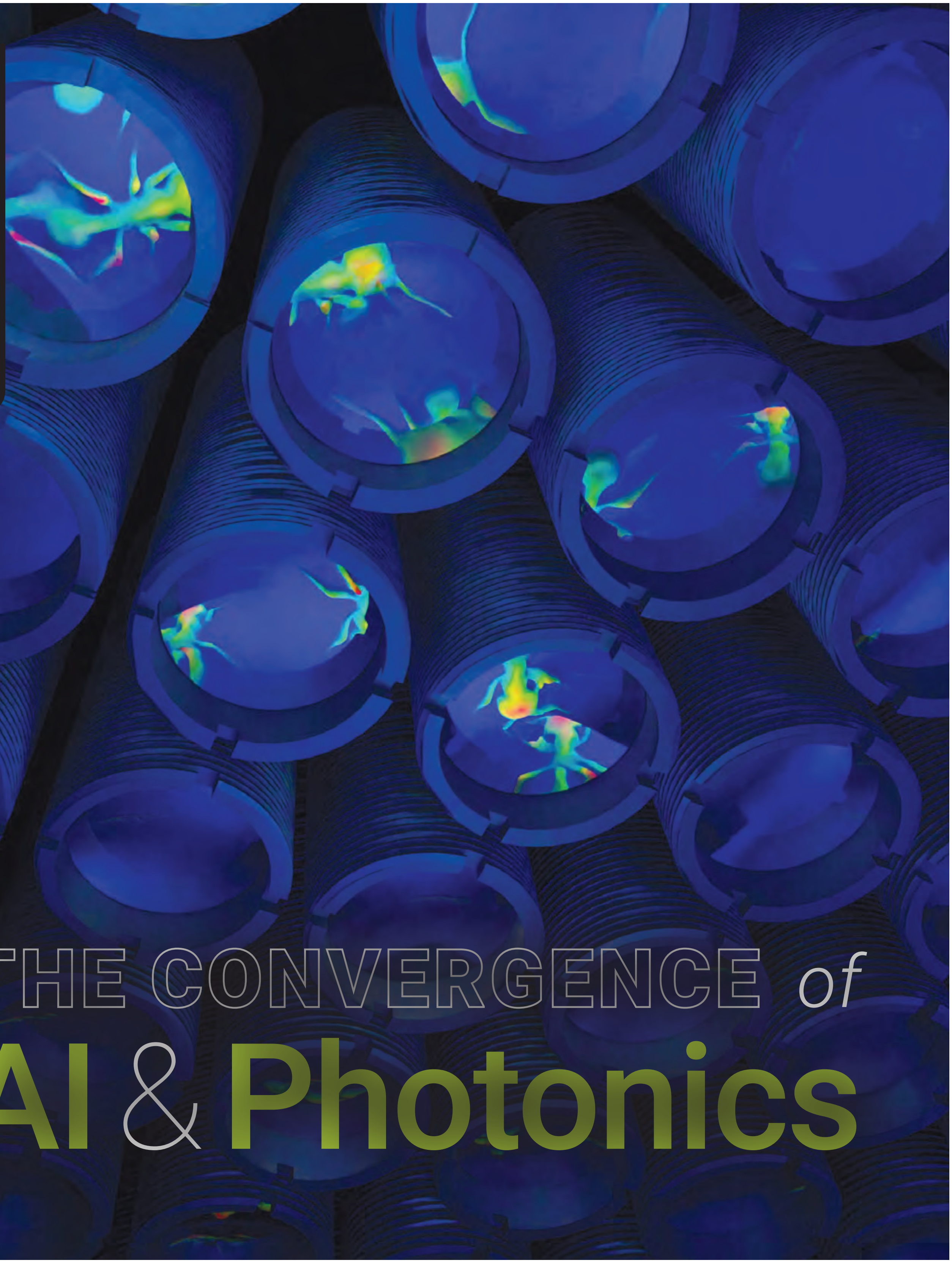
DukeBroadband
FITZPATRICK INSTITUTE FOR PHOTONICS / DUKE UNIVERSITY
Engineering light to change the world

Faculty Highlight
Roarke Horstmeyer
See page 8



THE CONVERGENCE *of* AI & Photonics

2023 VOLUME 16 ISSUE 1

DIRECTOR'S WELCOME

The FIP's growth trajectory remains a testament to its commitment to cross-disciplinary research, where the collective dedication of its faculty, students, and staff forms the bedrock of its development. The Institute embodies a vibrant, shared vision for interdisciplinary collaboration among Duke's faculty, evident in the increasing partnerships across diverse disciplines and departments. This collaboration speaks volumes about the resilience and relevance of the faculty's outstanding contributions and lasting accomplishments. FIP's faculty spans a wide spectrum, encompassing fields from engineering, medicine and science. Furthermore, the diversity extends to areas such as Art, Art History, and Visual Studies, exemplifying a comprehensive and inclusive approach to interdisciplinary engagement within the Institute.

We are delighted to present a special BROADBAND edition delving into the convergence of Photonics and Artificial Intelligence (AI). This special issue highlights the dynamic synergy between these cutting-edge fields, exploring how AI is revolutionizing Photonics and vice versa. This issue presents some examples of insightful research involving the fusion of AI algorithms with photonics technologies, paving the way for many transformative applications ranging from the design of silicon chips, medical imaging, early cancer diagnostics, and mental health, to environmental monitoring, and beyond. Discover how these innovations are reshaping basic and applied research, propelling us into a future where the marriage of Photonics and AI promises unparalleled advancements.

An exceptional highlight among recent activities was the 2023 FIP Symposium, marking a significant return to in-person gatherings after a sequence of virtual meetings due to the pandemic. The Symposium was distinguished by the esteemed presence of Professor Stefan W. Hell, a Nobel Laureate in Chemistry from the Max Planck Institute for Multidisciplinary Sciences in Germany, who delivered the keynote lecture. The event comprised various technical sessions and lectures conducted in-person, accompanied by a welcoming reception on the opening evening. Noteworthy features of the program included presentations from eminent speakers, research contributions, and posters from accomplished investigators. A special Panel Session dedicated to the utilization of photonics in global health applications was jointly organized by the FIP and the Duke Global Health Institute, underscoring the symbiotic relationship between the two entities.

Coming this spring, we are thrilled to take part in the grand celebration of *Duke University's 100th Anniversary* by hosting a special FIP Event: ***'Engineering Light to Empower the World'*** which will highlight the profound importance and impact of Duke's research and achievements in light-based technologies and how they serve society while empowering the world. This one-day special event, orchestrated and presented by FIP faculty, staff and students, will shine a spotlight on the contributions of FIP's esteemed leaders as well as the rising talents and future trailblazers in the field of light-based technologies. The program is structured to encompass four distinctive events throughout the day:

1) '*Light in Service of Society*': a poster session showcasing research contributions.
2) *'Lightning Speed' Centennial Symposium*: a special continuous video loop featuring 'Lightning Talks' presenting FIP faculty's groundbreaking research accomplishments in photonics.
3) *'Exploring The Wonder of Light'* exposition booths from the Duke Optical Student Chapter demonstrating Lasers, Lenses & Light.
4) *'Moving Forward at The Speed of Light through Space & Time*': A session on Light Painting dedicated to creating art inspired by the leaders of Duke's past, present, and future.

