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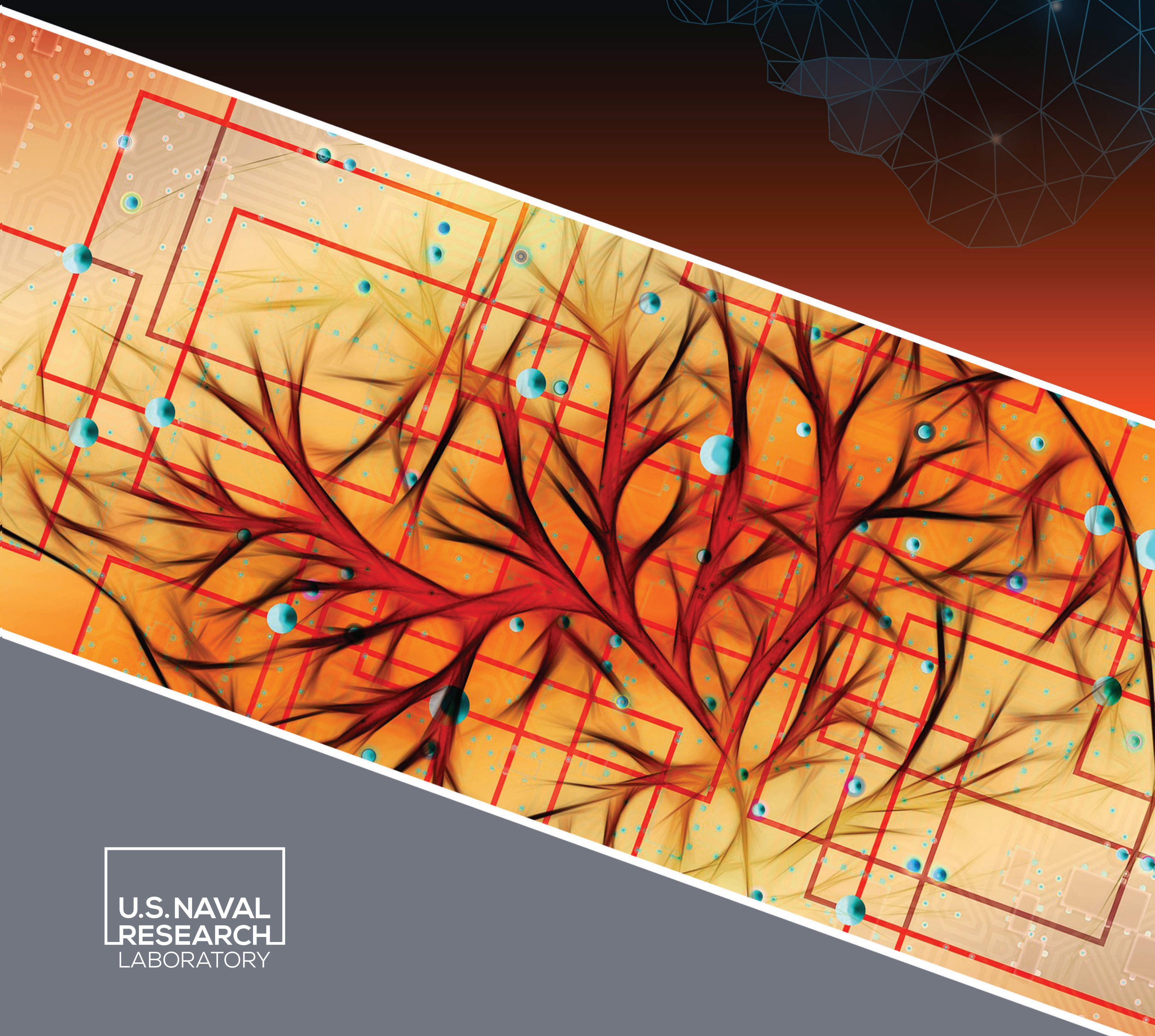
U.S. NAVAL RESEARCH LABORATORY | MAY 2019



U.S. NAVAL RESEARCH LABORATORY

From the Associate Director

DR. GERALD M. BORSUK
Associate Director of Research for Systems

The Systems Directorate applies the tools of basic research, concept exploration, engineering development and rapid prototyping to address operational warfighting gaps, to create new warfighting capabilities based upon Scientific and Technical advances for the Navy and Marine Corps and to prevent technological surprise while creating it for others. Emphasis is on accelerating these Research and Development results from the laboratory to the Fleet.

Current activities include:

- New and improved radar systems to detect and identify ever smaller targets in the cluttered littoral environment;
- Optical sensors and related materials to extract elusive objects in complex scenes when both processing time and communications bandwidth are limited;
- Advanced electronic support measures techniques for signal detection and identification;
- Electronic warfare systems, techniques, and devices including quick-reaction capabilities;
- Techniques and devices to disable and/or confuse enemy sensors and information systems;
- Small intelligent teams of autonomous land, sea, and air vehicles to carry sensors, communications relays, or jammers;
- Quantum information systems for superior sensors and quantum computing applications
- High performance/high assurance computers with right-the-first-time software and known security characteristics despite commercial off-the-shelf components and connections to public communications media; and
- Artificial intelligence and machine learning to enable more capable and intelligent decision aids.

Many of these efforts extend from investigations at the frontiers of science to the support of deployed systems in the field, which themselves provide direct feedback and inspiration for applied research and product improvement and/or for quests for new knowledge to expand the available alternatives.

In addition to its wide-ranging multidisciplinary research program, the Directorate provides support to the corporate laboratory in shared resources for high performance computing and networking, technical information collection and distribution, and coordination of Laboratory-wide efforts in signature technology, counter-signature technology, Theater Missile Defense, and the Naval Science Assistance Program.

PUBLISHER
NRL STRATEGIC COMM OFFICE
Victor Chen
MANAGING COORDINATOR
Jonna Atkinson, Head

EDITING AND DESIGN
EDITING
Kimberley Hall
GRAPHIC DESIGN
Daria Bodnaruk

PHOTOGRAPHY
Jonathan Sunderman
Jonathan Steffen

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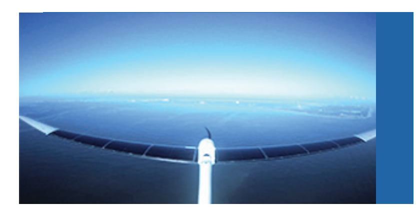
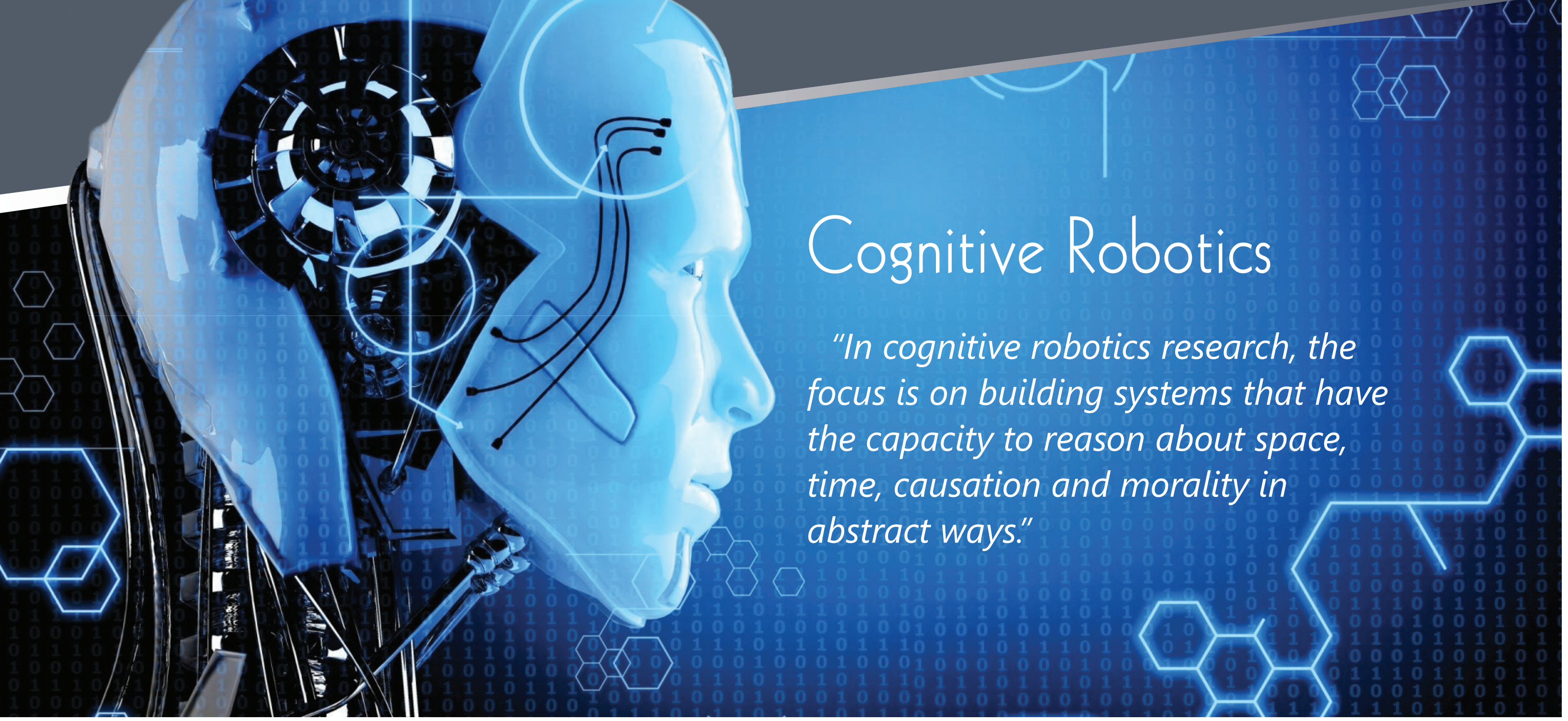


Thank you for picking up this copy of Spectra, a small sample of the research from the U.S. Naval Research Laboratory.



Cognitive Robotics

"In cognitive robotics research, the focus is on building systems that have the capacity to reason about space, time, causation and morality in abstract ways."

Research in the Human and Machine Intelligence (HMI) Section at the Navy Center for Applied Research in Artificial Intelligence (NCARAI) focuses on improving the ability of robots and other artificial agents to understand and interact with humans.

HMI scientists and researchers do this by taking an integrative approach to cognitive science, sensor processing and robotics that is guided by a theory-first systems perspective. This unique, multidisciplinary focus has yielded three main benefits.

First, by examining theories of human cognition the HMI researchers build a better understanding of how humans interact with the world as they carry out their respective goals. Second, this knowledge can be leveraged to improve robot behaviors, broadening the range of accomplishable tasks. The third and final benefit allows predictive and anticipatory models of humans to be built, improving teamwork, trust, and overall system performance.

For example, imagine a scenario where a robot is tasked with patrolling an area. Upon completion, it reports any discoveries to a human partner. During the course of the patrol, the robot encounters an unattended bag and must determine whether it is expected or anomalous. These seemingly simple events present a wealth of complex issues that need to be addressed intelligently.

Human Reasoning and Robotic Cognition

One of the core components of cognitive research at NCARAI is the development of rich process models of basic human cognitive skills, such as attention, memory and perception. Development is guided and constrained by the cognitive architecture within which the models are implemented. In this case, Adaptive Character of Thought-Rational/ Embodied (ACT-R/E) provides a set of theoretically motivated components and their interconnections.

These components are based on existing behavioral and neurological theories of human cognition. With these constraints in mind, higher-level cognition, like problem-solving or explanation, can be explored.

Robots can provide effective explanations to humans only if they understand how humans understand the world and are equipped with the ability to reason about abstract concepts. In daily life, the ability to reason abstractly allows people to creatively construct solutions for problems that they have never before experienced.

For instance, when you plan travel logistics for a place you have never visited, you are reasoning about space and time. When you infer that there is a mechanical problem in your car from a sound you have never before heard, you are reasoning about cause and effect. When you decide on a fair punishment for a child who broke a rule for the first time, you are reasoning about morality.

In cognitive robotics research, the focus is on building systems that have the capacity to reason about space, time, causation and morality in abstract ways so that robots can solve novel problems and generate effective explanations of those solutions. The goal is to make them solve problems in a way that parallels human reasoning. Therefore, the cognitive systems need to mimic both the strengths and weaknesses of how humans think.

In an effort to minimize the number of things they need to hold in memory, humans will sometimes exhibit systematic reasoning biases and errors. They may take mental shortcuts or forget to consider alternative possibilities. The goal here is to create computer models of the mental processes in humans that lead to such errors, as well as the mental processes that can correct those errors.

A robot that can implement the processes that lead to human mistakes can better detect when a mistake occurs. It can also assist a human's thinking and offer corrections and suggestions so that the human considers appropriate alternative possibilities before making decisions.

Humans Differ in the Way They Reason

Some humans are excellent at deliberating over abstract matters, some have unique pieces of information that others do not and some can develop reasoning strategies on the fly. Building computer models of mental processes aids in analyzing the flexibility and the complexity of human reasoning.

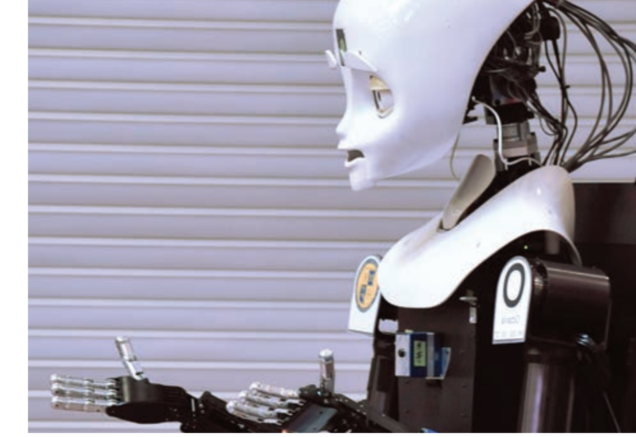
Almost every computer model developed in the HMI section at NCARAI is checked against data from behavioral studies on humans. Only after validation that the model is performing in a manner that mimics the actions of humans is the system implemented on a robot.

