. Some components have interactions between them and some have nonlinear interactions that typically involve some kind of threshold dynamics. This means that if the stress in a granular system reaches a particular threshold, its components tumble. Sand grains next to each other build up pressure until too many of them cause an avalanche.

Hoffmann also said that it is important to understand SOC, a property seen in many different systems, some unexpected. Earthquakes are perhaps the most common of these disasters, but power outages have the same fluctuations. Statistics of terrorist attacks or sizes of bot nets all have the scale-free property of size distributions.

"If we understand how power grids are maintained, based on models of grid maintenance, it could be possible to predict failure statistics," Hoffmann said. "Being scale-free means that very large events, even though less likely than small events, are orders of magnitude more likely than would be expected with different distributions. An example is the distribution of peoples' heights. The probability of seeing an increasing taller person drops dramatically at some point. Seeing someone twice as tall as us is extremely unlikely and seeing someone three times as tall is probably zero. It's different with power outages and earthquakes, in that an event three times as large as a smaller one is less likely, but still likely. While specifics cannot be predicted, we can predict certain qualities of the statistics. Whether an earthquake or power outage of a certain size is going to happen could be predicted. When it happens will remain unknown, but the chance of it happening can be predicted. With the probability of something like a power outage throughout a state the size of California, a one-in-a-million chance compared to a one-in-a-thousand chance is an important difference." ■

HRL Has Its *Ion Wellness* For Employee Health & Happiness

HRL Laboratories makes a great effort toward an attitude of positivity, encouragement, and engagement with its employees.

A significant contribution to that effort is Ion Wellness, HRL's employee health and wellness program. Through Ion Wellness, employees are offered many programs, services, and events that promote mental and physical health.

"Wellness is a big movement across many companies in America right now," said Ion Wellness coordinator Brandon VanDyke. "But it is not simple. There are multiple dimensions to it. A wellness program cannot be a boilerplate activity, and I think HRL does a good job of making sure our employees know that wellness has many facets that we attempt to address according to the concerns of our work force." VanDyke stated that HRL leadership has long recognized that healthy and happy employees are more engaged, work better, and in turn miss fewer days of work.

"Back in the day, Hughes Aircraft was ahead of its time as far as employee satisfaction programs go," VanDyke said. "It was an early adopter of employee education sponsorship and reimbursement. Hughes had one of the first learning and development programs at a time when such considerations were rare. Hughes employees valued this from the start, and today's HRL employees continue to value it because it helps them grow personally and professionally. This is borne out by the number of employees who have been here for decades. Employee loyalty is a byproduct of happiness and the feeling that your employer cares about your well-being."

Ion Wellness members pay close attention to the differences in interests of the many different kinds of people who work at HRL Laboratories, such as those who want family-oriented activities because they have children and limited amounts of time they can spend outside their households. All opinions must be weighed and considered when designing projects to attract employee participation.

As Ion Wellness progresses, VanDyke and his team will be adding metrics to their projects to ascertain return on investment. Keeping track of project effectiveness will inform decisions about which ones to continue and which to end in favor of new ideas, making the best use of wellness program resources.