I invite you to visit our website at www.fitzpatrick.duke.edu to learn more about our Institute, faculty, research programs, and activities.

Join us on this illuminating journey at the frontier of technology in our special newsletter issue. I send you my very best wishes for a successful, safe, and enjoyable year.

Tuan Vo-Dinh
Director, Fitzpatrick Institute of Photonics
R. Eugene and Susie E. Goodson Distinguished Professor of Biomedical Engineering
Professor of Chemistry

ON THE COVER: *A rendering of the multi-camera array microscope's lenses during 3D video acquisition of freely moving carpenter ants.*

CELEBRATING DUKE UNIVERSITY'S

100TH ANNIVERSARY

2024 FIP SYMPOSIUM

THE FITZPATRICK INSTITUTE FOR PHOTONICS

Engineering Light *to* Empower the World

SAVE THE DATE

APRIL 13, 2024
DUKE UNIVERSITY
DURHAM, NC USA

Duke FITZPATRICK INSTITUTE *for* PHOTONICS

Duke 1924 · 2024 100

SPECIAL SESSIONS

'Light in Service of Society' *poster session*

'Lightning Talks' *-groundbreaking research by faculty*

'Exploring The Wonder of Light' *expo booths for all ages*

"Moving Forward at The Speed of Light Through Space and Time"
Light painting demonstration for all ages

PARTICIPATING DEPARTMENTS AND INSTITUTIONS

150 Faculty Members | **40 Participating Departments, Centers, and Institutions at Duke University**

The Fitzpatrick Institute for Photonics is an extremely interdisciplinary Duke effort to advance photonics and optical sciences. The institute leverages Duke's faculty from the Pratt School of Engineering, Trinity College of Arts and Sciences, and the Duke School of Medicine to explore problems at the boundary nexus of nano-bio-info-opto convergence.

DEPARTMENTS

Anesthesiology
Art, Art History & Visual Studies
Biochemistry
Biology
Biostatistics and Bioinformatics
Biomedical Engineering (BME)
Cell Biology
Chemistry
Civil & Environmental Engineering (CEE)
Computer Science
Dermatology
Electrical and Computer Engineering (ECE)
Environmental Toxicology
Gastroenterology
Geriatrics
Immunology
Mathematics
Mechanical Engineering and Materials Science (MEMS)
Molecular Genetics and Microbiology
Neurology
Neurobiology
Neurosurgery
Obstetrics and Gynecology
Oncology
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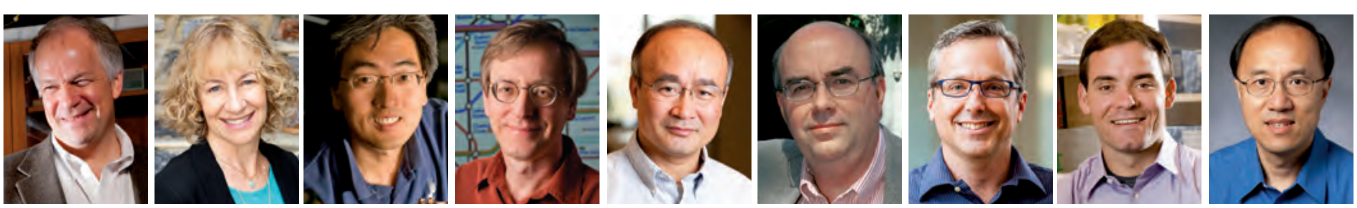
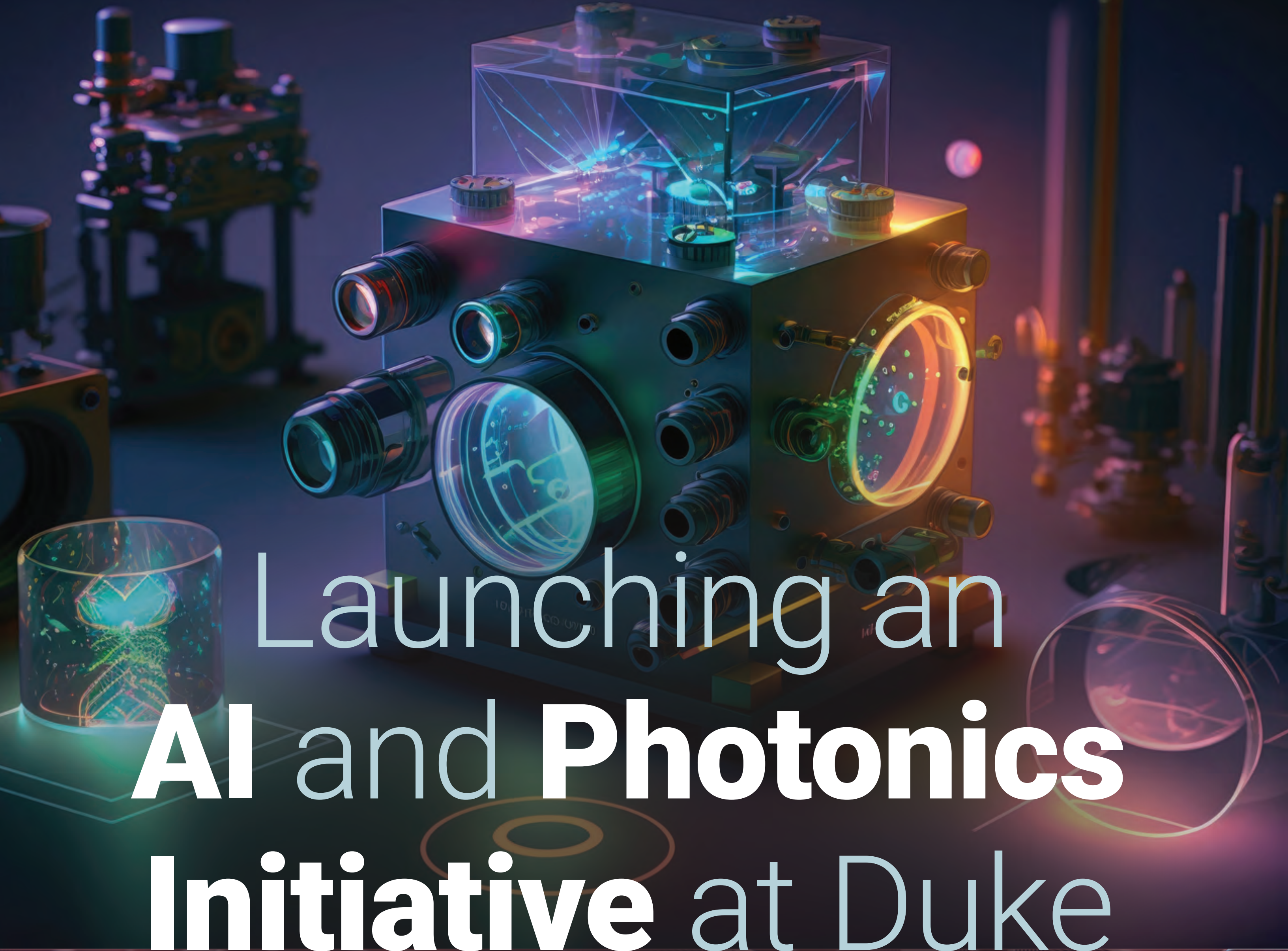
Orthopaedic Surgery
Pathology
Pediatrics
Pharmacology and Cancer Biology
Philosophy
Physics
Radiation Oncology
Radiology
Surgery
Urology
Center for Applied Genomics and Precision Medicine
Duke Cancer Institute
Global Health
Nicholas School of the Environment
School of Medicine
School of Nursing