Returning to the 'patrolling' example, the robot must engage in complex reasoning during and after the patrol. For example, when the robot discovers the unattended bag, it does not know if it is innocuous or if it could conceal a threat, such as an improvised explosive device. The robot uses its knowledge of the space it is patrolling (e.g. private office vs. classified lab space) to provide additional context concerning the appropriateness of the object's presence. Further, when it comes time to report what was found during the patrol, the robot needs to formulate its explanations using human-like representations so that people can quickly and efficiently understand the presented information.

Computer Perception

While the cognitive architectures make specific predictions about the cognitive processes, including perception, the actual implementation of perceptual systems falls to perceptual processing. Perception provides robotics platforms with the ability to recognize people and objects around the robot. Since the goal is making the robot an effective collaborator, the ability to recognize salient objects is an important component as this directly impacts how the robot can think and reason about the surrounding world.

To recognize people, multiple soft biometric attributes, which can recognize both inherent and extrinsic traits of a person such as age, gender, build, clothing, etc. are used. These attributes, are not permanent or distinctive, but can provide a powerful means of identification when combined together in sufficiently large numbers.



Moreover, soft biometric attributes can be communicated to a person (to describe someone else), or the robot can use these attributes to accept a description of a person. To accommodate this approach, the HMI team has developed a large-scale ontology which can understand almost 150 different attributes and has demonstrated how this can be an effective manner of locating and describing collaborators or teammates.

In addition to recognizing people, humans and robots must be able to recognize objects both predefined and novel. Towards this end, scientists in the HMI section have developed several perceptual systems that operate independently, and others that rely upon top-down information from the cognitive architectures.

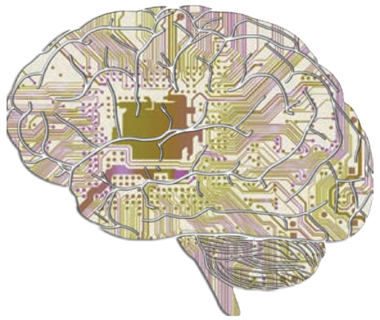
In the case of the anomalous bag detection, the cognitive architecture provides an awareness of the robot's location as well as what types of objects it is expecting to see. Anomalies are then simply violations of expectation.

The HMI lab's approach to human-robot systems and intelligent systems is multidimensional. The scientists and researchers at NCARAI focus on understanding how humans think. They develop process models of cognition that faithfully capture how humans solve real world problems and make intelligent systems more effective by taking advantage of human strengths. The results are models that help to reveal the limitations of human cognition and the development of systems that can mitigate through intelligent interactions.

Collectively, research at NCARAI improves the ability for robots and other artificial agents to understand and interact with their human counterparts.

By Anthony Harrison, Ed Lawson, Sangeet Khemlani, J. Gregory Trafton
Navy Center for Applied Research in Artificial Intelligence (NCARAI).
Contributing Editor: Daniel Parry, NRL Strategic Communication Office

AI Researcher Offers Insight on Promise, Pitfalls of Machine Learning



These days, the latest developments in artificial intelligence (AI) research always get plenty of attention, but an AI researcher at the U.S. Naval Research Laboratory believes one AI technique might be getting a little too much.

Ranjeev Mittu heads NRL's Information Management and Decision Architectures Branch and has been working in the AI field for more than two decades.

"I think people have focused on an area of machine learning—deep learning (aka deep networks) — and less so on the variety of other artificial intelligence approaches," Mittu said. "The biggest limitation of deep networks is that a complete understanding of how these networks arrive at a solution is still far from reality."

Deep learning is a machine learning approach that can be used to recognize patterns, such as identifying a collection of pixels as an image of a dog. The technique involves layering neurons together, with each layer devoted to learning a different level of abstraction.

In the dog image example, the lower layers of the neural network learn primitive details like pixel values. The next set of layers attempt to learn edges; higher layers learn a combination of edges as a nose. With enough layers, these networks are able to recognize images with nearly human-like performance.

But the systems can be fooled easily just by changing a small number of pixels, according to Mittu.

"You can have adversarial 'attacks' where once you've created a model to recognize dogs by showing it millions of pictures of dogs," he said. "...making changes to a small number of pixels, the network may misclassify it as a rabbit, for example."

The biggest flaw in this machine learning technique, according to Mittu, is that there is a large degree of art to building these kinds of networks, which means there are very few scientific methods to help understand when they will fail.

The Solution?

"There are a variety of AI techniques," he said. "While deep learning has been highly successful, it is also currently limited because there is little visibility into its decision rationale. Until we truly reach a point where this technique becomes fully "explainable", it cannot inform humans or other automation as to how it arrived at a solution, or why it failed. We have to realize that deep networks are just one tool in the AI tool box."

And humans have to stay in the loop

"Imagine you have an automated threat detection system on the bridge of your ship, and it picks up a small object on the horizon," he said. "The deep network classification may indicate that it is a fast attack craft coming at you, but you know that a very small set of uncertain pixels can mislead the algorithm. Do you believe it?

"A human will have to examine it further. There may always need to be a human in the loop for high risk situations. There could be a high degree of uncertainty and the challenge is to increase the classification accuracy while keeping the false alarm rate low – it is sometimes very difficult to strike the perfect balance. "

The Problem with Machine Learning

When it comes to machine learning, the key factor, simply put, is data.

Consider one of Mittu's previous projects: an analysis of commercial shipping vessel movements around the world. The project's goal was to use machine learning to discern patterns in vessel traffic to identify ships involved in illicit activities. It proved a difficult problem to model and understand using machine learning, Mittu said.

"We cannot have a global model because the behaviors will differ for vessel classes, owners, etc." he explained. "It is even different seasonally, because of sea state and weather patterns."

But the bigger problem, Mittu found, was the possibility of mistakenly using poor quality data.

"Ships transmit their location and other information, just like aircraft. But what they transmit can be spoofed," Mittu said. "You don't know if it is good or bad information. It is like changing those small numbers of pixels on the dog image that causes the system to fail."

Missing data is another issue. Imagine a case in which you must move large numbers of people and materials on a regular basis to sustain military operations, and you're relying on incomplete data to predict how you might act more efficiently.

"The difficulty comes when you start to train machine learning algorithms on data that is of poor quality," Mittu said. "Machine learning becomes unreliable at some point, and operators will not trust the outcomes of the algorithms."

Current Work in AI

Today Mittu's team continues to pursue AI innovations in multiple areas of the field. They advocate an interdisciplinary approach to employing AI systems to solve complex problems.

"There are many ways to improve predictive capabilities, but probably the best–of-breed will take a holistic approach and employ multiple AI techniques and strategically integrate the human decision-maker," he said.

"Aggregating various techniques (similar to 'boosting'), which may 'weight' algorithms differently, could provide a better answer, or learning combined with reasoning, etc. By employing combinations of AI techniques, the resulting system may be more robust to poor data quality."

One area Mittu is excited about is recommender systems. According to him, most people are already familiar with these systems, which are used in search engines and entertainment applications such as Netflix. He's excited about the potential military applications.

"Think of a military command and control system, where users need good information to make good decisions," he said. "By looking at what the user is doing in the system within some context, we can anticipate what the user might do next and infer the data they might need."

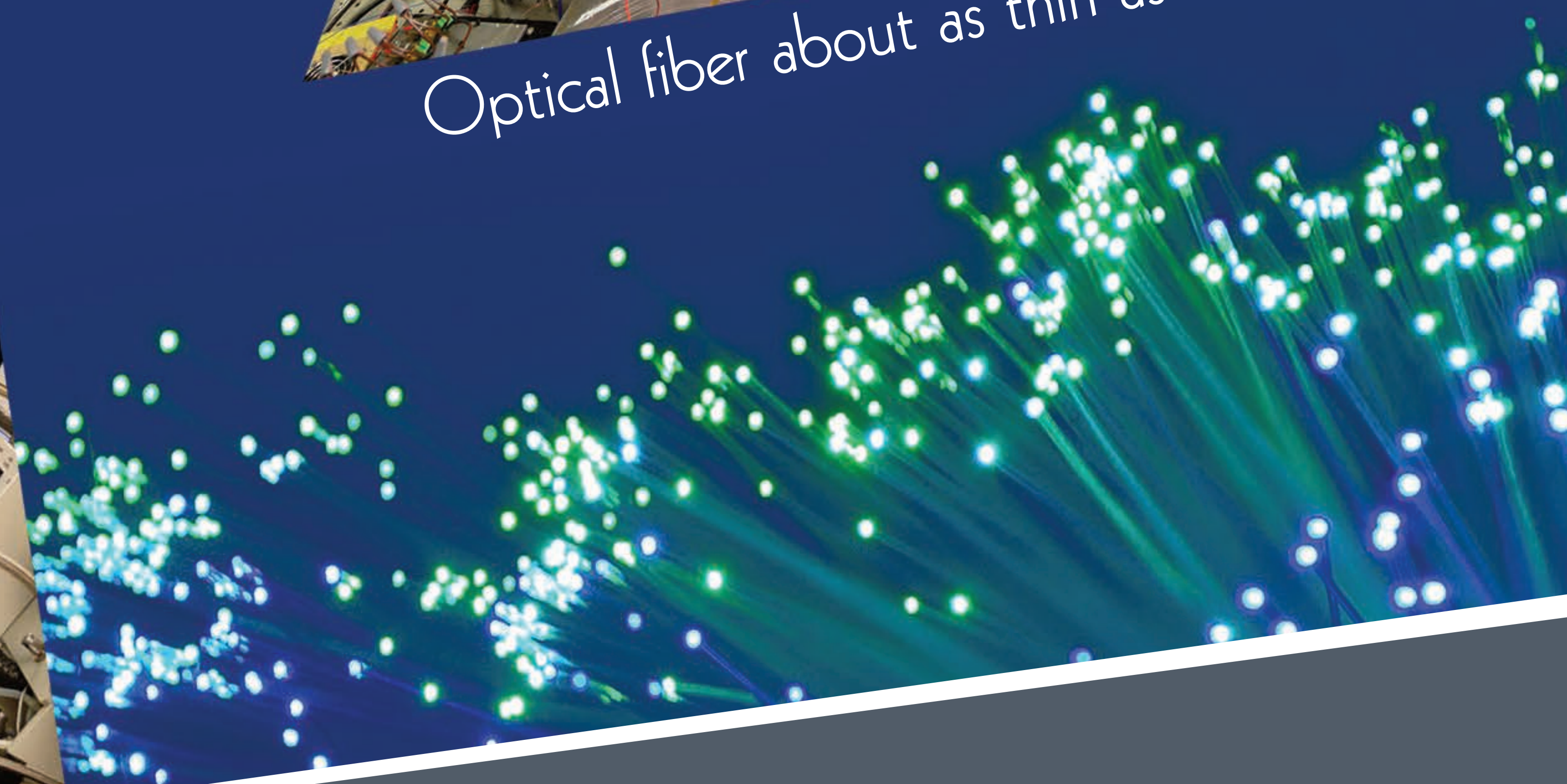
While the field of AI offers almost limitless potential for innovative solutions to today's problems, Mittu said, researchers obviously have many years of work ahead of them.

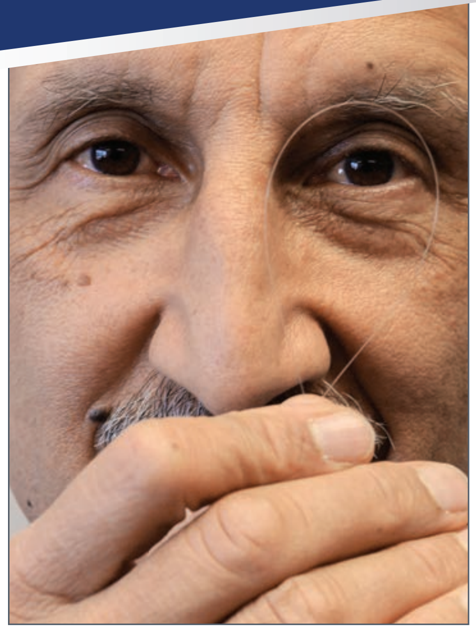
"We need to determine the right techniques, their limitations, and the data that is needed in order to get reliable answers in order for the users to trust the resulting system," he said. "The field of AI has a long way to go in taking a holistic approach by strategically integrating the decision-maker in order to improve the performance of the human and machine system."

By Victor Chen, NRL Strategic Communication Office

Improving eye safety of fiber lasers

Optical fiber about as thin as a human hair





Jas Sanghera, NRL branch head for Optical Materials and Devices, holds up optical fiber that will be used to produce eye safer lasers .

Researchers Use Nano-Particles to Increase Power, Improve Eye Safety of Fiber Lasers

Scientists at the U.S. Naval Research Laboratory have devised a new process for using nano-particles to build powerful lasers that are more efficient and safer for your eyes.

They're doing it with what's called "rare-earth-ion-doped fiber." Put simply, it's laser light pumping a silica fiber that has been infused with rare earth ions of holmium. According to Jas S. Sanghera, who heads the Optical Materials and Devices Branch, they have achieved an 85 percent efficiency with their new process.

"Doping just means we're putting rare earth ions into the core of the fiber, which is where all the action happens," Sanghera explained. "That's how we've produced this world record efficiency, and it's what we need for a high-energy, eye-safer laser."