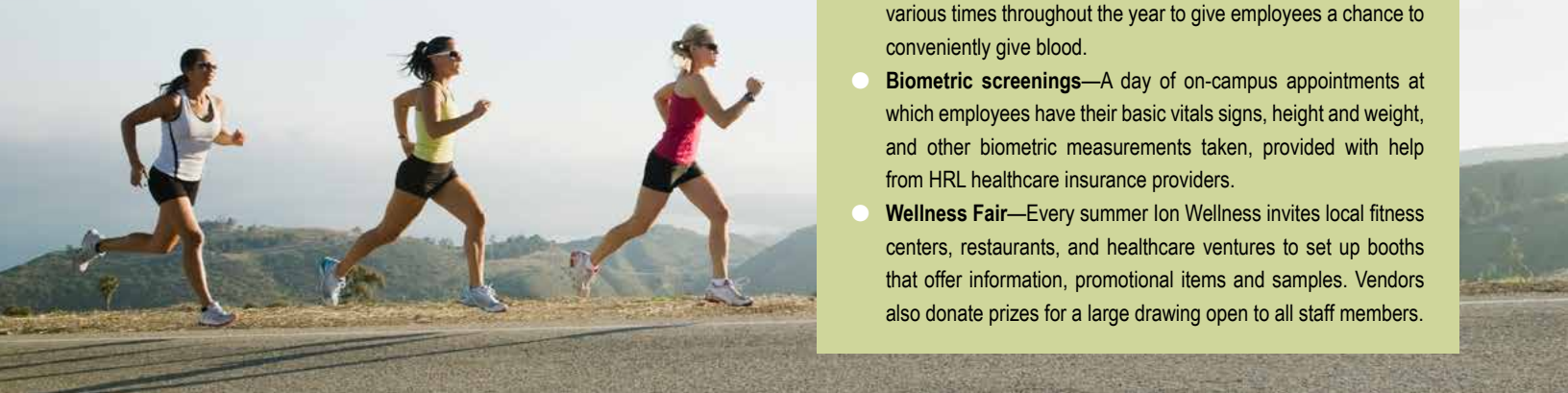
"Ion Wellness provides a foundation for our employees to maintain healthy lifestyles and take care of their bodies and minds," VanDyke said. "It's a holistic effort to maintain and improve the wellness of HRL's most important resource, our people. Because of our remote location, people respond well to efforts such as our free on-site flu shots and biometric screenings. Additional support from our health insurance providers gives us flexibility with what we can offer."

"With this kind of help along with the full support of HRL leadership, I hope to continue to expand our projects and reach out to employees in more areas in the coming years," VanDyke said. "Wellness is obviously a subject on employees' minds throughout their working lives and beyond, and we hope to always encourage it as a priority at HRL Laboratories." ■

ION WELLNESS
HRL LABORATORIES • MALIBU, CALIFORNIA

Among the services offered by Ion Wellness are:

- **WW at Work**—an opportunity to participate in the well-known weight-loss facilitation program at a discount through a group that meets on HRL's campus once a week at lunchtime.
- **Walkingspree**—a walking challenge in which employees log their daily steps with a phone app to earn points for prize drawings. This program includes scheduled group walks on the HRL campus grounds and other organized exercise events.
- **Meditation Zone**—a group open to all employees that meets for 30 minutes of guided meditation twice a week. Guest meditation teachers are often invited to lead sessions.
- **Blood drives**—A Red Cross Bloodmobile visits campus at various times throughout the year to give employees a chance to conveniently give blood.
- **Biometric screenings**—A day of on-campus appointments at which employees have their basic vitals signs, height and weight, and other biometric measurements taken, provided with help from HRL healthcare insurance providers.
- **Wellness Fair**—Every summer Ion Wellness invites local fitness centers, restaurants, and healthcare ventures to set up booths that offer information, promotional items and samples. Vendors also donate prizes for a large drawing open to all staff members.



Reaching out to OUR COMMUNITY

As the largest employer in Malibu, California, HRL's commitment to education and community outreach has wide-ranging influence. In that spirit HRL began offering educational tours to student groups in 2018.

An open invitation to local schools garners one tour per month, during which students are led to active laboratories where working scientists give demonstrations of current projects in many fields of research. Each tour consists of up to three live demonstrations and a curated visit to the viewing corridor that completely surrounds HRL's 10,000-square-foot Level 4 cleanroom. Large groups are split up and guided by separate staff members to the demonstration areas separately to ensure a more personal experience for each student.

The demos last 25 minutes and students are encouraged to ask questions about the demonstration, the research field featured, and the educational backgrounds of our scientists. Everyone involved, from the scientists to the staff guides, is asked what their job is and how they got to HRL.

The guests must be high-school students, and must be US persons. Groups must not be larger than 40 people, students and chaperons together. Every guest is required to sign a release form ahead of the tour and no photographs or any kind of recording is allowed on campus. A picnic-style lunch is provided on our Oceanside patio, overlooking the Pacific, and a group photograph on the front stairs is arranged at the conclusion of the tour. Because of the high demand since the tours began, interested parties are encouraged to apply early for a slot.