FIP RESEARCH PROGRAMS AND DIRECTORS, LEFT TO RIGHT: Biophotonics: Joseph Izatt Nano & Micro Systems: Nan Jokerst Quantum Optics and Information Photonics: Jungsang Kim and David Beratan Systems Modeling, Theory & Data Treatment: Weitao Yang Novel spectroscopes: Warren Warren Photonic Materials & Advanced Photonics Systems: Steven Cummer & Charles Gersbach Nanophotonics: Fan Yuan



Launching an **AI** and **Photonics Initiative** at Duke

The Fitzpatrick Institute for Photonics is creating a new group focused on a quickly growing and evolving marriage of technologies

BY KEN KINGERY


Jessilyn Dunn and Roarke Horstmeyer

AI and photonics have a long history with one another. As the nascent field of machine learning took hold in areas outside of niche programming applications in the 1990s, one of its first major successes was in image recognition.

At Duke, this growing revolution was led by **Larry Carin** and **Leslie Collins**—both new faculty members in electrical and computer engineering at the time—who began teaching computers how to spot buried landmines. But it didn't take long for those early image-processing strategies to move from their military roots to the medical realm.

Researchers at the University of Pennsylvania soon added Carin's algorithms to software they were developing to help doctors classify cancerous cells. While the software already worked reasonably well, the new algorithms made it more accurate and more consistent. The enhanced toolkit also reduced the time physicians had to spend labeling cell samples to train the system because the algorithm automatically selected the best examples.

Jump ahead a quarter of a century, and AI algorithms built to distinguish and classify images—and even to generate original images based on descriptions—are now commonplace. They've moved well beyond military and health care applications, too; researchers across Duke are using AI for light-based research ranging from tracking the movements of live organisms to helping autonomous vehicles navigate to shaping electromagnetic waves to carry information.

This widespread growth between the two disciplines is why the Fitzpatrick Institute for Photonics (FIP) is launching a new AI and Photonics Initiative that intends to draw together researchers and increase cross-campus collaboration in these tactics.

"The marriage between AI and photonics represents a powerful and rapidly evolving interdisciplinary field leading to many important applications ranging from medical imaging, robotics and advanced manufacturing to quantum cryptography, computer vision and augmented reality," said **Tuan Vo-Dinh**, the R. Eugene and Susie E. Goodson Distinguished Professor of Biomedical Engineering at Duke and director of FIP. "At our institute, we are very excited to be at the interface of these emerging cross-disciplinary areas integrating photonics and AI."

Co-leading the new initiative are two Duke Engineering faculty members who are at the forefront of this scientific intersection: **Jessilyn Dunn** and **Roarke Horstmeyer**, both assistant professors of biomedical engineering.

"**AI is a great fit for Photonics** – it can assist with complex system design, data processing, and even inform new experiments. We're excited to really thing deeply about how these two rapidly developing disciplines are connected."

- HORSTMEYER

Horstmeyer uses machine learning methods and deep learning networks to synthesize data taken from imaging devices such as microscopes (see page 8). The abilities of AI help construct new nonlinear algorithms to assemble overlapping views from different cameras into a single, cohesive picture in real-time. The results allow him to develop platforms that stitch dozens of cameras together to create movies of a microscope platform's entire field of view with resolutions down to the cellular level.

> "AI is expanding the speed of imaging and analyzing pathology slides at the cellular scale **beyond human capabilities**."
>
> **- HORSTMEYER**

Horstmeyer's collaborators are using these AI tools to classify cells or detect cancer within slides containing cytopathology material during surgeries. The approach speeds their reading of these slides by automatically segmenting and highlighting important image areas for review and even by offering initial diagnoses.

"AI is expanding the speed of imaging and analyzing pathology slides at the cellular scale beyond human capabilities," Horstmeyer said.

Dunn's research in the field mirrors Horstmeyer's. She is a leading expert in exploring how wearable technologies like smart watches can gather more accurate bioinformation and then translate that data into actionable knowledge and predictions about a person's health (see feature in last year's edition of Broadband).

In some instances, Dunn uses AI to label data collected by sensors so that other algorithms can quickly make use of it. Beyond these recognition tasks, Dunn also uses AI to take that input data and connect it to a particular outcome, like automatically detecting different stages of sleep or certain types of arrhythmias from heartbeats.

"We're also using AI to help combine information about a person's various biosignals like heart rate and sleep and predict markers of prediabetes or respiratory infections like Covid, the flu, RSV and others," Dunn said.

While Horstmeyer's and Dunn's specialties lie primarily within the health care industry, there are also many examples of researchers across Duke using AI and photonics in other fields, such as Duke's trailblazing metamaterials group.

Metamaterials are synthetic materials composed of many individual engineered features, which together produce properties not found in nature through their structure rather than their chemistry. In many of the labs at Duke, the metamaterials are built to interact with certain wavelengths of light such as the terahertz, infrared or microwave regimes.

Depending on the goal, metamaterials can be built to steer specific wavelengths of light around an object, essentially creating a 2D cloaking device. Metamaterials can also act like flat lenses, shaping and focusing light to better transport data stored in Wifi signals or wirelessly charge a battery.

Designing the size, shape and configuration of the individual elements within a metamaterial, however, is not a straightforward task. Several electrical and computer engineering researchers at Duke are enlisting the help of AI to quickly tackle the job for them rather than trying to write new traditional design software.