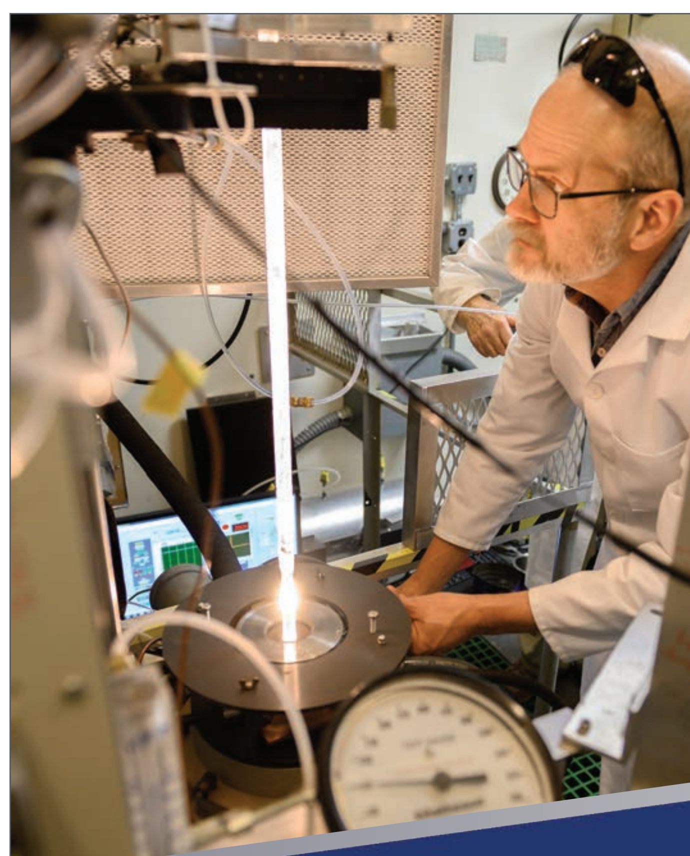
According to Colin Baker, research chemist with the Optical Materials and Devices Branch, the lasing process relies on a pump source--most often another laser—which excites the rare earth ions, which then emit photons to produce a high quality light for lasing at the desired wavelength.

"But this process has a penalty," Baker said. "It's never 100 percent efficient. What you're putting in is pump energy, not the high quality light at the wavelength you want. What's coming out is a much higher quality of light at the specific wavelength that you want, but the remaining energy that isn't converted into laser light is wasted and converted into heat."

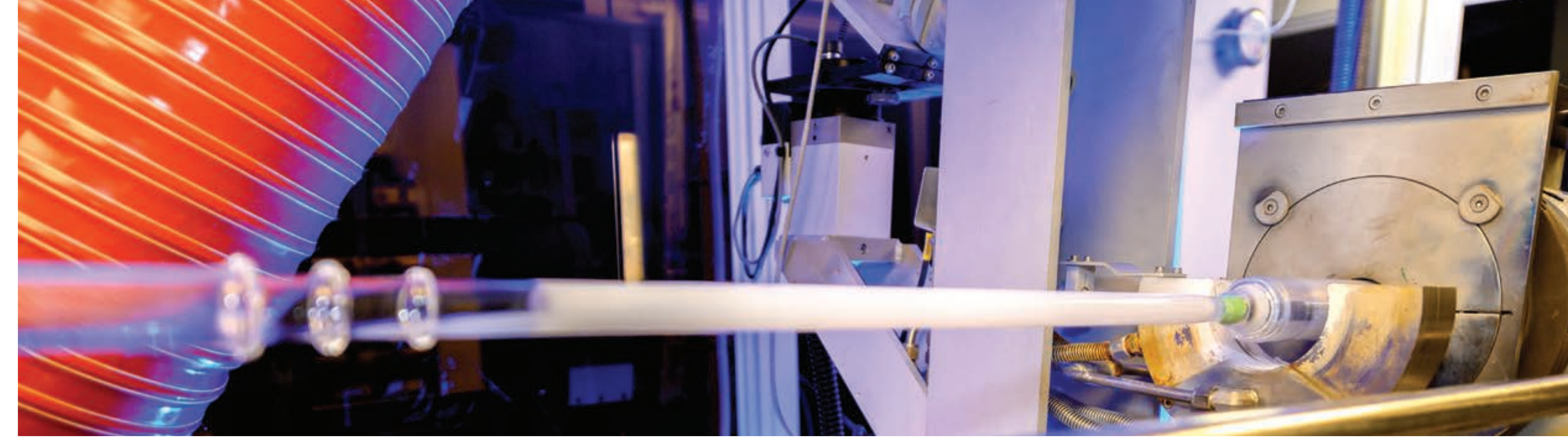
That loss of energy, Baker said, ultimately limits power scaling and the quality of the laser light, which makes efficiency especially important.

With the aid of a nano-particle 'dopant,' they're able to achieve the 85 percent level of efficiency with a laser that operates at a 2 microns wavelength, which is considered an "eye-safer" wavelength, rather than the traditional 1 micron. Of course, Baker pointed out, no laser can be said to be safe when it comes to the human eye.

The danger arises from the potential of scattered light to be reflected into the eye during a laser's operation. Scattered light from the path of a 100-kilowatt laser operating at 1 micron can cause significant damage to the retina, leading to blindness. With an eye-safer laser, operated at wavelengths beyond 1.4 micron, however, the danger from scattered light is considerably lessened.



Daniel Rhonehouse, NRL research chemist, lowers a silica rod into the draw tower furnace in preparation for pulling optical fiber.



According to Baker, the nano-particle doping also solves several other problems, such as that it shields the rare earth ions from the silica. At 2 microns, the silica's glassy structure can reduce the light output from the rare earth ions. The nano-particle doping also separates the rare earth ions from each other, which is helpful since packing them closely together can also reduce the light output.

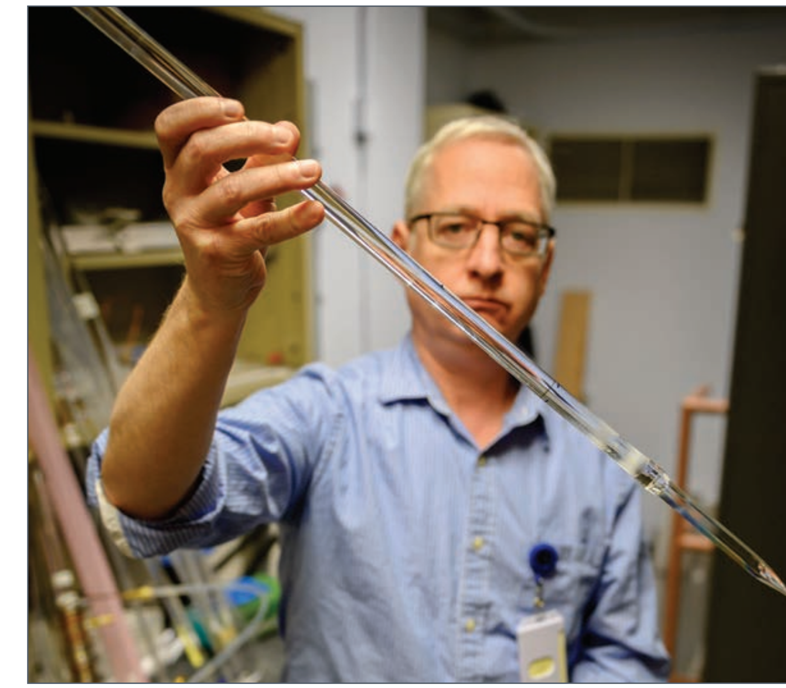
(Traditional lasers that operate at 1 micron, using an ytterbium dopant, aren't nearly as affected by these factors, Baker said.)

"The solution was some very clever chemistry that dissolved holmium in a nano-powder of lutetia or lanthanum oxide or lanthanum fluoride to create a suitable crystal environment [for the rare earth ions]. Using bucket chemistry to synthesize this nano-powder was key in keeping the cost down," Sanghera said. The particles of the nano-particle powder, which Sanghera's team had originally synthesized for a previous project, are typically less than 20 nanometers, which is 5,000 times smaller than a human hair.

"Additionally, we had to be able to successfully dope these nano-powders into the silica fiber in quantities that would be suitable to achieve lasing," he added.

At the Optical Materials and Devices Branch, Sanghera's team of scientists are working with a room-sized, glass-working lathe, where the glass that will eventually become the fiber is cleaned with fluorine gases, molded with a blow torch and infused with the nano-particle mixture – what the scientists call a "nano-particle slurry." The result is a rare-earth-ion-doped, one-inch diameter, glass rod, or "optical preform."

Next door, scientists use a fiber pulling system – a tower so massive that it takes up two large rooms and; the height of two floors of the building – to soften the preform with a furnace and elongate it, in a process akin to pulling taffy, into an optical fiber about as thin as a human hair, which then spools onto a nearby large spindle.



Colin Baker, NRL research chemist, holds a silica glass rod (optical preform) that will be pulled into an optical fiber suitable for production of an eye safer laser.

Sanghera's team has already submitted a patent application for the process. Among the potential applications they envision for the new specialty fiber laser are high powered lasers and amplifiers for defense, telecommunications and even welding and laser-cutting.

"From a fundamental perspective, the whole process is commercially viable," Sanghera said. "It's a low-cost process to make the powder and incorporate it into the fiber. The process is very similar to making telecom fiber."

By Emanuel Cavallaro, NRL Strategic Communication Office

Waveguides for Non-Mechanical Beam Steering in the Mid-Wave Infrared

Introduction

The mid-wave infrared (MWIR) portion of the optical spectrum is of interest for a variety of military and civilian applications, including molecular fingerprint chemical sensing and thermal detection. Traditionally, in applications where an MWIR laser is used to illuminate a target of interest, the beam is steered mechanically using a gimbal. While mechanical gimbals have some positive attributes, including high efficiency, they are typically bulky and heavy, consume large amounts of power, have relatively slow slew rates, and, because they contain multiple motors and moving parts, require frequent maintenance. Combined, these attributes make mechanical gimbals unsuitable for new and emerging applications, including installation on small, unmanned vehicles that have constraints on the allowable size and weight of their components. New technologies are required that are free of the drawbacks associated with mechanical steering.

A New NRL Beam Steerer

In a combined effort between the Optical Sciences Division, the Center for Biomolecular Science and Engineering, and the Tactical Electronic Warfare Division, the U.S. Naval Research Laboratory (NRL) is developing an agile non-mechanical beam steerer suitable for advanced applications. The new NRL beam steerer, called a Steerable Electro-Evanescent Optical Refractor (SEEOR), is based on a variable refractive index waveguide first developed by Vescent Photonics (Arvada, Colorado) (in the short-wave infrared) under U.S. Navy Small Business Innovation Research funding.[1] Development of the beam steerer has been fully transitioned to NRL for research into its possible usefulness in defense-related applications and exploration of its potential for expansion into other optical bands.[2]

Each SEEOR consists of three key regions, as shown in Fig. 1. First, polarized light must be efficiently coupled into the waveguide. This is accomplished via the use of an Ulrich coupler[3] which relies on a faceted substrate, a precisely tapered subcladding, and a waveguide core. By illuminating the facet at a precise, wavelength-dependent angle, light is efficiently coupled through the substrate and confined within the waveguide core because of its high relative refractive index. The subcladding, which is tapered at angles that require microradian precision, is grown in the Optical Sciences Division using advanced deposition techniques.

Once in the waveguide core, light propagates until it enters the horizontal steering region. Here, the waveguide stack consists of the (now untapered) subcladding, the core, and an upper cladding of aligned liquid crystal. Liquid crystal is used because it has a variable, orientation-dependent refractive index due to its birefringent nature, which originates from the collective property of rod-shaped molecules possessing orientational order in a fluid-like state. In the absence of an applied electric field, the aligned liquid crystal molecules will orient in one preferred direction relative to the core with a certain refractive index. When a voltage is applied across the device, the molecules will reorient, controllably altering the refractive index. This effect is exploited to create steering.

The waveguide in this region is designed to ensure that the optical mode is not strongly confined to the core and that part of the mode, the evanescent field, extends into the liquid crystal upper cladding. Because part of the mode is now interacting with the liquid crystal, any changes in the liquid crystal refractive index will change the overall effective refractive index of the mode propagating in the waveguide. Because the electrodes have been designed with a prismatic pattern, changing the refractive index of the liquid crystal with an applied voltage effectively creates a variable prism pattern that steers light to either the left or the right.

The final region of the waveguide is the outcoupling region, where the voltage-dependent refractive index of liquid crystal is used to create vertical steering. The outcoupling region is another Ulrich coupler with a tapered subcladding, but there is now an electrode present over the tapered region that is used to apply voltage and tune the liquid crystal index. As the index is varied, the exit angle of light from the waveguide also changes, resulting in vertical steering.

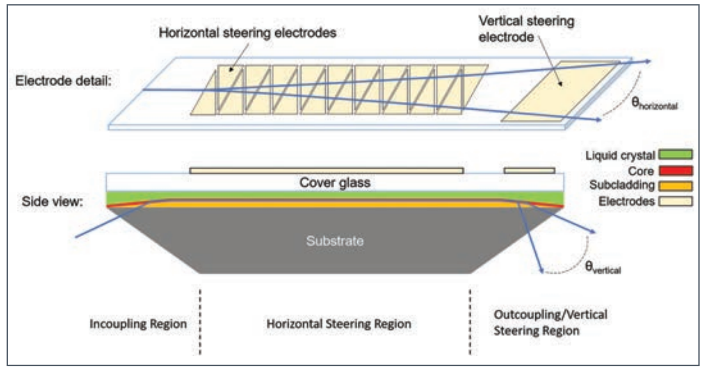


FIGURE 1. Schematic overview of a Steerable Electro-Evanescent Optical Refractor (SEEOR) non-mechanical beam steerer, denoting (top) the electrode detail required to achieve horizontal and vertical steering, and (bottom) a side-view cross-section of the waveguide, showing the different layers and steering regions (thicknesses not to scale).