Schools can get more information by reaching out to media@hrl.com. Come and join us for a fun day of science! ■

Transcranial Thinking Cap Enhances Learning and Memory During Sleep

Putting on your thinking cap may no longer be just a figure of speech. Using a cap that covers the head and targets transcranial alternating current stimulation (tACS), researchers at HRL have proven a technique to help individuals improve their ability to learn and remember recent experiences in a completely non-invasive way, while they sleep.

According to current theories, information is initially encoded in the hippocampus of the brain for short-term storage. Because they can be quickly forgotten, the memories are transferred during sleep from the hippocampus to the cerebral cortex where they are integrated and consolidated with previous knowledge. This enables the new knowledge to be remembered and generalized better, increasing retention of new skills for longer periods.

The HRL technique is an automated process for enhancing memory consolidation during the sleep phase called slow-wave sleep. Many studies have shown that memory consolidation occurs during slow-wave sleep, and the potential to enhance it has been shown in some limited capacity. During the slow-wave phase, brain-wave oscillations are detected and enhanced through the scalp with alternating electric stimulation that matches the frequency and phase of those brain-wave oscillations. That frequency and phase matching defines the "closed-loop" system. This technique is unique to HRL Laboratories, and although others have speculated on the concept, HRL researchers were the first to publish results on a closed-loop slow-wave tACS system.

"By measuring the electrical signals on the scalp, we detect changes in the underlying brain state that indicate when recent experiences are likely to be reactivated or remembered during sleep," said HRL researcher Praveen Pilly. "We can enhance that process by prolonging the consolidation state using the closed-loop electrical stimulation. Prolongation results in better integration of recent experiences into more coherent and complete memories."

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Measuring brain activity with electrical signals on the scalp is difficult because the fields are noisy, attenuated, and distorted, and contain electrical artifacts during and following the closed-loop stimulation. This also makes detecting and matching electrical stimulation to the brain waves difficult. Much of the work involved was focused on optimizing the closed-loop system to shut out noise and make sure stimulation was delivered at the precise time with the exact phase and frequency to match the brain's natural slow waves during sleep. Data analysis that could show that the stimulation matched was a challenge, and sophisticated analytics were used to avoid artifacts and ensure the memory improvements were resultant from closed-loop stimulation.

When done properly, tACS is nearly imperceptible to the subject receiving it, and they do not awaken during the stimulation. People do not always respond to stimulation the same way. Across the group tested, HRL participants had an average improvement in memory, with some more prominently improved than others. With this milestone achieved, the HRL team must now explore the limits of the memory enhancement, where the brain stimulation works, and where it might fail.

The HRL team's publications on this research can be found in recent issues of the journals *Frontiers in Human Neuroscience*, *Frontiers in Neuroscience*, *Journal of Neuroscience*, *Brain Sciences*, and *Scientific Reports*. ■

A Look Inside
HRL's Leadership Development Program

Since early in its history, HRL Laboratories has considered leadership a very important quality that can and should be cultivated in employees.

Developing qualities in staff members that help them become successful and respected leaders has benefitted many of HRL's current upper echelon staff through educational and management support throughout the years. In today's competitive business world, developing future leaders is a necessity, and at HRL it has always been a strength.

Each year HRL executives poll managers for candidates for HRL's Leadership Development Program, an extensive 12-month course to help invited participants develop and improve their leadership skills. The program includes 20-25 invitees per year who are deemed by their managers to be appropriate for management-level training, or have recently attained a position with increased responsibility. One goal of the program is for participants to gain insight and a multilayer view of what can be expected from a leader at HRL and how to meet those expectations.

Program participants meet once a month on a varied schedule for facilitated discussions led by two outside lecturers. HRL front-office leadership members and department heads also talk to the group several times during the year about their experiences, how they dealt with difficulties they may have had along the way, and events that enriched the journey to where they are now.

"For me there was definitely a camaraderie within the group. The program gave us an opportunity to meet and bond with staff members we otherwise might have very little

LEFT: The graduating class of 2017 with their managers. ABOVE: Leadership Expert Bob Sadler works with the group on presentation skills.

involvement with," said Katie Nash, staff member and recent graduate of the program. "We were able to share issues we all have and get perspectives from people we wouldn't have exposure to otherwise. Often a fresh point of view from a person in an unrelated department can be enlightening and helpful."