AI and machine learning have been an area of great interest among FIP faculty. In addition to

> "We're also **using AI to help combine information about a person's various biosignals** like heart rate and sleep and predict markers of prediabetes or respiratory infections like Covid, the flu, RSV and others." **- DUNN**

"We are **arming healthcare professionals with tools and information** to detect illness, intervene early, and deliver the right treatment." - JESSILYN DUNN

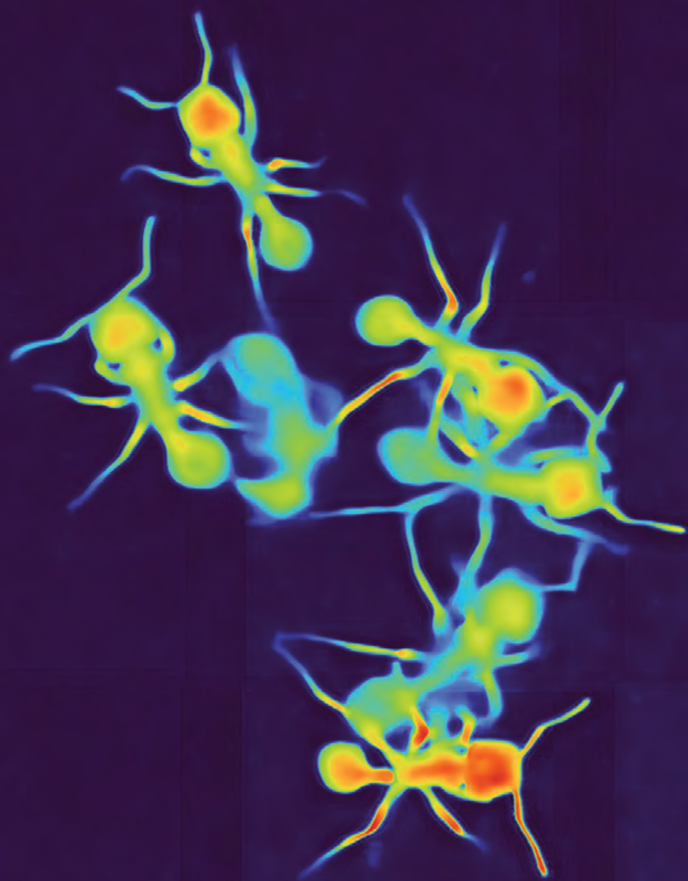
Jessilyn Dunn and Roarke Horstmeyer, other FIP faculty include:

- **Natasha Litchinitser** is using AI to design small silicon chips for routing optical interconnects.
- **Willie Padilla** is designing sustainable types of thermal energy harvesters and lighting.
- **David Smith**, one of the original inventors of metamaterials, is creating new types of imaging sensors that work with microwaves.
- **Guillermo Sapiro** works extensively on theory and applications in computer vision, computer graphics, medical imaging, image analysis and machine learning.
- **Sina Farsiu** and Joe Izatt have integrated machine learning and optics to design a multi-aperture optical system capable of sampling non-confocal light while simultaneously performing confocal imaging.
- **Tuan Vo-Dinh** and his team use machine learning methods to rapidly analyze biomedical markers' signals for early cancer detection and environmental monitoring of toxic pollutants.
- **David E. Carlson** is focused on novel machine learning and artificial intelligence techniques for ecological and mental health applications.
- **Timothy Dunn** develops machine learning techniques in computational neuroscience and traumatic brain injury studies.

"AI is a hot topic today in simulating human responses and fully automating platforms that mimic what humans would do," Horstmeyer said. "But most of what's happening with AI and photonics at Duke has more to do with advanced design and data analytics, synthesizing many types of data in a complex way using similar tools."

With such a wide range of research topics and a large number of faculty in the space, Dunn and Horstmeyer say their first steps with the new initiative will be to build a community, making connections among physics, chemistry, biology, medicine, engineering and more. Even if a researcher isn't currently using AI but is interested in exploring potential applications, they want to bring them into the group and help get them started.

The duo also plans to create a series of lectures specifically targeting AI in photonics to expand the group's knowledge base and bring in new ideas for researchers to consider. And, eventually, they want to apply for a large training grant or collaborative grant to cement the AI in Photonics Initiative as an active entity for years to come ■



Gigapixel 3D Microscope

Captures Life in Unprecedented Detail

Stitching videos from dozens of cameras together provides unique 3D view of macroscopic experiments with microscopic detail | **BY KEN KINGERY**

When a couple of plucky graduate students took the first picture with their pieced-together microscope, it turned out better than they'd hoped. Sure, there was a hole in one section and another was upside down — but they could still find Waldo.

By the following day, the duo sorted out their software issues and demonstrated a successful proof-of-principle device on the classic children's puzzle book. By combining 24 smartphone cameras into a single platform and stitching their images together, they created a single camera capable of taking gigapixel images over an area about the size of a piece of paper.

Six years, several design iterations and one startup company later, the researchers made an unexpected discovery. Perfecting the process of stitching together dozens of individual cameras with subpixel resolution simultaneously allowed them to see the height of objects too.

"It's like human vision," said **Roarke Horstmeyer**, assistant professor of biomedical engineering at Duke University. "If you merge multiple viewpoints together (as your two eyes do), you see objects from different angles, which gives you height. When our colleagues studying zebrafish used it for the first time, they were blown away. It immediately revealed new behaviors involving pitch

A single 3D height map frame from a high-speed video of freely-moving harvester ants, captured using an AI-driven, highly-parallelized, multi-aperture microscope.

and depth that they'd never seen before."

In a recent paper, Horstmeyer and his colleagues showed off the capabilities of their new high-speed, 3D, gigapixel microscope called a Multi Camera Array Microscope (MCAM). Whether recording 3D movies of the behavior of dozens of freely swimming zebrafish or the grooming activity of fruit flies at near cellular-level detail across a very wide field of view, the device is opening new possibilities to researchers the world over. The latest version of MCAM relies on 54 lenses with higher speed and resolution than the prototype that found Waldo. Building upon recent work completed in close collaboration with Dr. Eva Naumann's lab at Duke, innovative software gives the microscope the ability to take 3D measurements, provide more detail at smaller scales and make smoother movies.

The highly parallelized design of the MCAM, however, creates its own data processing challenges, as a few minutes' worth of recording can produce over a terabyte of data. "We've developed new algorithms that can efficiently handle these extremely large video datasets," said **Kevin C. Zhou**, a postdoctoral researcher in Horstmeyer's lab and lead author of the paper. "Our algorithms marry physics with machine learning to fuse the video streams from all the cameras and recover 3D behavioral information across space and time. We've made our code open source on Github for everyone to try out."

"When our colleagues studying zebrafish used it for the first time, they were blown away. It immediately revealed new behaviors involving pitch and depth that they'd never seen before."

At the University of California – San Francisco, Matthew McCarroll watches the behavior of zebrafish exposed to neuroactive drugs. By looking for changes in behavior due to different classes of drugs, researchers can discover new potential treatments or better understand existing ones.

In the paper, McCarroll and his group describe interesting movements they'd never seen before thanks to using this camera. The 3D capabilities of the MCAM, coupled with its all-encompassing view, allowed them to record differences in the fish's pitch, whether they trended toward the top or bottom of their tanks and how they tracked prey.

"We've long been building our own rigs with single lenses and cameras, which have worked well for our purposes, but this is on a whole other level," said McCarroll, an independent scientist studying pharmaceutical chemistry in the UC system's professional researcher series. "We're just biologists tinkering with optics. It's incredible to see what a legit physicist can come up with to make our experiments better."

At Duke, the laboratory of Michel Bagnat, professor of cell biology, also works with zebrafish. But rather than watching for drug-induced behavioral changes, the researchers study how the animals develop from an egg into a fully formed adult on a cellular level.