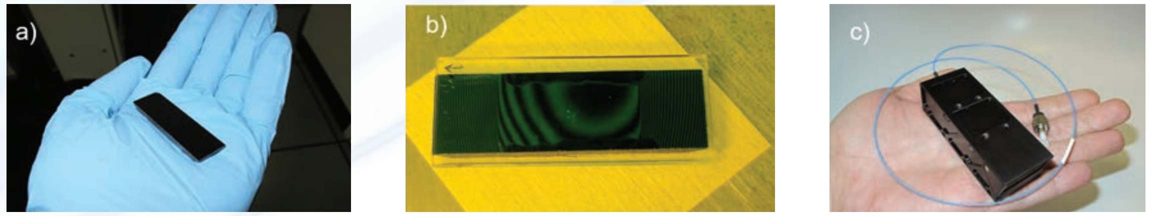


FIGURE 2. Examples of SEEOR devices at various stages of assembly. (a) Bare faceted substrate chip, prior to waveguide deposition. (b) Assembled mid-wave infrared SEEOR under crossed polarizers. Fine optical interference fringes show the tapering of the subcladding layer. (c) Fully assembled and packaged short-wave infrared SEEOR.

Technologies and Applications

These devices have been enabled by multiple key technologies. First, the subcladding and core layers utilize MWIR-transparent chalcogenide glasses (based on As-S and As-Se compounds) developed at NRL as part of the DARPA MGRIN program.[4] These glasses exhibit robust processing as thin films via thermal evaporation and high transparency throughout the infrared.

Second, new liquid crystal mixtures have been developed with low absorption in the MWIR. Common commercial liquid crystal mixtures exhibit strong molecular absorption throughout the MWIR corresponding to resonant molecular vibrations of individual atomic bonds. By designing new liquid crystal blends based on halogenated compounds, the characteristic molecular absorptions are shifted away from the MWIR, making them suitable for use in our MWIR SEEORs.

These new, refractive beam steerers have numerous advantages over traditional gimbals — they are extremely light and very compact (Fig. 2), and the beam steerer itself consumes ~mW of power. In addition, because the steering mechanism utilizes liquid crystal reorientation rather than moving parts, steering can be incredibly fast, with point-to-point slew times of less than 1 ms. Further, the basic mechanism of operation is compatible across all bands from the visible to long-wave infrared, and we are actively developing steerers in numerous optical bands. With continued development, this technology shows immense potential for replacing mechanical steering in a wide range of applications, enabling new capabilities for applications relevant to both Department of Defense and civilian interests.

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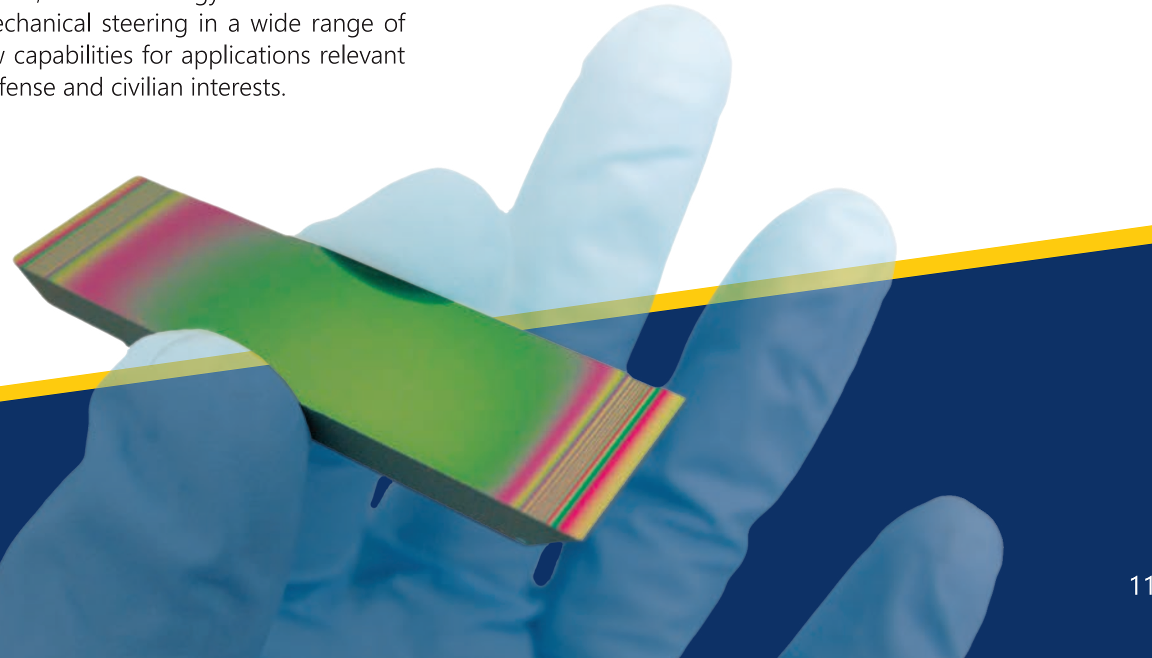
J.D. Myers,[1] J.A. Frantz,[1] C.M. Spillmann,[2] R.Y. Bekele,[4] L.B. Shaw,[1] J. Naciri,[2] J. Kolacz,[2] H. Gotjen,[2] M. Pauli,[3] C. Dunay,[3] D. Burchick,[3] J. Auxier,[3] and J.S. Sanghera[1]

[1] Optical Sciences Division
[2] Center for Bio/Molecular Science and Engineering
[3] Tactical Electronic Warfare Division
[4] University Research Foundation



Simultaneous Optical Beam Forming for Phased-Array Applications

Motivation

As platforms for electronic warfare continue to decrease in size, phased-array-based apertures offer potential improvements in effective isotropically-radiated power; reductions in size, weight, power and cost (SWaP-C); and new capabilities including direction-finding from a static aperture. A key component for phased-array apertures is the beam forming network which tailors the amplitude- and phase-response of each array element to form the desired beams. While radio-frequency (RF) multi-beam beamformers (Rotman lenses) have been demonstrated, their size precludes their use on small platforms as well as across a wide frequency range. In Code 5652 we are developing simultaneous optical beamformers for SWaP-C-constrained platforms. Optical fiber-based implementations of a Rotman lens suitable for use from <1 - 40 GHz have demonstrated four simultaneous beams on both transmit and receive. Translation of these architectures to photonic integrated circuit (PIC) and planar lightwave circuit (PLC) topologies and critical analysis of the performance of these topologies is currently underway.

Wideband True-Time-Delay Optical Beamforming

Conventional radio-frequency (RF) beamformers–whether digital or analog–are inherently narrowband. In the case of electronically-steered arrays (digital beamforming) the required phase step between elements is determined modulo 2π leading to main beam directions which are frequency-dependent (squint). The size of analog multi-beam beamformers scales with the RF wavelength, limiting the achievable bandwidth to the order of ~ 4:1. Optical beamformers, on the other, hand may be constructed using true time delays (TTD) to provide the appropriate phasing between array elements. Optical TTD lends itself to inherently broadband and squint-free operation when compared to traditional phased-arrays or microstrip-based Rotman lenses. This allows a given array to function over a wide frequency range without redesign of the beamforming architecture. The small size and weight afforded by photonic architectures allow formation of multiple wideband beams on platforms where use of conventional multi-beam RF beamformers would be intractable.

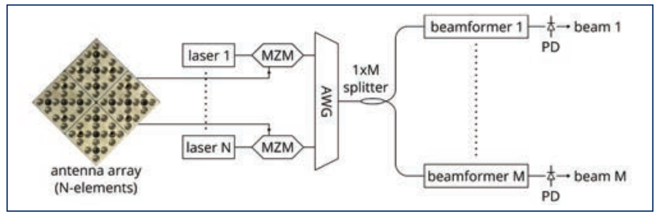


FIGURE 1: Schematic of a receive-mode optical simultaneous beamforming architecture. MZM: Mach-Zehnder modulator; AWG: arrayed-waveguide grating; PD: photodiode).

Figure one shows dthe basic architecture of a receive-mode multi-beam optical beamforming architecture. The output of a wideband phased-array antenna (for example, a planar ultrawideband modul ar array (PUMA), N elements) feeds an array of microwave photonic links where the RF output of each antenna is impressed onto a unique wavelength optical carrier with a Mach-Zehnder modulator (MZM). These modulated optical carriers are then combined using an optical multiplexer (here, an arrayed-waveguide grating (AWG)). The output of the multiplexer is then distributed to M optical beamformers. Within each beamformer the unique wavelengths are demultiplexed, weighted in amplitude, and each path is given an incremental time delay. The time delay increment between channels is chosen such that a beam is formed in the desired direction. This optical delay may be imparted using the wavelength-dependent propagation delay (chromatic dispersion) in a waveguide (fiber) or physical changes in the waveguide length (group delay) on a channel-by-channel basis. The modulated carriers are then recombined and the RF signal representing the desired beam is recovered through direct-detection of the modulated intensity with a high-speed photodiode. In this architecture, unique beams are formed in parallel allowing the desired field of view (FOV) to be subdivided into multiple simultaneous beams.

Figure 2 shows the beamforming performance of a dispersion-based architecture designed to provide M = 4 beams for an N = 8 element array of wideband dipole antennas (elements of a PUMA as shown in Figure 1). The time delay steps between elements are chosen to produce beams in the -17.3°, -10.5°, 0°, and +17.3° directions from broadside (normal to the array). The relative delay between elements (left) and the normalized measured antenna array patterns as a function of angle and frequency (right) show excellent agreement with theory. The residual delay between antenna elements is within ± 600 fs – roughly 5 times better than is achievable by controlling the length of bulk fiber.

The Push for Integration

While dispersion-based beamformers are readily designed for high delay accuracy, the wavelength-dependent delay used to form the beams can lead to RF fading, which limits the achievable bandwidth. Wideband arrays such as the PUMA will therefore require changes in physical path length on a scale smaller than may be achieved using bulk fiber. Beamformers will need to be integrated at the chip-scale to be applicable to such arrays.

Figure 3 shows silicon on insulator (SOI) integrated beamformer. This device (~0.5 mm x 2 mm), enables a reduction of >1000 in area as compared to a bulk fiber implementation. Here, microfabrication allows changes in path length suitable for beamforing in high-frequency arrays such as the PUMA. Figure 4 shows The measured delay per element for three integrated beamformers. These delay steps would theoretically produce beams in the -1.7°, -7.5°, and -12° directions for the PUMA.

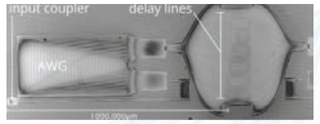


FIGURE 3. Integrated silicon-on-insulator (SOI) group delay-based optical beamformer.

Summary and Future Work

Code 5652 currently developing several optical beamformer techniques suitable for phased-array applications. These techniques offer the potential for formation of multiple simultaneous staring beams over a wide field of view which opens new opportunities in EW. Work is currently underway to translate and evaluate these techniques for integrated photonic architectures suitable to small SWaP-C-constrained platforms such as unmanned aerial, surface and underwater vehicles. State-of-the art photonic integration could improve device performance by an order of magnitude enabling integrated optical beamformer performance to rival that of bulk fiber-based architectures and provide suitable optical performance for a variety of EW systems.

By J.D. McKinney, P. Goetz, Z. T. Zern, M.R. Hyland, R.C. Duff, and K.J. Williams, Optical Sciences Division.

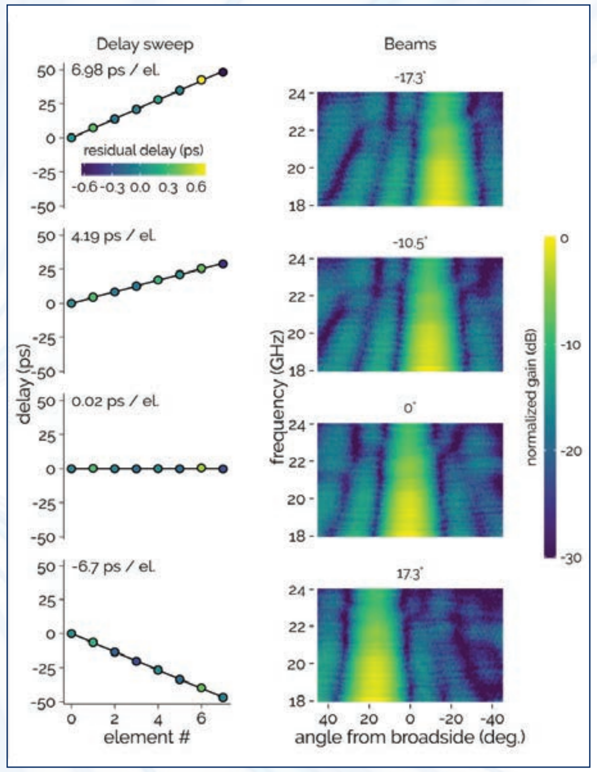


FIGURE 2: Time delay sweep across an 8 – element antenna array (left) and measured receive-mode antenna array patterns (right) for four simultaneous beams.

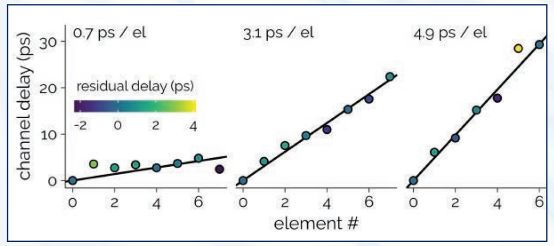


FIGURE 4. Time delay sweep across three integrated optical beamformers similar to that shown in Fig. 3.

Quantum Memories Based on Optically Trapped Neutral Atoms

A quantum memory uses matter to store and retrieve quantum information, typically via an interface with an optical channel that transmits single photons. Quantum memories are key components of secure quantum communication and quantum information processing schemes. Our research group in the Optical Sciences Division of the U.S. Naval Research Laboratory is interested in the development of a quantum memory in ensembles of laser-cooled rubidium atoms. We have made progress toward the creation of a quantum repeater based on four such memories. To demonstrate the storage of quantum information, we have operated a single quantum memory as a source of heralded single photons via collectively enhanced spontaneous Raman emission. We have demonstrated optical lattice trapping of 106 atoms that can dramatically increase the possible storage time. Non-classical operation of the heralded photon source is indicated by a measured value of the normalized cross-correlation coefficient, $g^{(2)}$, of 150. The memory operates at the 1/e coherence time of 3 ms.