The program initiates with a DiSC assessment (Dominance, influence, Steadiness, Conscientiousness), a profile published by Wiley that is a non-judgmental tool for determining behavioral differences based on personality types. Participants complete a series of questions that are used to produce a detailed report about a participant's personality and likely behavioral traits. The DiSC assessment is then used to offer tips on how people of different personality types may successfully interact with one other.

"The DiSC assessment was done for everyone, which was eye-opening in terms of how many different types of personalities we had in our class," Nash said. "Seeing what kind of person and leader you are compared to others, you can apply the analysis to figure out who might work together the best. This is a useful exercise that can be taken back and used within one's own department to coordinate successful teams."

Because the program is spread out over a year, the activities and study it entails can be managed along with the participants' normal work load.

"We're hoping to create a culture at HRL that develops the skills sets needed for leaders in professional research and development," said HRL CEO Parney Albright. "This program is young but is working the way we envisioned. Success at this early stage has encouraged us to keep going and improve the program where we can. It is very gratifying to see our people come out of this after a year with a more positive attitude toward leadership opportunities and their fellow team members."

"The program is a commitment, and requires work and a good amount of thought, but it was very fun," Nash said. "I enjoyed many interesting and dynamic conversations and made a new group of friends along the way. There are now people who I didn't know before who I go to for advice, or who can even serve as a test audience for a presentation I have to make, for example. Being able to talk with like-minded staff members about difficulties faced and how they were faced has been shown to be a powerful tool for building effective management skills. That kind of team building was definitely a goal of the program and I thought it was a great experience."

Besides group and individual discussions, program participants are given books for study, as well as videos such as TED Talks that offer unique and helpful perspectives. There is sometimes homework and participants critique each other's presentations and speeches. Sometimes there are two-day events and many subjects are covered. At the end of the program the participants are given a graduation party attended by their supervisors and front-office personnel. Although the Leadership Development Program is relatively new, it has been very successful so far based on the feedback from participants that is unanimously positive. ■

Doing Hard Things

HRL Laboratories' Brad Jones on how Running the Boston Marathon Translates to Successful Research

Photo courtesy of Brad Jones

Doing hard things describes HRL Laboratories in a nutshell. Our scientists and engineers work to solve problems thought to be impossible through imaginative thinking, determination, and top-grade applied science. Behind our many inventions are people like Brad Jones, an HRL engineer and program manager who seeks out hard things to do. Besides being a leader in his field, Brad is a Boston-qualified marathoner with a personal best time of 2 hours and 49 minutes.

"For the 2018 race, the temperature in Boston was 42 degrees and there was still snow on the ground," Jones said. "On top of that was torrential rain and a 25-35—mph headwind. I put plastic grocery bags over my shoes to keep them from getting caked over with mud before the start."

Brad thought it seemed close to impossible to run a full marathon let alone run well in that weather. He had seen good runners talk themselves out of doing well before the start, so he stayed focused.

"My college track coach always preached: 'you never know what you can do until you try.' This sounds simple, but if taken to heart it may be applied to may aspects of life. You truly can never know until you try and the surest way to fail is to not try at all."

"The difference happens at the start," Jones said. "At that point, I'm in control. I decide what I'm going to do that day, how fast I go, when I stop. I know that once I start, the faster I get to the 26.2-mile mark, the sooner this will be over. Trust your training and accept that it's going to be hard."

Jones finished the 2018 Boston Marathon in 3 hours and 11 minutes. He's also quick to point out that his mindset for running Boston also applies to working at HRL.

"Because we are doing very innovative technology—right on the cutting edge—there is always risk involved, and a chance that you will fail. But rather than protecting ourselves because we fear being held accountable for something that doesn't work, we have to push forward, do our absolute best, and see what happens. With that attitude you can accept positive or negative results."