In previous studies, the researchers needed to anesthetize and mount the developing fish to keep them steady while measurements were taken with lasers. But knocking them out for prolonged periods of time might also cause changes in their development that could skew the experiment's results. With the help of the new MCAM, the researchers have shown that they're able to get all of these measurements while the fish live their lives unencumbered, no knockouts or clamps required.

"With the 3D and fluorescent imaging capabilities of this microscope, it could change the course of how a lot of developmental biologists do their experiments," said Jennifer Bagwell, a research scientist and lab manager in the Bagnat lab. "Especially if it turns out that anesthetizing the fish affects their development, which is something we're studying right now."

Besides tracking entire communities of small animals such as zebrafish in experiments, Horstmeyer hopes this work will also allow for larger automated parallel studies. For example, the microscope can watch a plate with 384 wells loaded with a variety of organoids to test potential pharmaceutical reactions, recording the cellular responses of each tiny experiment and autonomously flagging any results of interest.

"The modern laboratory is becoming more automated every day, with large well plates now being filled and maintained without ever touching a human hand," Horstmeyer said. "The sheer volume of data this is creating demands for new technologies that can help automate the tracking and capturing of the results."

Along with coauthor **Mark Harfouche**, who was the brains behind capturing their first image of Waldo, Horstmeyer has launched a startup company called Ramona Optics to commercialize the technology. One of its early licensers, MIRA Imaging, is using the technology to "fingerprint" fine art, collectables and luxury goods to inoculate against forgery and fraud. ■

RESEARCH HIGHLIGHT

Eyes in the Skies Confirm the End of **Trash Burning** in the Maldives

Maldives Plume – A smoke plume rises from a trash pile being burned in the Maldives.

A new AI approach needs only a small amount of visual data to identify and track plumes of smoke in satellite imagery | **BY MIRANDA VOLBORTH**

White sand beaches. Crystalline waters. Toxic smoke plumes wafting across a paradise clogged with plastic trash.

That was the Republic of Maldives in early 2021, which prompted its government to ban open trash burning and single-use plastics later that year. But until recently, uncertainty remained as to whether or not the government actually put its money where its mouth was and enforced the policy changes.

New research from Duke University which used advanced AI techniques to analyze satellite images of the nation of islands in the middle of the Indian Ocean has demonstrated that the government's ban on open burning has indeed effectively stamped out the smoke plumes.

This approach has the potential to spot similar plumes generated by wildfires, power plants, or industrial facilities. The findings were published on July 7th in Environmental Science & Technology Letters.

The Maldives is made of 1200 islands. Its largest, Male, is one of the most densely populated places on earth, generating hundreds of tons of waste every day. A nearby artificial island named Thilafushi serves as its dump — but at sea level, much of the plastic trash deposited there was washing into the ocean. Much more of it was being burned, sending toxic smoke drifting across the islands and pristine Indian Ocean. There was massive plastic contamination at every level.

Mike Bergin, the Sternberg Family Professor of Civil & Environmental Engineering at Duke, runs a large global air quality program that uses low-cost sensors to gather information. Bergin's group was working with collaborators in the Maldives to install air quality sensors when he first heard about the situation on Thilafushi. He wanted to know what kind of air quality data was available for the island country, so he turned to satellite imagery from a commercial data company called PlanetLabs. What he saw troubled him.

"The island was smoking all the time," said Bergin. He asked colleague **David Carlson**, assistant professor of civil and environmental engineering at Duke and a machine learning expert, if there was anything they could do to help track who was being exposed to the toxic smoke.

The two decided to develop an AI tool that used advanced image segmentation and something called transfer learning to examine satellite imagery of the island to see whether or not they could identify the smoke plumes from space.

Soon after Bergin and Carlson began, however, the Maldivian government banned both trash burning and single-use plastics on its islands. The massive policy changes created a unique opportunity for the pair to see whether an AI tool could tell the difference between images of Thilafushi before and after the ban — and to confirm whether the ban had actually been enacted.

Training AI tools to recognize a certain shape usually requires thousands of images, but environmental applications generally don't have huge data sets to work from. To get around this shortfall, the team turned to an approach called transfer learning, which borrows from lessons already learned by existing convolutional neural networks trained on similar tasks, allowing the AI to gain accuracy from far fewer images.

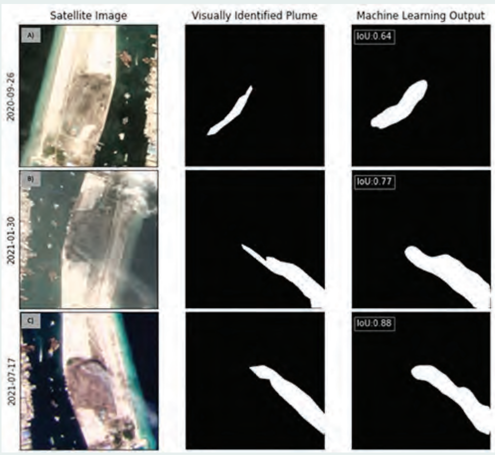
Carlson started with a model trained on a canonical image recognition task — classifying an unnamed animal as either a cat or a dog. "It initializes your AI tool, so that when you apply it in a new area, the established baseline allows it to succeed with far less data," said Carlson.

Image segmentation — the ability of an AI tool to recognize a shape and lift it from the background — has gotten a lot better in recent years, and those advances also played a big role. "Highlighting the area in each image that might be a plume provides a lot of additional information to the AI tool, so that it continues to learn," said Carlson. "Localized info teaches it exactly what is relevant, so that it gets better and better at the task."

They were then able to apply their AI tool to the image classification problem at hand. The verdict? There were no smoke plumes in the images of Thilafushi after the burning ban was instated.

And after comparing the AI's abilities against its human teachers', the researchers found that the tool achieved 88% accuracy in its classification task. Through the process, it also learned the typical shape of a plume and how to distinguish between plumes and clouds, which have similar diffuse boundaries.

"Asking a human to identify a plume is such an objective task," said CEE PhD student Sarah Scott, the paper's first author. "That's why we had several people performing it, and why we blended plume images together — to show how different people might perceive the shapes. But the computer is looking at when the signals change within the image, pixel by pixel. Humans can't see change at that level."



__Plume Learning__ – These photos reveal how the AI learns to outline and tease out smoke plumes from complex satellite imagery.

"It is encouraging for a small developing country like the Maldives to be recognized for its efforts to **regulate environmental problems**." **- KHALEEL**

"The results were impressive, and confirmed the time the ban was implemented," said Noora Khaleel, a PhD student at the University of Malaya, who worked with the Duke team on the project. "It is encouraging for a small developing country like the Maldives to be recognized for its efforts to regulate environmental problems."

In the future, if the AI tool is made more robust — something that Carlson and Bergin acknowledge will take much more data and the participation of a large citizen science effort — it could give people more power to surveil numerous environmental problems around the world.

"It would be amazing to be able to scan for plumes, find them and keep track of them," said Bergin. "We could let the public know when they're being exposed to pollution from plumes, and they could hold parties accountable to clean up their acts." ■

Nanorattles Shake Up New Possibilities for **Disease Detection**

New nanoparticle shape can greatly enhance signals from multiple separate biomarkers at once, accurately detecting head and neck cancers without biopsies | **BY KEN KINGERY**

Researchers at Duke University have developed a unique type of nanoparticle called a "nanorattle" that greatly enhances light emitted from within its outer shell.