Background

The beginning of research into quantum information science can be traced to Richard Feynman's 1982 proposal[1] that computers that take advantage of quantum mechanical principles may have certain advantages over classical computers. Since then, researchers have proposed or demonstrated various methods of using quantum information to achieve results that cannot be obtained with classical physics. One of the most striking proposals is the quantum computer itself. Using Peter Shor's algorithm[2] to find prime factors of large numbers, quantum computers can, in principle, defeat current cryptography techniques. Although practical quantum computers do not exist as of this writing, work is under way in many countries to create such a computer. Furthermore, current classically encrypted information can be stored for now and kept until decryption by quantum computers someday becomes possible.

Threats to conventional cryptography have fueled research into fundamentally unbreakable cryptographic techniques. Here, quantum information science again comes to the rescue with a technique called quantum key distribution, or QKD. Using QKD, the communicating parties use unique aspects of quantum mechanics (QM) to construct a cryptographic key for encrypting communication. QM allows the parties to ensure the secrecy of their information by detecting with absolute certainty if someone is trying to eavesdrop on their key construction. It is now possible to buy commercial QKD systems, but these systems are limited to an effective distance of about 100 kilometers because of photon loss in their optical fibers. Optical losses in a fiber occur in classical communication as well, but here the problem is solved by using larger numbers of photons and classical repeaters that amplify and clean up the signal before it becomes too weak. This solution is not viable in QKD because QKD relies on single photons and QM does not allow noiseless amplification or cloning of photons. That principle underscores the fundamental security of QKD, i.e., QKD is secure because QM prohibits the photon cloning that otherwise would allow an intruder to steal information without detection.

Researchers have proposed "quantum repeater" protocols that allow joining of multiple shorter QM entangled segments into a longer one by performing certain measurement on portions of the segments. Quantum repeaters extend techniques such as QKD and quantum teleportation to longer distances. Quantum memories are a critical component of such quantum repeaterbased protocols.

Quantum memory research has been an active field in recent years.[3] Quantum memories have been demonstrated in single trapped atoms and ions, warm and cold atomic ensembles, quantum dots, rare-earth ions in solids, and nitrogen vacancy centers in diamond. The different approaches have distinct advantages and disadvantages, with respective tradeoffs between memory storage time, photon emission rates, photon frequency width, and environmental sensitivity. Our research in the Optical Sciences Division of the U.S. Naval Research Laboratory focused first on warm, and later on cold, trapped atomic ensembles.

Cold Atom Quantum Memory

Figure 1 illustrates our quantum memory implementation in rubidium (Rb) atoms. The quantum memory relies on a "Λ" (Lambda) level configuration in the Rb atom, with two long-lived ground states "g1" and "g2" and an excited state "e". Initially, the entire ensemble of 10^7 atoms is prepared in the "g1" ground state. A near-resonant, classical laser beam generates a spontaneous Stokes photon via a Raman process, creating a single excitation in the atomic ensemble, as shown in Fig. 1(a). Classically, one would say that one of the atoms has made a transition to the other "g2" ground state. However, quantum mechanics tells us that this single excitation is distributed over all the atoms in the ensemble, and, therefore, is relatively insensitive to some atomic losses. Furthermore, ground states are long-lived, and we can prepare atoms in atomic states with minimal sensitivity to the environment, such as those used in atomic clocks.

Detection of the Stokes photon signifies creation of the unit excitation in the form of atomic coherence between the two ground states (Fig. 1(a)). The quantum information is now stored in the form of this long-lived coherence. One can also say that the Stokes photon is entangled with the quantum state stored in the memory. To access the quantum information, we read it out from the atomic ensemble memory as an anti-Stokes photon using a classical read laser beam, as depicted in Fig. 1(b). Now, the initial Stokes photon and the antiStokes photons are entangled.

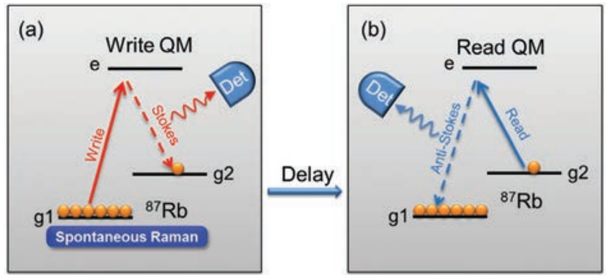


FIGURE 1. Writing and reading quantum memory based on ^{87}Rb atoms.

The non-classical nature of this entanglement is measured by the second-order normalized cross-correlation function $g^{(2)}$ between the Stokes and anti-Stokes photons. $g^{(2)}$) is simply the ratio of the measured rate of photon coincidences (between Stokes and anti-Stokes photons) to the rate of coincidences that would be expected with uncorrelated photon production. Under stable experimental conditions, a value of $g^{(2)} > 2$ indicates that the photon production, and hence the excitation stored in memory is not described by classical statistics.

The storage time of the quantum memory depends on environmental factors such as magnetic and electric fields, and on collisions as well as coherence-destroying atomic motion. In our previous work using a warm atomic vapor as a quantum memory, [4] we were limited to 4 µs quantum memory time due to atomic motion, even with the shielding of the external fields. This atomic motion is greatly reduced in laser-cooled, trapped atomic ensembles such as those produced in a magneto optic trap (MOT), where temperatures of 20 µK are readily achieved. Figure 2 shows an image of fluorescence from such a cloud of cold, trapped atoms in our laboratory.

In principle, since the MOT trapping beams and fields have to be turned off during the quantum memory operation, the memory storage time can be limited by the gravitational falling of the atoms to a few milliseconds. In practice, a small angle between the Write/Read beams and the detected Stokes/anti-Stokes photons is used to reduce optical backgrounds. This angle increases susceptibility to motional dephasing. Together with the Larmor precession in the residual magnetic field, this limits the storage time in the MOT to a few microseconds.

In our MOT-based quantum memory setup, we measured $g^{(2)}$ at t = 0 to be 40.1 ± 3.2. The 1/e decay time of the coherence was measured to be ~30 µs, and the memory storage time (the time it takes the value of $g^{(2)}$ to drop to 2) to be ~90 µs.

Optical Lattice

Additional techniques have been developed to reduce the effect of the magnetic field by using optical pumping and first-order magnetic field insensitive atomic states (clock states). Other techniques permit completely overcoming motional decoherence in cold atoms; in one technique, far red-detuned interfering optical beams can trap atoms in sub-micron regions of high intensity by forming what is known as an optical lattice.

Figure 3 shows a schematic of the optical lattice setup and the fluorescent image of the optical lattice. Because of the in-plane geometry of the incident and emitted optical fields, we only need the optical lattice to confine the atoms tightly in one dimension to arrest atomic motion. Motion along the beam direction or in the vertical plane does not affect the memory time. The lifetime of atoms in our optical lattice is limited by collisions with the background gas in the imperfect vacuum, and is about 20 s. This lifetime can be increased with a better vacuum. The memory time is determined now only by the coherence between the two ground states, which depends on external fields and also on the inhomogeneous dephasing of the atomic spins due to energy shifts caused by the intense lattice laser beams (so-called AC Stark shifts). With magnetic field compensation, our memory time increased to over 600 µs. Using optical pumping to magnetic field insensitive atomic sublevels, the 1/e memory time in our setup was increased to about 3 ms.

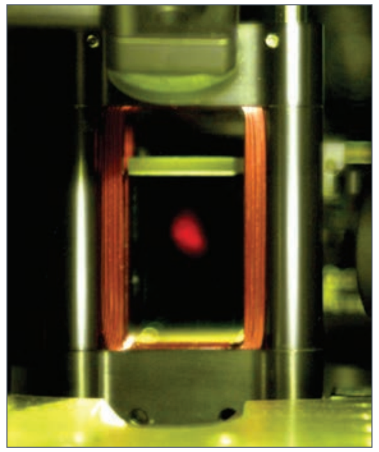


FIGURE 2. Fluorescence image of a cloud of ^{87}Rb atoms confined in a magneto optical trap.

It is possible to use uniform ing this approach, memory time was demonstrated to increase to hundreds of ms.[5] More sophisticated techniques[6] are available to increase the cold atom memory time to over 10 s.

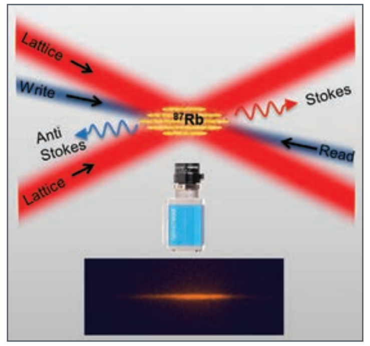


FIGURE 3. Setup for ^{87}Rb quantum memory in an optical lattice and a flourescenece image of a cloud of ^{87}Rb atoms confined in an optical lattice.

Quantum Repeater

The overarching goal of the present work is to implement four quantum memories to create a quantum repeater. To securely transmit an encryption key, two remote quantum memories QM1 and QM2 must be entangled. This entanglement is produced nondeterministically, by detecting a single Stokes photon from two quantum memories simultaneously, as shown in Fig. 4(a). When such a photon is detected, a single quantum excitation is shared between the two remote quantum memories, and the two quantum memories can be used as an entanglement resource. To create a quantum repeater, we need one quantum excitation shared between quantum memories QM1 and QM2 and a second quantum excitation shared between QM3 and QM4, as shown in Fig. 4(b). We then read out any stored excitations in QM2 and QM3 at the same time. When a single anti-Stokes photon is detected from QM2 and QM3, the quantum excitation in QM2 and QM3 is destroyed, while the remaining single quantum excitation is shared over a longer distance between QM1 and QM4. This "entanglement swapping" process can, in principle, be extended over many quantum repeater nodes to produce entanglement over very long distances. These measurements are probabilistic: sometimes they fail, and sometimes they succeed. When an internal measurement succeeds, the result has to be stored in quantum memory, while the failed ones are repeated and all links are successfully created from one end of the communication channel to the other.

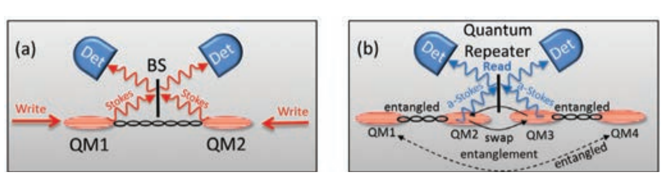


FIGURE 4(a). Entangling two quantum memories by detecting a single Stokes photon generated from both memories. (b) Quantum repeater is implemented by reading out a single anti-Stokes photon from the adjacent memories.

Conclusion

This article discusses the application of cold trapped atoms to quantum memories and illustrated techniques that can be used to improve memory storage time. Improvements in single-photon detectors and various optical components are still needed to achieve long distance quantum networks. We are developing newer techniques to improve scalability, such as internal conversion to telecommunication wavelengths and combining cold atom memories with Rydberg atom interactions. We are also developing passive stabilization schemes to reduce requirements on interferometric stability, which is normally required for the quantum repeater operation.

Acknowledgments

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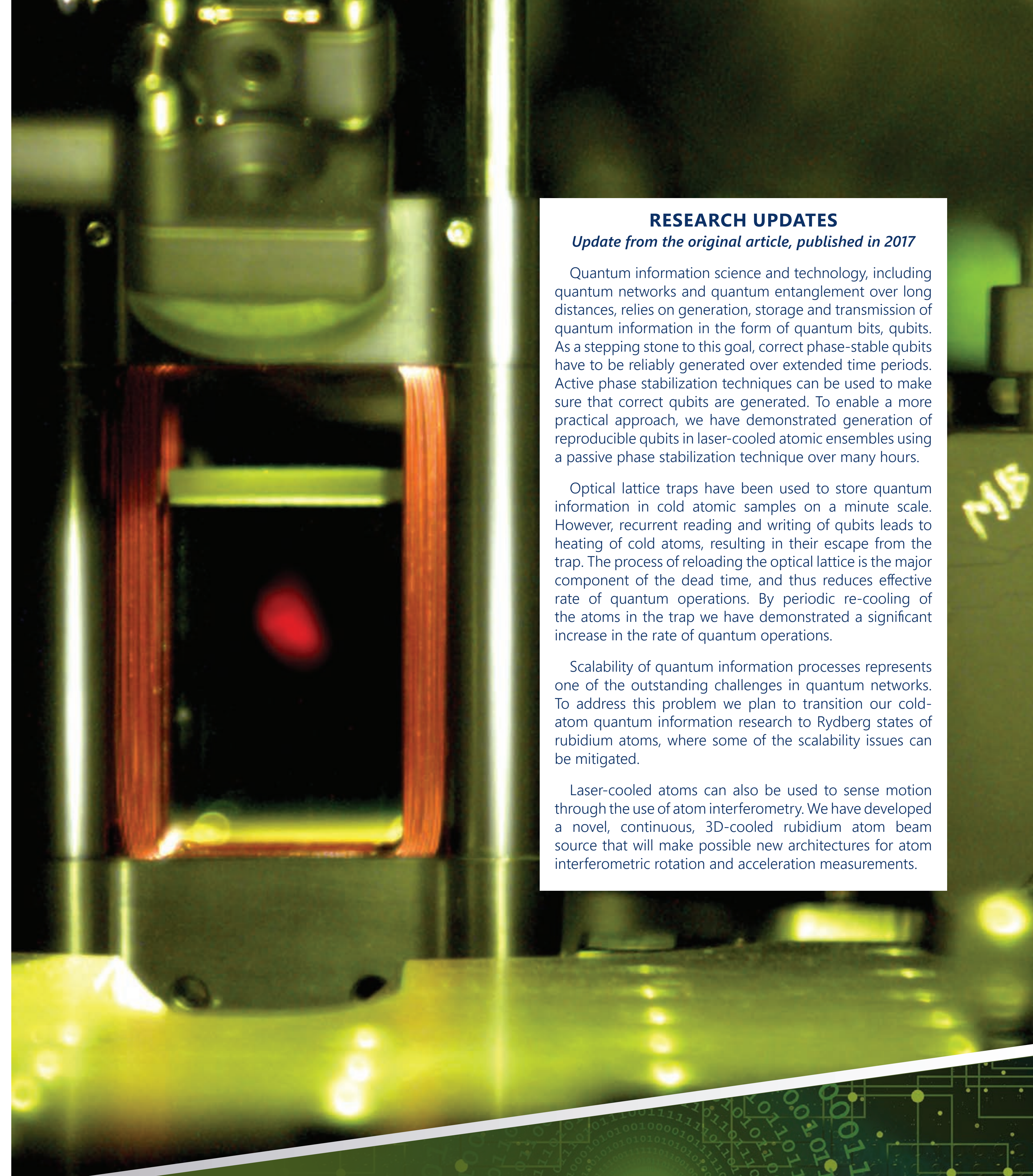
By M. Bashkansky,[1] A. Black,1 T. Akin,[2] M. Piotrowicz,[3] A. Kuzmich,[4] and J. Reintjes[3]

[1] Optical Sciences Division
[2] National Research Council Postdoctoral Research Associate
[3] Sotera Defense Solutions, Inc.
[4] Department of Physics, University of Michigan



RESEARCH UPDATES

Update from the original article, published in 2017

Quantum information science and technology, including quantum networks and quantum entanglement over long distances, relies on generation, storage and transmission of quantum information in the form of quantum bits, qubits. As a stepping stone to this goal, correct phase-stable qubits have to be reliably generated over extended time periods. Active phase stabilization techniques can be used to make sure that correct qubits are generated. To enable a more practical approach, we have demonstrated generation of reproducible qubits in laser-cooled atomic ensembles using a passive phase stabilization technique over many hours.