"You've got to push through to failure sometimes," Jones adds. "That's why the running analogy works perfect for me. I can say that I've tried for a 2-hour 45-minute marathon and run a 2-hour 58-minute race with a slow and painful finish, but I never would have known how close I could get unless I'd pushed beyond what I thought was the limit. You can't start with fearing failure. You have to keep a can-do attitude, understanding that to do really great things you're going to be uncomfortable, things will be hard, and you're going to fail before you succeed. Then you try again, you train harder, and maybe change something to find the way that works. Sometimes you have a bad day, but you never quit because tomorrow could bring that breakthrough you've been searching for. In our research, sometimes your hypothesis is wrong, sometimes your program doesn't go the way it was supposed to or something isn't delivered the way you expected. You have to stay resilient, adjust, and try again. If running marathons has taught me anything, it's that real success does not come easy or on the first try. Resilience, planning, and hard work keep you in the race and on the cutting edge of your field." ■

Building a Brain

"We believe that scalable active and passive biomimetic memristors could unleash the potential of neuromorphic computing."

Scientists and engineers often use biomimicry—imitation of structures or mechanisms from nature—for novel engineering. With neuromorphic or brain-inspired computing, biomimicry is useful for electronic neurons, the brain's basic nerve cells. Neurons communicate through tiny synapses between them via chemicals or electric current.

The brain is a biological computer roughly 1.2 liters in volume that makes decisions, recognizes images, and analyzes scenes instantly, using less power than a 40-watt light bulb. It also learns and adds to its knowledge base, using experience to make associations between dissimilar concepts. No electronic computer matches its power, size, and efficiency. Scientists see neuromorphic computers as possible alternatives beyond the limits of silicon chips.

A bottom-up approach to brain emulation could start with biomimic neurons and synapses. HRL Laboratories researchers hope to create those building blocks with nanoscale electronic devices called memristors (memory+resistor). These are two-terminal circuit elements that remember their dynamic history and adjust current resistance based on how much and which direction charge last flowed through them. Memristors can be passive or active based on whether that influence is maintained after external stimuli are removed.

"Synapses connect neurons and can remember data, which is how learning happens in the brain. Connections between neurons also evolve constantly. As some grow, others disappear," said Wei Yi, HRL's lead scientist on the project. "We haven't yet approached those capabilities electronically. For building intelligent machines, nature provides

insight. Our brains work differently than our Von Neumann-architectured laptops, desk tops, smart phones, etc. Compact circuits of active memristors can emulate neurons, and passive memristors can emulate synapses. Memristor neurons and synapses form a self-sufficient basis for a transistorless neural network that can do difficult computations. Theoretically, such networks could be augmented and scaled up to build an electronic human brain mimic," Yi said.

"We are trying to build a machine that can compute like a brain, with delicate motion control, attention focusing, and decision-making," said researcher Dana Wheeler. "Humans are slower than computers when values are ones and zeroes, but we are orders of magnitude faster at integrating sensory data, filtering choices, mining data, and being creative."

Brains do not need programming and fixed algorithms like Von Neumann computers. Dynamic brain networks of 100 billion neurons and 100 trillion synapses adapt with experience. A self-learning electronic brain would be a breakthrough, and building biologically plausible neurons and synapses is key to all-memristor neuromorphic computers that mimic the cerebral cortex.

"A biomimic that competes with a brain is a grand challenge requiring disruption on many fronts," Yi said. "The first step industry is taking is departure from von Neumann architecture, so memory and computation are spatially and temporally integrated, not separated, to save energy and computing time. The second little-known step is departure from silicon transistors, which are not optimal neuron and synapse mimics. We believe that scalable active and passive biomimetic memristors could unleash the potential of neuromorphic computing." ■

HRL researches Wei Yi (left) and Kenneth Tsang (right) inside the HRL cleanroom at the electrical test setup. They are pointing at a captured experimental waveform of vanadium oxide neuron spiking, indicating that their memristor was successfully mimicking the function of a biological brain nerve cell.