Loaded with light scattering dyes called Raman reporters commonly used to detect biomarkers of disease in organic samples, the approach can amplify and detect signals from separate types of nanoprobes without needing an expensive machine or medical professional to read the results.

"Once we had the nanorattles working, we wanted to make **biosensing devices to detect infectious diseases or cancers** before people even know they're sick." **- Vo-Dinh**

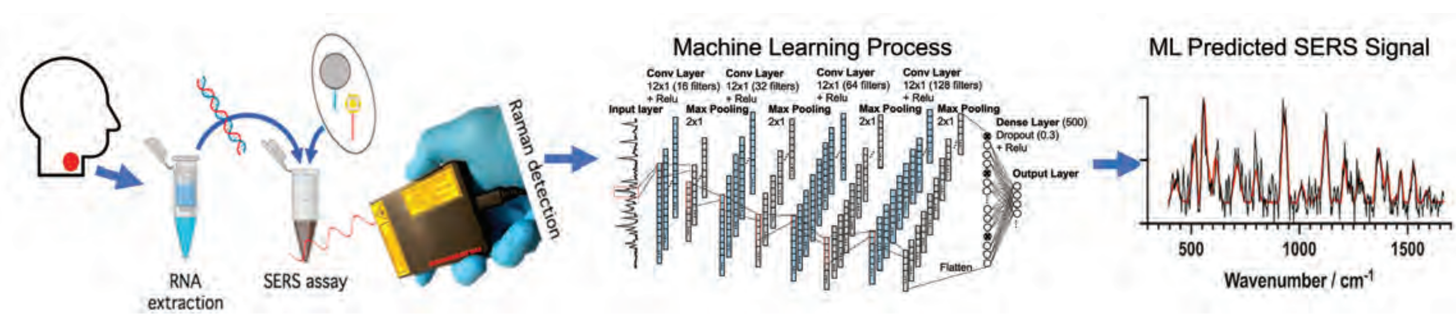
In a small proof-of-concept study, the nanorattles accurately identified head and neck cancers through an AI-enabled point-of-care device that could revolutionize how these cancers and other diseases are detected in low-resource areas to improve global health.

"The concept of trapping Raman reporters in these so-called nanorattles has been done before, but most platforms had difficulty controlling the interior dimensions," said **Tuan Vo-Dinh**, the R. Eugene and Susie E. Goodson Distinguished Professor of Biomedical Engineering and professor of chemistry at Duke.

"Our group has developed a new type of probe with a precisely tunable gap between the interior core and outer shell, which allows us to load multiple types of Raman reporters and amplify their emission of light called surface-enhanced Raman scattering," Vo-Dinh said. "More recently, our group has further applied machine learning techniques to detect miRNA biomarkers for detecting gastrointestinal cancer and for monitoring polyaromatic pollutants in water samples".

To make nanorattles, researchers start with a solid gold sphere about 20 nanometers wide. After growing a layer of silver around the gold core to make a larger sphere (or cube), they use a corrosion process called galvanic replacement that hollows out the silver, creating a cage-like shell around the core. The structure is then soaked in a solution containing positively charged Raman reporters, which are drawn into the outer cage by the negatively charged gold core. The outer hulls are then covered by an extremely thin layer of gold to lock the Raman reporters inside.

The result is a nanosphere (or nanocube) about 60 nanometers wide with an architecture that resembles a rattle—a gold core trapped within a larger outer silver-gold shell. The gap between the two is only about a few nanometers, which is just large enough to fit the Raman reporters.



***Biomarker detection process:** RNA is extracted from tumor biopsy tissue, the Nanorattle sandwich assay is used to detect the specific mRNA biomarker via SERS signal, which are analyzed through spectral unmixing using machine learning. Figure and research on machine learning by Joy Li, Duke BME PhD. Candidate.*

Those tight tolerances are essential to controlling the Raman signal enhancement the nanorattles produce.

When a laser shines on the nanorattles, it travels through the extremely thin outer shell and hits the Raman reporters within, causing them to emit light of their own. Because of how close the surfaces of the gold core and the outer gold/silver shell are together, the laser also excites groups of electrons on the metallic structures, called plasmons. These groups of electrons create an extremely powerful electromagnetic field due to the plasmons' interaction of the metallic core-shell architecture, a process called plasmonic coupling, which amplifies the light emitted by the Raman reporters millions of times over.

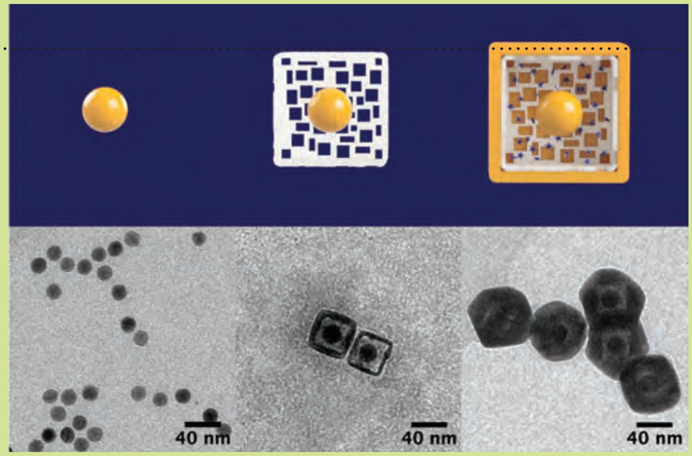
"Once we had the nanorattles working, we wanted to make biosensing devices to detect infectious diseases or cancers before people even know they're sick," Vo-Dinh said. "With how powerful the signal enhancement of the nanorattles is, we thought we could make a simple test that could be easily read by anybody at the point-of-care."

In a recent paper, Vo-Dinh and his collaborators apply the nanorattle technology to a lab-on-a-stick device capable of detecting head and neck cancers, which appear anywhere between the shoulders and the brain, typically in the mouth, nose and throat. Survival rate for these cancers have hovered between 40 and 60 percent for decades. While those statistics have improved in recent years in the United States, they have gotten worse in low-resource settings, where risk factors such as smoking, drinking and betel nut chewing are much more prevalent.

"In low-resource settings, these cancers often present in advanced stages and result in poor outcomes due in part to limited examination equipment, lack of trained healthcare workers and essentially non-existent screening programs," said **Walter Lee**, professor of head and neck surgery & communication sciences and radiation oncology at Duke, and a collaborator on the research.

"Having the ability to detect these cancers early should lead to earlier treatment and improvement in outcomes, both in survival and quality of life," Lee said. "This approach is exciting since it does not depend on a pathologist review and potentially could be used at the point of care."