Optical lattice traps have been used to store quantum information in cold atomic samples on a minute scale. However, recurrent reading and writing of qubits leads to heating of cold atoms, resulting in their escape from the trap. The process of reloading the optical lattice is the major component of the dead time, and thus reduces effective rate of quantum operations. By periodic re-cooling of the atoms in the trap we have demonstrated a significant increase in the rate of quantum operations.

Scalability of quantum information processes represents one of the outstanding challenges in quantum networks. To address this problem we plan to transition our cold-atom quantum information research to Rydberg states of rubidium atoms, where some of the scalability issues can be mitigated.

Laser-cooled atoms can also be used to sense motion through the use of atom interferometry. We have developed a novel, continuous, 3D-cooled rubidium atom beam source that will make possible new architectures for atom interferometric rotation and acceleration measurements.

Increasing UAV Endurance with Solar Soaring Technology

Researchers at the U.S. Naval Research Laboratory (NRL) are developing technology for unmanned aerial vehicles that has given them the ability to fly for more than 12 hours by harvesting energy from the atmosphere and the sun.

Solar-Soaring is a pair of endurance enhancer technologies. They aid the warfighter by enabling a UAV to fly longer without carrying extra weight in batteries.

"One of the common complaints that we hear across industry and the warfighters is that they want aircraft to fly longer," said Dr. Dan Edwards, senior aerospace engineer in NRL's Tactical Electronic Warfare Division. "One great way to do this is to capture atmospheric wind energy or solar energy to extend the endurance."

Since 2005, Edwards has been exploring how to teach an autopilot how to soar using thermals in the atmosphere, much like how a bird flies. Using special sensing and guidance algorithms, the UAV flies a waypoint route until it senses a thermal updraft, then commands the aircraft to circle in the rising air. "Sunlight heats up the surface of the Earth, which in turn heats the lowest layer of air. That warm air eventually bubbles up as a rising air mass called a thermal, which the airplane can use to gain altitude. It's indirectly solar powered," said Edwards.

Solar power is also used directly to power the UAV using solar cells, which are semiconductor devices that convert light into electricity. While these devices have been around for some time, it was only recently that photovoltaic technology advanced to the point where a UAV could be solar powered. For an aircraft, every gram of weight has to be justified essentially, it has to pull its own weight. Until recently, solar cells were not worth the added weight.

"For a long time, even though there has been solar aircraft since the 1990s, the efficiency of the solar cells wasn't high enough to pay the mass penalty, meaning you weren't getting enough energy to justify the additional mass," said Phil Jenkins, head of the Photovoltaics Section in NRL's Electronics Science & Technology Division. "But over the last 10 years, that has really changed. The cells have gotten more efficient and lighter."

The aircraft still carries a battery. However, the battery can be smaller because of the solar and soaring capabilities on board. "With Solar-Soaring, the UAV doesn't need a huge battery because it is getting energy from the environment," said Edwards. "It just carries more intelligent software in the case of the autonomous soaring algorithms, or a lightweight integrated solar array that captures much more energy from the sun compared to the amount of mass."

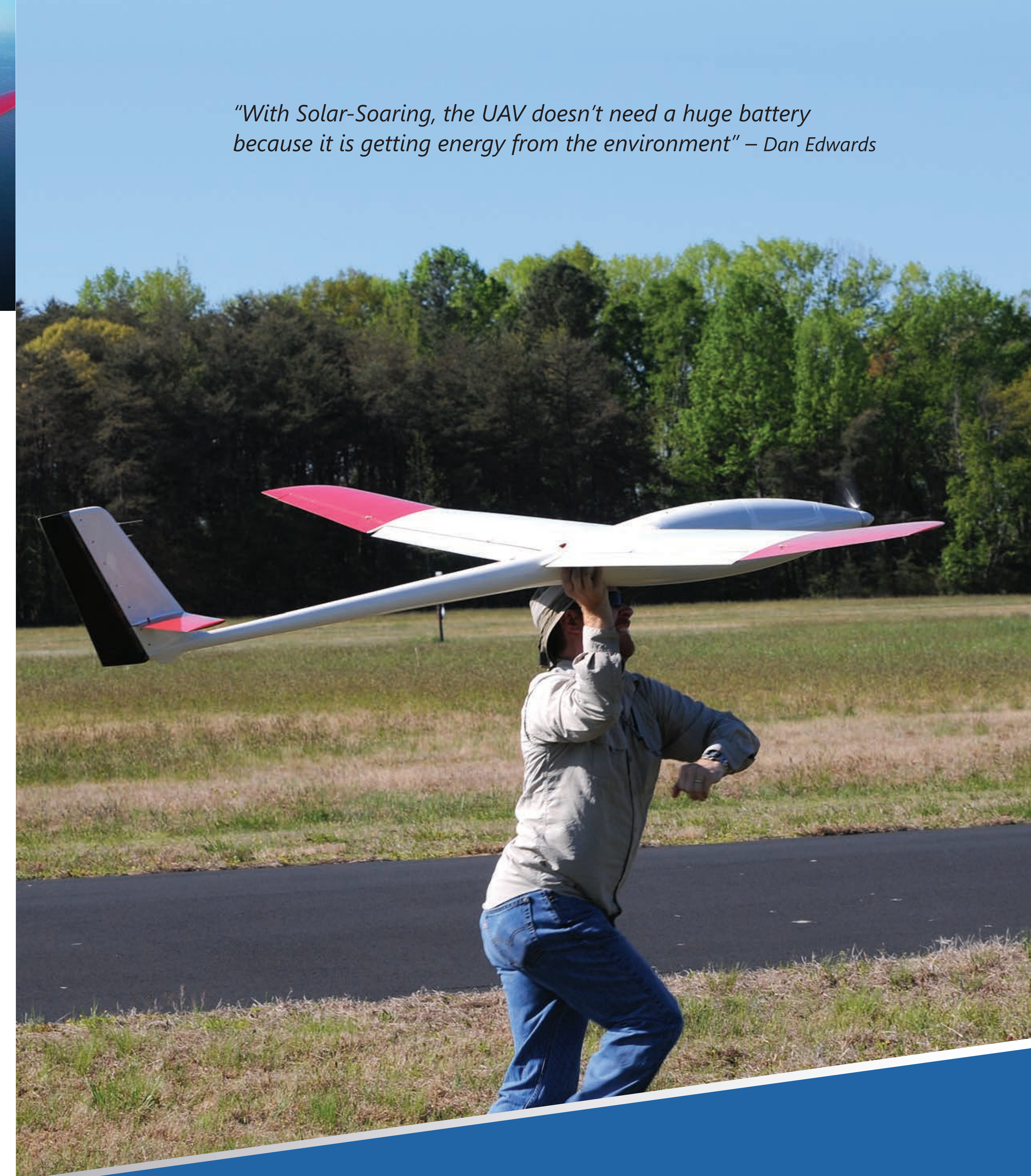
Bringing these two technologies together, NRL found the combination works better than either individually. While soaring, the motor is turned off and the solar array can recharge the onboard battery faster. This increases the mission availability of a UAV for warfighters. "Between the two, you have the most robust energy harvesting platform because sometimes you'll be able to soar and sometimes you won't have the solar, and vice versa," said Jenkins.

The NRL developed technologies are applicable to platforms that are already in use by the military such as the Raven, a small hand-launched remote-controlled UAV or the Predator, a larger UAV.

Having a UAV with extended endurance capabilities is important for military information, surveillance and reconnaissance missions or a communications relay. The technology also has important uses for civilian applications, including monitoring and inspection of railways and oil pipelines, surveying crops and search and rescue.

"The technology could be very useful for coastal monitoring or pollution monitoring, for example," said Jenkins. "In these cases, you just want eyes up there for hours and hours, and Solar-Soaring makes that possible." Both Edwards and Jenkins identified a hurdle that they would eventually have to overcome with Solar Soaring; the ability to fly through the night.

By Raeanna Morgan, Formerly, NRL Strategic Communication Office



"With Solar-Soaring, the UAV doesn't need a huge battery because it is getting energy from the environment" – Dan Edwards

Insect Behavior, Miniature Blimps May Unlock the Key to Military Swarming Technology

Researchers at the U.S. Naval Research Laboratory flew a fleet of 30 miniature autonomous blimps in unison to test the swarming behavior of autonomous systems. The blimps responded to each other while in flight and responded to changing conditions.

Don Sofge, lead for the distributed autonomous systems group at NRL, and his team are working to further research for autonomous super swarms. Their goal is to fly more than 100 controlled miniature blimps this year.

Georgia Tech researchers created the miniature blimp platform and continue to provide design upgrades in collaboration with Sofge's group. This year, they are upgrading the motors, adding sensors and making design tweaks.

"The process is a constant give-and-take with design and scale," Sofge said. "It's better to start with a simple design. You start with something that works and then make incremental changes. There are challenges with design and there are challenges with scaling. So we are redesigning and then scaling up to produce the 100 blimps. We are taking it one step at a time."

The Science of Swarming

One of the goals for Sofge's research is to understand the potential uses for swarms of autonomous systems — both defensive and offensive. Some desired emergent behaviors include protecting an asset, providing area coverage, conducting reconnaissance missions, or simply moving in formation from one location to another.

He likens individual autonomous agents to ants in a colony. Ants perform actions often equated with the functions of a society, but they do not have a central control. The possibility of replicating individual behaviors in autonomous systems is of great interest to researchers.

"We are using these as platforms to demonstrate swarm behaviors," Sofge said. "Behaviors are programmed into each agent individually. The idea is that each agent is making its own decisions, sensing the world around it so that the action of the group results in some desirable emergent behavior."

"In order to get the swarm to do something useful, you have to think about how to program the individual," he said. "What behaviors or algorithms are running on the individual agent? In nature, most colony or swarm systems have no centralized control. Each individual is basically interacting with its environment, but collectively they are able to do very interesting and useful things."

Sofge and his team plan to design such behaviors to scale up emergent swarming behavior to involve as many as 10,000 autonomous systems.

"If you are working with a traditional centralized control architecture you have to deal with the challenges of communicating with 10,000 agents individually," Sofge said. "You can't assume everyone knows where everyone else is because they are only interacting locally based on what they sense and the decisions they are making and the actions they are taking locally."

The NRL research team is also working to establish a seamless networking architecture. They are leveraging existing network architectures and protocols for large numbers of objects working together. Each object in a swarm is dynamic and its location is never fixed. The object may move in and out of the network, which makes overlaying a network architecture extremely difficult.

Autonomous objects in a swarm must deal with a challenge common in military environments: communication. The U.S. Department of Defense operates all over the world, from the chilling Arctic to hot tropical forests. Staying in communication with an agent despite inhospitable environments and potential enemy jamming is something Sofge and his team must keep in mind as they develop swarming technology.

Researchers at the U.S. Naval Research Laboratory have developed a fleet of autonomous platforms to test the swarming behavior of autonomous systems. They successfully demonstrated the operation of 30 blimps in December 2018. This year they aim to fly more than 100 controlled balloons (also known as miniature autonomous blimps).

The History of Autonomy Imitating Life

The study of swarming behavior at NRL began in the 1990s and was founded on the concept of physicomimetics, a physics-based approach that models the behavior of charged particles interacting with one another. Later, swarming approaches developed at NRL were biology-inspired by animal swarms, such as bees, ants and birds in nature.

"In physicomimetics, you define objects as being particle types and create force laws to describe action between those particle types," Sofge said. "By choosing your particle type and force laws appropriately you could get swarms of agents to do interesting things, like move in formation and flow around objects."

Using bio-inspired concepts such as quorum sensing, an ability that bacteria use to communicate and coordinate via signaling molecules, Sofge's team demonstrated complex group decision-making using simple agent-based behaviors.

NRL's researchers have advanced physicomimetics and nature-inspired techniques for teams of autonomous systems and plan to continue to develop new algorithms for swarming behaviors. The most recent findings have advanced swarm technology and show potential for making advances in human-machine interfaces.

By Cassandra Eichner, NRL Strategic Communication Office

NRL's Edison Program Funds Study into Knee Joint Brace Efficacy

With its large staff of doctoral students and lab employees, the U.S. Naval Research Laboratory is an ideal setting for grooming the nation's future science leaders.