IP Highlights

114 PATENTS ISSUED in 2018

9,985,121 P-TYPE DIAMOND GATE-GAN HETEROJUNCTION FET STRUCTURE – Kenneth R. Elliot

10,178,120 METHOD FOR DETERMINING CONTAGION DYNAMICS ON A MULTILAYER NETWORK – Matthew S. Keegan, Kang-Yu Ni, Tsai-Ching Lu

10,166,394 DEVICE AND METHOD TO AUTOMATICALLY TUNE THE NERVE STIMULATION PATTERN OF A SENSORY-FEEDBACK CAPABLE PROSTHESIS – Heiko Hoffmann, Jaehoon Choe, Corey M. Thibeault

10,177,741 ENVELOPE TRACKING ACTIVE CIRCULATOR – Johngchan Kang and Hasan Sharifi

10,177,737 HIGH-Q QUARTZ-BASED INDUCTORS FOR HIGH POWER LF COMMUNICATION – Randall L. Kubena and Walter S. Wall

10,177,454 LUMPED ELEMENT TENSOR IMPEDANCE SURFACES – Amit M. Patel

10,176,407 NONLINEAR SPARSE REPRESENTATION-BASED CLASSIFICATION FOR FOVEATED ANALYSIS OF SPECTRAL DATA WITH DISTORTIONS – Shankar R. Rao and Yuri Owechko

10,176,382 METHOD AND APPARATUS FOR SPARSE ASSOCIATIVE RECOGNITION AND RECALL FOR VISUAL MEDIA REASONING – Yuri Owechko, Shankar R. Rao, Shinko Y. Cheng, Suhas E. Chelian, Rajan Bhattacharyya, and Michael D. Howard

10,175,307 FM DEMODULATION SYSTEM FOR QUARTZ MEMS MAGNETOMETER – Logan D. Sorenson, Hung Nguyen, Raviv Perahia, David T. Chang, L.X. Coco Huang, and Joshua A. Erbland

10,174,223 FORMULATIONS, METHODS, AND APPARATUS FOR REMOTE TRIGGERING OF FRONTALLY CURED POLYMERS – Tao Xie, Andrew P. Nowak, and Thomas Boundy

10,172,532 FEATURE TRANSFORMATION OF NEURAL ACTIVITY WITH SPARSE AND LOW-RANK (SLR) DECOMPOSITION – Kang-Yu Ni and James Benvenuto

WHAT'S NEXT

by Leslie Momoda, Vice President

In this issue of HRL Horizons we present a glimpse into some of our research and development efforts toward critical elements for next-generation complex systems.

Each technology creates new mission-enabling capabilities. These include the ability to accurately know position from a compact device, to predict and mitigate catastrophic failures in a distributed system, and to understand how the human brain stores and enhances memory with an aim to eventually electronically replicate its function and low-power operation. These foundational elements are the underpinnings of future multifunctional autonomous systems.

And as we advance today's cutting-edge technologies, we continue to learn the lessons of our past. Formerly the Hughes Research Laboratories—birthplace of such critically enabling technologies such as the laser, modern transistor processing, and ion propulsion—HRL's storied history is now chronicled in our *HRL's History of the Future* podcasts. These episodes contain insights into how our historical breakthroughs were produced, nurtured, and introduced into modern systems, giving us valuable lessons as we create the next generation of innovations.

What's next at HRL is our continued focus on the development and demonstration of enabling technologies for increasingly complex systems. These inherently multidisciplinary endeavors are supported by HRL's agile size and closely coupled campus, enabling frequent collaboration among highly skilled researchers and engineers. Our rich history and unique partnerships continue to inform and refine our ability to effectively and rapidly transition these technologies to systems. HRL teams are engineering systems with the ability to communicate and discriminate in congested environments, operate reliably at high temperatures, aid humans in effective collaboration with machines, and explain and mimic human-like decision making. We look forward to describing these technologies and the complex systems they enable in future HRL Horizons issues.

"What's next at HRL is our continued focus on the development and demonstration of enabling technologies for increasingly complex systems."

HRL LABORATORIES

HRL Horizons

HRL LABORATORIES, LLC
3011 Malibu Canyon Road
Malibu, CA 90265

www.hrl.com

LinkedIn.com/hrl-laboratories

Facebook.com/HRLlaboratories

Twitter.com/HRLLaboratories