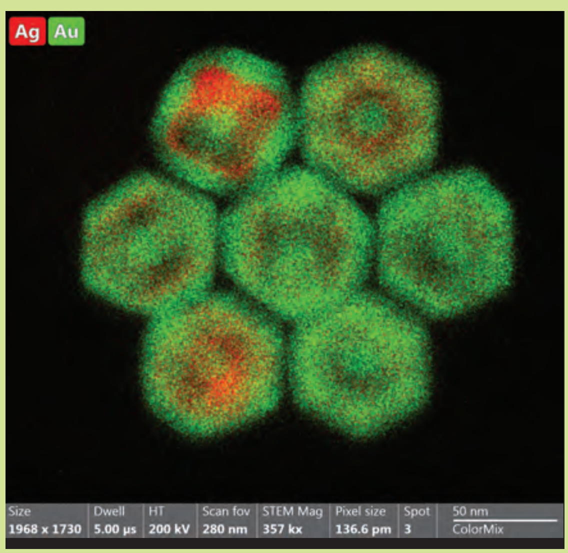
The prototype device uses specific genetic sequences that act like Velcro for the biomarkers the researchers are looking for — in this case, a specific mRNA that is overly abundant in people with head and neck cancers. When the mRNA in question is present, it acts like a tether that binds nanorattles to magnetic beads. These beads are then concentrated and held in place by another magnet while everything else gets rinsed away. Researchers can then use a simple, inexpensive handheld device to look for light emitted from the nanorattles to see if any biomarkers were caught.



***Nanorattles synthesis process:** the starting gold nanosphere seeds (left) are surrounded by a hollow, porous silver cage (middle) and become a nanorattle filled with Raman reporters inside a gold shell. Figure and research on machine learning by Joy Li, Duke BME PhD. Candidate.*

In the experiments, the test determined whether or not 20 samples came from patients that had head and neck cancer with 100% accuracy. The experiments also showed that the nanorattle platform is capable of handling multiple types of nanoprobes, thanks to a machine learning algorithm that can tease apart the separate signals, meaning they can target multiple biomarkers at once. This is the goal of the group's current project funded by the National Institutes of Health.

"Many mRNA biomarkers are overly abundant in multiple types of cancers, while other biomarkers can be used to evaluate patient risk and future treatment outcome," Vo-Dinh said. "Detecting multiple biomarkers at once would help us differentiate between cancers, and also look for other prognostic markers such as Human Papillomavirus (HPV), and both positive and negative controls. Combining mRNA detection with novel nanorattle biosensing will result in a paradigm shift in achieving a diagnostic tool that could revolutionize how these cancers and other diseases are detected in low-resource areas." ■



***Energy dispersive X-ray spectroscopy** - scanning transmission electron microscopy image showing the elemental composition of nanorattle nanoparticles. Photo by Aidan Canning, Duke BME PhD. Candidate.*

Tablet-based AI App

Measures Multiple Behavioral Indicators to Screen for Autism

A 10-minute app can accurately screen for autism in children by automatically detecting a wide range of behavioral characteristics | **BY KEN KINGERY**

Researchers at Duke University have demonstrated an app driven by AI that can run on a tablet to accurately screen for autism in children by measuring and weighing a variety of distinct behavioral indicators.

Called SenseToKnow, the app delivers scores that evaluate the quality of the data analyzed, the confidence of its results and the probability that the child tested is on the autism spectrum. The results are fully interpretable, meaning that they spell out exactly which of the behavioral indicators led to its conclusions and why.

This ability gives health care providers detailed information on what to look for and consider in children referred for full assessments and intervention. SenseToKnow's ease of use and lack of hardware limitations, combined with its demonstrated accuracy across sex, ethnicity and race, could help eliminate known disparities in early autism diagnosis and intervention by allowing autism screening to take place in any setting, even in the child's own home.

"Autism is characterized by many different behaviors, and not all children on the spectrum display all of them equally, or at all," said Geraldine Dawson, director of the Duke Center for Autism and Brain Development, who is a co-senior author on the study. "This screening tool captures a wide range of behaviors that more accurately reflect the complexity and variability found in autism."

Recent research has shown promising results from tracking children's eye movements in response to specially designed movies that can help diagnose autism in a clinical setting. SenseToKnow, the researchers say, detects a wider range of behaviors such as facial expression, gaze patterns, head movements and blink rate. It also incorporates an on-screen bubble-popping game to assess motor movement and skills, as delays in motor skills are one of the earliest signs of autism.

A toddler plays a bubble- popping game as part of a 10-minute tablet app that can greatly aid in screening children for autism.

The app uses almost every sensor in the

tablet's arsenal to measure and characterize the child's response without the need for any sort of calibration or special equipment. It then uses AI to analyze the child's responses to predict how likely it is that the child will be diagnosed with autism.

"The AI we've built compares each child's biomarkers to how indicative they are of autism at a population level," said **Sam Perochon**, a PhD student working in the laboratory of **Guillermo Sapiro**, the James B. Duke Distinguished Professor of Electrical and Computer Engineering and co-senior author of the study. "This allows the tool to capture behaviors other screening tests might miss and also report on which biomarkers were of the most interest and most predictive for that particular child."

The AI tool is able to provide scores for both the quality of data that the app was able to capture as well as its level of confidence in its own analysis—both of which, the researchers believe, are a novel feature.

"This is an important aspect for a health care provider to know, just like they would need to know if a blood test did not have a big enough sample to produce reliable results," said Matias Di Martino, assistant research professor of electrical and computer engineering at Duke, who co-led the analysis of the study with Sapiro and Perochon.

In a recent study, SenseToKnow was administered to 475 children during a pediatric well-child visit, 49 of whom were subsequently diagnosed with autism and 98 with developmental delay without autism. The app showed 87.8% sensitivity for detecting autism, meaning it correctly identified most children with the condition. Its specificity—the percentage of children without autism who screened negative—was 80.8%.

Overall, participants who screened positive for autism using the app had a 40.6% probability of subsequently being diagnosed with the condition. In comparison, only about 15% of children who screen positive using the standard parent questionnaire are later diagnosed with autism. Combining the app with the standard questionnaire boosted the probability of a positive screen resulting in later diagnosis to 63.4%—meaning fewer children are falling through the cracks.

A toddler watches a movie on a tablet while the tablet tracks characteristics such as eye movement, gaze and head movement to screen for autism. Credit: Duke University

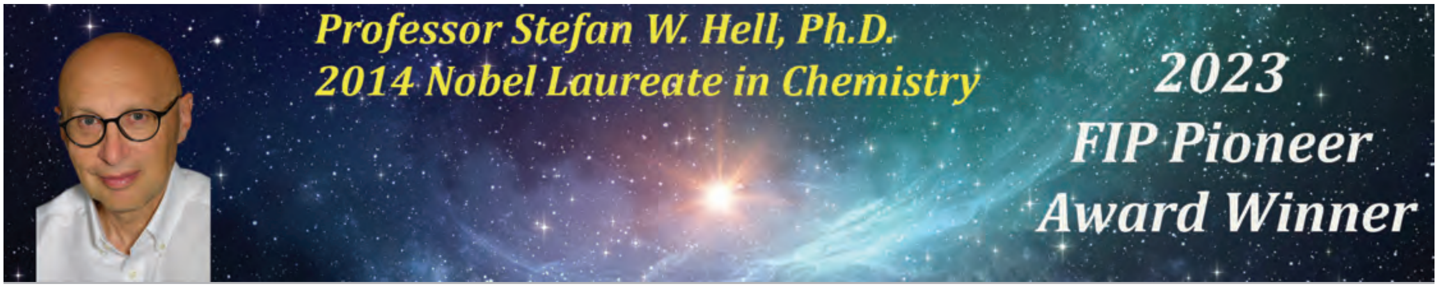
The American Academy of Pediatrics recommends that every toddler be screened for autism at 18 and 24 months. However, concerns have been raised that current screening methods that rely solely on parent reporting are missing children. Girls and children of color, in particular, are often missed.