NRL's Edison Program provides an avenue through which these high achieving employees can pursue graduate studies related to their current occupational field. Because the program's participants all have work experience, they're equipped to tailor their educational pursuits to practical applications in their given fields.

One employee completing research through the Edison Program is Christine Dailey Walck, a mechanical engineer turned space ergonomics expert (and STEM-podcast host). Walck already wears many hats on the lab. Now she is pursuing yet another with her doctorate studies in mechanical engineering with a focus on biomedical engineering.

"My supervisor at the time told me about the Edison Program," Walck said. "My advisors support—plus the sponsored time—have been invaluable to my research."

Walck's current area of research involves studying the response of the knee complex—the knee joint and its surrounding muscles—to a newly designed knee joint orthosis, or knee brace. Her resulting computational models have set a new benchmark for determining the effects of a knee brace on the knee complex.

Commonly used by both military personnel returning from tour of duty and the average citizen recovering from a knee injury, the knee brace is the preferred treatment for rehabilitation and injury prevention around the knee complex. However, most measures of knee brace success are based on qualitative observations rather than quantitative measurement.

"When you're studying how a knee joint orthosis works, you often get measurements from asking a patient how they feel with the brace," Walck said. "But that information can be subjective. Therefore, we combined motion-captured data with a musculoskeletal model to find internal muscle forces, which gave more insight into how the brace actually affected the patient."

Walck's study does what a qualitative study could not: it tests the brace's capabilities through an inverse dynamic solution that provides quantitative data. This information could prove crucial not only for the companies that design knee braces, but also for the doctors who provide them to patients. The study aims to give doctors the data necessary to determine which knee brace will work best for each patient.

Walck's models rely on two main computations to determine success of a knee brace: joint range of motion and muscle force during a squat exercise. During her studies, the subject would perform the squat with a brace and without a brace, thereby allowing for comparative results showing improvement or change while wearing the brace.

Walck determined range of motion through the combination of three-dimensional muscle modeling through OpenSim software and her study of inverse kinematics through motion capture, which allowed her to gain a better understanding of how the muscles of the knee complex move during a squat exercise.

She determined muscle force by having the test subject complete the exercise while on a force plate located under the foot. She evaluated the subject's performance with an inverse dynamics tool. This tool, used in conjunction with inverse kinematics, determines the generalized net forces and torques responsible at each given joint movement during the exercise.

According to Walck, the research has already provided valuable data, but she still has other aspects of the study she wishes to pursue, including expanding her number of test subjects and exploring variables that contribute to and are affected by the knee brace.

"Based on the results, the next study should take a step back.," she said. "This study focused on nonlinear spring technology in the knee joint orthosis. The evaluation of knee joint orthosis without nonlinear spring technology could determine if the results from study stem from the nonlinear spring or from the brace itself."

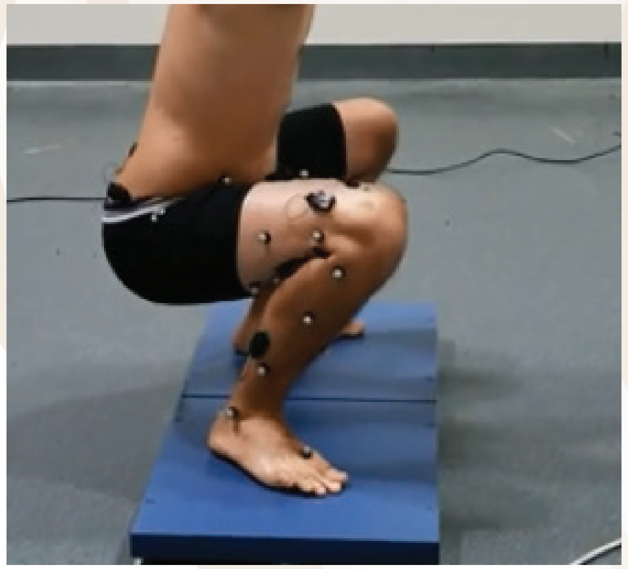
Walck also wants to study how wearing a knee brace on one knee affects the other healthy, un-braced knee.

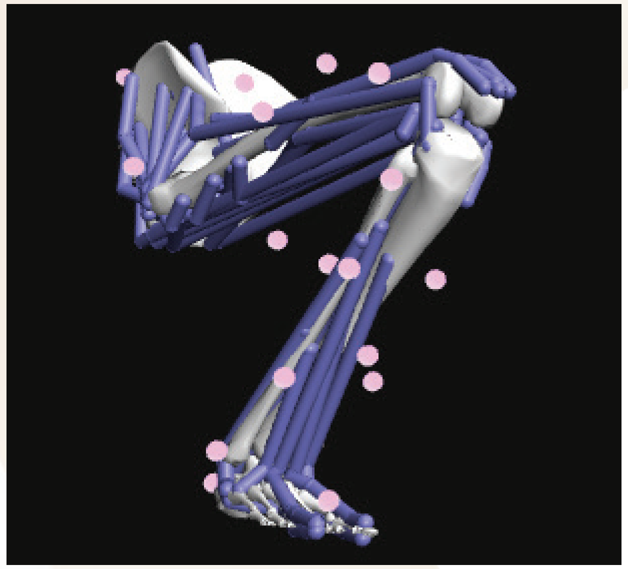
"This is important to understand because many athletes or military personnel returning to the field wearing knee joint orthosis experience injuries in the healthy knee," said Walck. "This raises the question of whether or not the joint knee orthosis negatively affects the opposite knee."

As far as this study is concerned, Walck remains intrigued by the results and optimistic about future possibilities.

"I loved seeing the captured motion played out through simulations," she said. "And I was surprised by how the brace encouraged a more balanced synergy throughout the squat movement versus an offload effect which I was expecting."

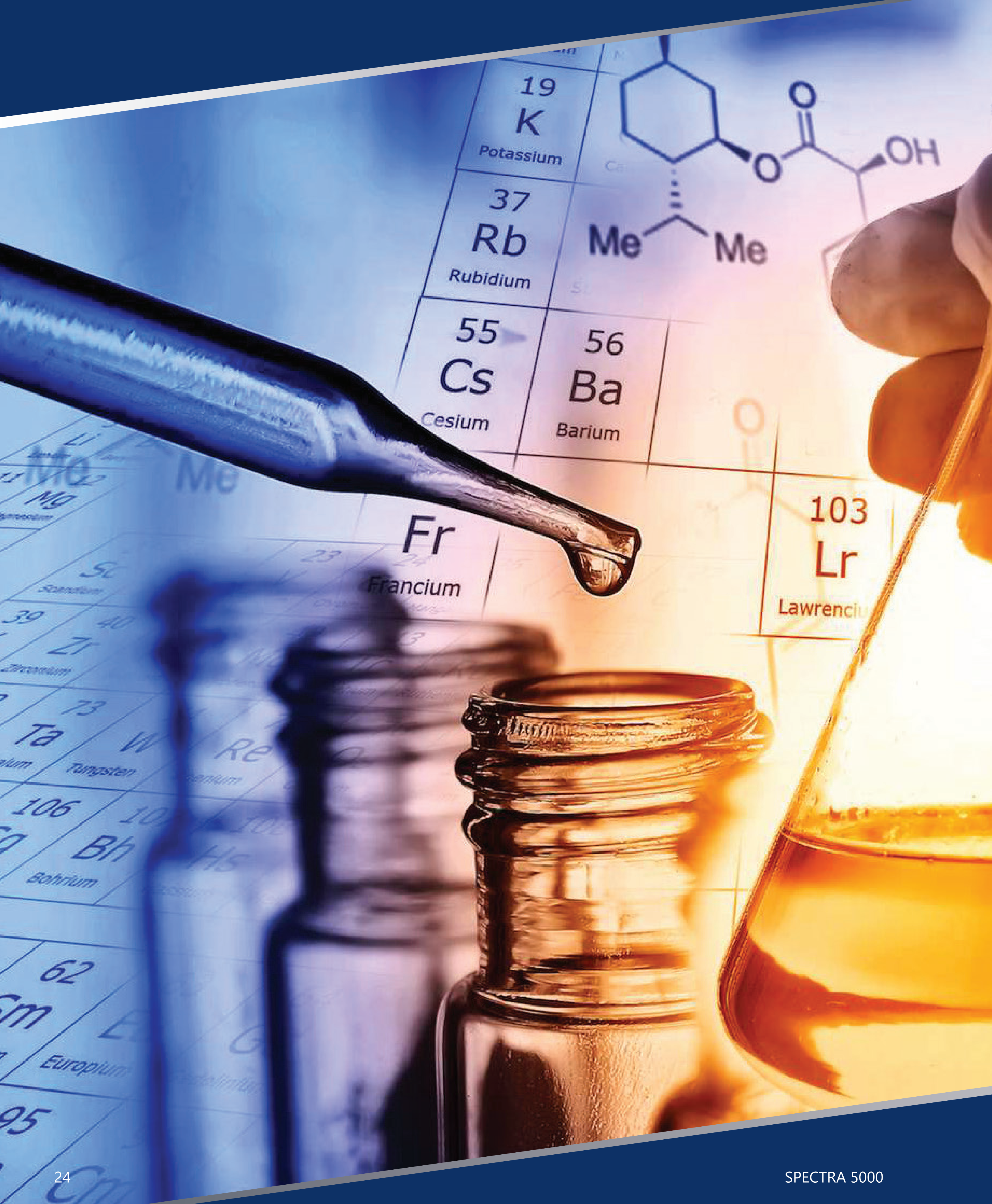
By Gabrielle Gibert, NRL Strategic Communication Office





Inverse kinetics were computed through results from experimental motion capture data, indicated by the sensor placed along the subject's leg and modeled through software on the right. Inverse dynamics were measured through the blue force plate the subject is standing on.

– Photo provided by Christine Dailey Walck.



National Academy of Inventors inducts NRL Research Chemist Brian Justus

By the National Academy of Inventors (NAI) standards, an NAI Fellow is an academic who has demonstrated a spirit of creating or enabling inventions or innovations that have made a tangible impact on quality of life, economic development and the welfare of society.

Dr. Brian L. Justus, head of the U.S. Naval Research Laboratory's (NRL) Optical Physics Branch, was elected a NAI Fellow on Dec. 12, 2017, and was be inducted into the NAI during the Seventh Annual NAI Conference on April 5, 2018 in Washington, D.C.

Justus joined NRL when he completed his Ph.D. in physical chemistry from the University of California, Riverside, in 1983. He has since registered approximately 30 patents with the U.S. Patent and Trademark Office in several different scientific areas.

"All of the projects that I have worked on during my time here, including both basic and applied research programs, were pursued in the hopes that they would have a positive impact on the U.S. Navy," said Justus. "Our focus here at NRL is to keep the Navy on the cutting edge of science and technology."

Although he has worked on a variety of research programs within the Optical Sciences Division, Justus argued that his most productive work was on radiation dosimeter technologies.

Radiation dosimetry is the accurate measurement of the radiation dose received by a person during medical diagnostic or treatment procedures, or during the performance of their work. Justus worked to develop those technologies longside his NRL colleague Dr. Alan Huston.

"Much of our work was based on the discovery of novel radiation sensitive materials that had very favorable characteristics for dosimetry applications," said Justus.

The initial efforts to develop the materials yielded an unexpected result that Justus and Huston thought to be a failure.

"Once we examined it more closely, we realized we had stumbled onto a new radiation sensitive material that had a lot of promise," said Justus. "The material became the enabler for many of our subsequent patents in radiation detection."

According to Justus, his 35-year career at NRL has kept him continuously learning and has been ever-evolving.

"As a Department of Defense scientist, being inducted as a NAI Fellow is a very welcome recognition of our work, and it's rare because most Fellows are academics," said Justus. "I feel very fortunate that all of my work here at NRL has been extremely interesting and incredibly rewarding."

By Raeanna Morgan, Formerly, NRL Strategic Communication Office

Facilities Listing

Radar

Shipboard radar research and development test beds:
- AN/SPS-49-A(V)1
- S-Band radar wavefrom development testbed
- Electromagnetic Maneuver Warfare Testbed
  - FlexDAR demonstration system (every element digital beamforming)