SenseToKnow's ability to detect autism was similar across children of different sexes, races and ethnicities. While the researchers do not envision the digital screening tool replacing parent reporting, they believe it is important to augment the subjective questionnaire with objective tools to help close the gap.

"Just like when any patient goes to their doctor, the doctor listens to them describe what they are experiencing, but they also use thermometers and other objective tests to provide additional information to guide next steps and referrals for further evaluation," Dawson said. "Such objective tests have been missing for autism."

The researchers are currently conducting a study in which parents deliver the app at home. They hope that the app will also be useful for measuring a child's progress within an early intervention program as well as to studying the effectiveness of such programs.

"There is a wide range of expertise amongst health care providers in knowing and being able to recognize all the potential signs of a child being on the autism spectrum," Dawson said. "This app could help clinicians focus on the areas in which the child needs help, as well as identify areas of strength." ■



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2023 FIP SYMPOSIUM

Highlights

After three years of virtual symposiums, we were excited to have the Fitzpatrick Institute for Photonics (FIP) Symposium in-person this year. Our keynote speaker, **Dr. Stefan W. Hell**, 2014 Nobel Laureate in Chemistry from Max Planck Institute for Multidisciplinary Sciences in Germany, was unable to travel to the symposium and gave his presentation during a virtual lunch celebration honoring him as the 2023 FIP Pioneer Awardee for his contributions in the field of photonics and particularly for the development of super-resolved fluorescence microscopy. Our Plenary Speaker, **Dr. Mike Wasielewski**, Clare Hamilton Hall Professor of Chemistry, Executive Director of the Institute of Sustainability & Energy, Director of the Center for Molecular Quantum Transduction at Northwestern University kicked off our symposium with the topic of "Using Light to Generate Molecular Spin Qubits for Quantum Information Science". We covered a diverse group of topics and sessions focused on nanoscopy & super-resolution as well as AI and the quantum era of photonics. Our visitors and guest speakers were also treated to a behind the scenes tour of the new Duke Quantum Center. FIP collaborated with the Duke Global Health Institute to host a panel and session on Photonics & Global Health.

To learn more visit **http://fitzpatrick.duke.edu/fip-annual-symposia**

FIP FELLOWS & SCHOLARS

THE SCHOLARS PROGRAM provides existing Duke graduate students within the FIP full funding toward their stipend, tuition remission, grad school fees and health insurance for two years. This program is designed to reward the most outstanding individuals within FIP for their accomplishments and potential. Each candidate, nominated by a FIP professor, was judged on the criteria of demonstrated excellence in their academic studies, research and projects that involved inter-group or interdisciplinary research stimulating new collaborations among FIP faculty.

THE FELLOWS PROGRAM, used as recruiting tool for the top candidates, provides incoming graduate students a one year fellowship program, which awards $10,000 top-up on their stipend and $1,000 towards educational travel. Each candidate is nominated by a FIP professor and judged on the criteria of research accomplishments, research potential, personal qualities and collaborative potential.

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DUKE OPTICAL STUDENT CHAPTER

We are a group of graduate students that care about growing the optics and photonics community here at Duke. We act as the student chapters of Optica and SPIE as well as an outreach organization promoting optics and science education in our local community. We host monthly events like the FIP Breakfast and DOSC Journal Club that stoke conversation and community with optics presentations... and of course, food. We also have a long history of outreach, whether it be demonstrations for local K-12 students at school or hosting visiting professors after symposiums on campus.

Lasers, Lenses & Light

Lasers, Lenses, and Light (LLL) Day is the latest version of a program DOSC has hosted for a couple of years. With the support of many Duke student volunteers, FIP, and other various sponsors, we have been able to host local middle school aged students and their families on campus for a day filled with photonics and fun. We perform a large variety of demonstrations, lab tours, and hands on learning experiences to help excite the next generation of scientists. To learn more visit **http://fitzpatrick.duke.edu/outreach**

OUTREACH & ART EXHIBIT

Light Painting

The Fitzpatrick Institute for Photonics and **Art@DukeEngineering,** both in the **Pratt School of Engineering, Duke University** hosted an outreach in October 2022 in the newly designed Wilkinson Building. The vision was to bring talented light painters to inspire and empower others within our community. The hope was to ignite their own light within and express themselves through this art form of light painting. The spark would expand their own journey to connecting with other light painters. Those connections could lead them to new people, new places and new experiences. As the story unfolds, we teleport back to how these light painters came together for the inaugural Light Painting outreach workshop. **August Burns**, the business manager for the Fitzpatrick Institute for Photonics began her own light painting journey in 2019 after the loss of her mother. She had seen on social media an image created by **Jess Cruger**, another light painter who worked as a lab analyst in Duke Biomedical Engineering. August reached out to Jess who also had lost her mother and so began a beautiful glowing friendship. The connections grew as Jess introduced her to more light painters such as Johnny (a/k/a JEDII Light Painting) and Jason Rinehart, Ambassador of Light Painting Brushes. Each light painter brought their own special connections. Through space and time, we seem to find each other by connecting from one light painter to the next amplifying each other's light and making us brighter because of our collaborations. As we met on campus to bridge connections between Duke's faculty, staff, students and the Durham Community, we hoped sparks would soar to amplify light not only at the heart of Duke but throughout our global community.

What is light painting? It is the use of a light source to create art through long exposure photography.

"Teleporting to Duke Chapel"
Photo by August Burns
Light painting by August Burns & Laura DelPrato

The light painters taught Duke students, faculty, staff, and Durham community members the definition of light painting, a short history and demonstrated different styles of the various artists. At the end of the outreach, attendees got to test their own hand at light painting in breakout groups.

After the workshop, the light painters submitted their art for a gallery display in the Allen Building sponsored by Duke Trinity College of Arts & Sciences and Duke Arts from May 2023 through Spring 2024.

To learn more goto: **sites.duke.edu/fiplightpainting**

Special thanks to our volunteers, sponsors and guest light painters.

Photo by Jason D. Page
Light painting by Jason D. Page & Jason Rinehart

"Inside the Inside"
Photo by Laura DePrato
Light painting by Jess Cruger & Laura DelPrato

Special Thanks to Guest Light Painters

Johnny Dickerson
Laura DelPrato
Jason D. Page
Jason Rinehart
John Shockey

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