Airborne research radar facility, AN/APS-137D(V)5

Airborne 94 GHz radar system

Radar signature calculation facility

Computational Electromagnetics facility

Compact range and near-field antenna measurement laboratory

Electronic Protection (EP) and adaptive pulse compression (APC) testbed

Electronics and mechanical computer aided design facility

High Frequency (HF) Multiple-Input Multiple-Output (MIMO) testbed

HF Surface Wave Radar Testbed

Microwave and RF instrumentation laboratories

Information Technology

Extended Spectrum Experimentation Laboratory

Robotics and Autonomous Systems Laboratory

Immersive Simulation Laboratory

Warfighter Human-Systems Integration Laboratory

Audio Laboratory

Mobile and Dynamic Network Laboratory

Integrated Communications Technology Test Lab

General Electronics Environmental Test Facility

Key Management Laboratory

Crypto Technology Laboratory

Navy Cyber Defense Research Laboratory

Communications Security (COMSEC) Laboratory

Navy Shipboard Communications Testbed

Behavior Detection Laboratory

Virtual Reality Laboratory

Service Oriented Architecture Laboratory

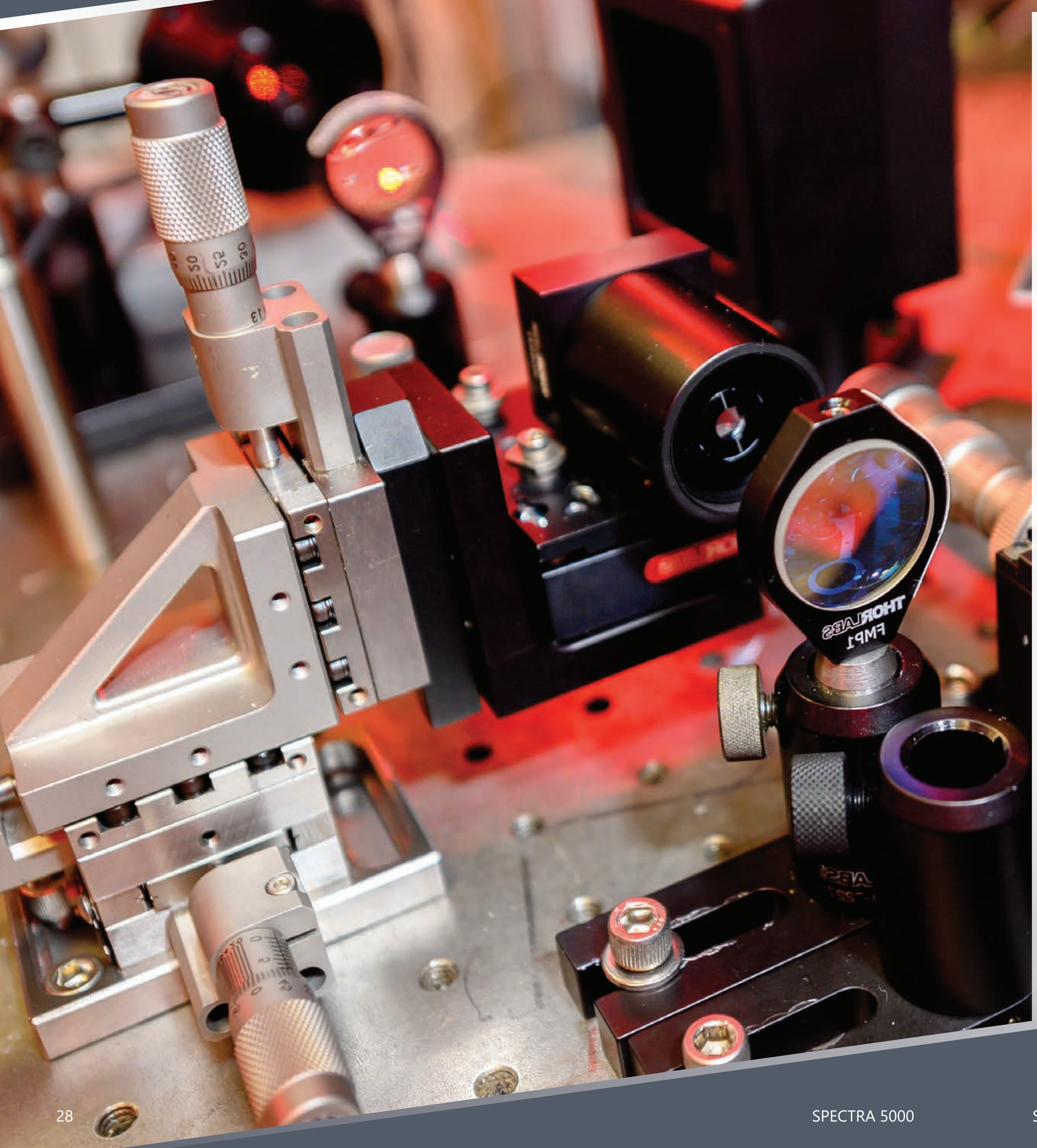
Distributed Simulation Laboratory

Motion Imagery Laboratory

Laboratory for Large Data Research

Affiliated Resource Center for High Performance Computing

Ruth H. Hooker Research Library



Facilities Listing

Optical Sciences

Facilities for rapid manufacturing of optically transparent windows and armor

Thin film laboratory for the development and characterization for optical waveguides and beam-steering devices

Design, manufacturing, and testing of high-gain media for laser applications

High power and ultrafast laser labs

Microstructures clean room

IR laser facility for optical characterization of semiconductors

Facilities for synthesis and characterization of novel optical materials and specialty optical fibers

Environmental testing of fiber sensors (acoustic, magnetic, electric field, etc.)

Laboratory for the development and demonstration of advanced quantum devices

Infrared countermeasure techniques laboratory

Emitter/Detector fabrication facilities

EO/IR technology/systems modeling and simulation laboratory

Focal plane array evaluation facility

Field-qualified EO/IR measurement devices

Facilities for fabricating and testing integrated optical devices

Computing cluster for digital imaging processing, machine learning, and Artificial Intelligence

Laboratory for the characterization and mitigation of turbulence in optical systems

Development and Integration of advanced Airborne EO/IR (visible through long-wave infrared), hyperspectral, and radar sensors

Optical probes laboratory to study viscoelastic, structural, and transport properties of molecular systems

Aerosol generation and detection laboratory

Flight testing equipment

Free-space optical communications range

Laboratory for the development and characterization of high speed (>100 Gbps), high performance photodetectors and optical communication links

Facility for reception, transmission, and optical processing of microwave signals

Bio-aerosol containment chamber for testing the limits of new optical detection strategies

Facilities Listing

Tactical Electronic Warfare

- Visualization display room
- Transportable step frequency radar
- Vehicle development laboratory
- Offboard test platform
- Compact antenna range facility
- Millimeter-Wave Antenna Range Facility
- TEWD Mechanical Fabrication Shop
- RFCM techniques development chamber facility
- Low-power anechoic chamber
- High-power microwave research facility
- Electro-optics mobile laboratory
- Infrared-electro-optical calibration and characterization laboratory
- Infrared missile simulator and simulator development laboratory
- Secure supercomputing facility
- CBD/Tilghman Island IR field evaluation facility
- Ultrashort pulse laser effects research and analysis laboratory
- Central Target Simulator facility
- Flying Electronic Warfare laboratory
- High-power RF explosive laboratory
- Classified material lay-up facility
- Classified computing facilities
- RF measurement laboratory
- Wet chemistry laboratory
- Ultra-near-field test facility
- RF and millimeter-wave laboratory
- Optical laboratory
- Paint room
- Secure laboratories for classified projects
- Offboard Test Platform (Wind Tunnel)
- Near and Far Field Antenna Measurement Facility

LABORATORY FOR AUTONOMOUS SYSTEMS RESEARCH
WASHINGTON, D.C.

In Remembrance of

ALAN C. SCHULTZ

Director of the Navy Center
for Applied Research in Artificial Intelligence
and the Laboratory for Autonomous Systems Research

Alan Charles Schultz, former Director of the U.S. Naval Research Laboratory's Navy Center for Applied Research in Artificial Intelligence (NCARAI) and the Laboratory for Autonomous Systems Research (LASR) passed away on Sunday, Jan. 20, 2019, at his home.

Over the years, his research focused on the areas of human-robot interaction, autonomous systems and adaptive systems. Because of his leadership and research, NRL is now an international leader in robotics research, dynamic autonomy and human-computer interaction.

While Schultz continued to serve as Director of NCARAI, he was asked to be the first Director of NRL's Laboratory for Autonomous Systems Research (LASR), which opened in March 2012, as a 50,000 square foot facility supporting basic and applied research in autonomous systems. He was responsible for directing its design, construction, eventual maintenance and research programs.

Expanding the research focus areas of the NCARAI, Schultz formed NRL's first Robotics Lab. Under his direction, he attracted researchers from many different disciplines, such as robotics, cognitive modelling and natural language processing. Throughout his career, he collaborated with scientists from other Department of Defense laboratories, industry and academia.

At Carnegie Mellon University (CMU), for example, he became a chief collaborator with the robotics group and collaborated on numerous research projects for several years. As a result of this work, Schultz was appointed as a visiting research scientist in the Robotics Institute at the university.

His affiliation with CMU and his position at NRL led to cutting-edge research in autonomous robotics systems. One of Schultz's earliest robotic projects, a robot named Coyote, was featured in a robotic competition at the Association for the Advancement of Artificial Intelligence (AAAI) Mobile Robot Conference in 1997. Coyote interacted with conference attendees, served hors d'oeuvres, and won first place in the competition.

In 2002, the robot GRACE, a collaboration with CMU, Northwestern University, Metrica, Inc., and Swarthmore College, participated in another AAAI competition. This time the robot self-navigated through a conference center to register for the conference and then went to a room where she gave a lecture and answered questions. GRACE received the judge's awards for Human-Computer Interaction and for Robustness in Recovery from Action and Localization Errors, as well as the Ben Wegbreit Award for Integration of Artificial Intelligence Technologies.

With his years of experience as a research scientist, a section head, branch head, and then as director of a second world-class research facility at NRL, he produced more than 140 publications in artificial intelligence, autonomous systems, robotics, human-robot interaction and machine learning. He is the recipient of more than 20 Navy special achievement awards for significant contributions in several scientific areas of investigation and is a recipient of the prestigious Schultz Berman Research Publication Award.

Schultz was a principal investigator on numerous research projects funded by the Office of Naval Research, the Office of the Secretary of Defense, the Defense Advanced Research Projects Agency, the National Aeronautics Space Administration, and the Department of Energy. In 2005, Schultz got together with several AI researchers and roboticists and formed the Human-Robot Interaction Conference, which will celebrate its 15th year in Daegu, South Korea.

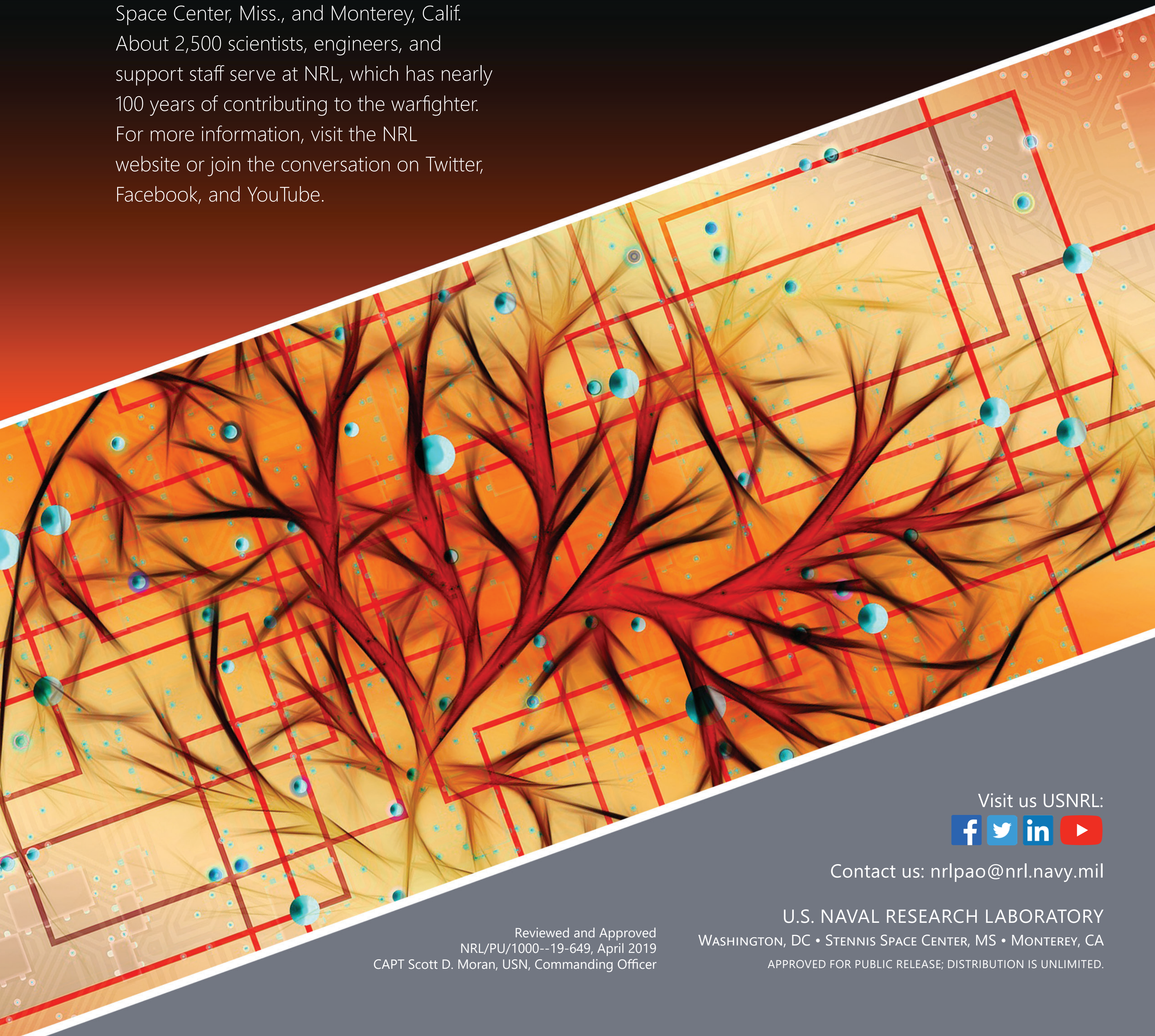
Schultz's dedication, foresight and commitment to research provided opportunities for young research scientists from universities to work collaborate with NRL researchers throughout the year. When he was not actively involved in research, Schultz dedicated his time and energy to mentoring high school and college students who, under his tutelage, went on to become world-class researchers and scientists in their own right.

Schultz was a leader and guide to many people within and outside of NRL, sharing his excitement and vision for conducting research in Artificial Intelligence and autonomous systems. He will be sorely missed and will remain an inspiration to all.

By Dennis Perzanowski, Acting Director of the Navy Center for Applied Research in Artificial Intelligence

About the U.S. Naval Research Laboratory

The U.S. Naval Research Laboratory provides the advanced scientific capabilities required to bolster the nation's position of global naval leadership. NRL is headquartered in southwest Washington, D.C., with other major sites at the Stennis Space Center, Miss., and Monterey, Calif. About 2,500 scientists, engineers, and support staff serve at NRL, which has nearly 100 years of contributing to the warfighter. For more information, visit the NRL website or join the conversation on Twitter, Facebook, and YouTube.



Visit us USNRL:

Contact us: nrlpao@nrl.navy.mil

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CAPT Scott D. Moran, USN, Commanding Officer

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