

# ENGINEERING **RESEARCH** REVIEW 2020



**SOUTH DAKOTA STATE UNIVERSITY**

Office of Engineering Research





## Dear Colleagues,

We are living in unprecedented times. The first global pandemic in nearly a century has taught us, possibly more than ever before, about the integral role research plays in our daily lives. Despite the adversities we are facing as a society, my colleagues have been resilient in continuing their innovative research projects.

This edition of the Research Review provides a sampling of the diverse research being conducted in the Jerome J. Lohr College of Engineering and features several of the interdisciplinary research ventures in which our junior faculty members are engaged. As an example of timely and impactful research, assistant mechanical engineering professor Saikat Basu was the first South Dakota State University faculty member to receive National Science Foundation funding for COVID-19 research.

In addition, our early career faculty are developing new battery materials and are leading innovative biomaterials and robotics research. Others are evaluating potential pollutants and examining water quality in area lakes using an underwater drone. Our statisticians are also helping precision agriculture researchers assess the variables affecting yield to help farmers find ways to increase productivity. As we transition into a new decade of research, our faculty strive to conduct innovative research that has tangible outcomes for our communities, state, nation and the world.

During the last 12 months, it has been my honor and privilege to work with our talented research faculty, students, university and state leaders, and external stakeholders as interim associate dean for research. This summer, we welcomed our first full-time associate dean for research, Rajesh Kavasseri, who comes to SDSU after serving 18 years as an electrical engineering faculty member at North Dakota State University. We look forward to his leadership, insight and fresh perspective as we work together to advance our college's research portfolio.

I encourage you to visit campus, meet our researchers and see what has been happening at SDSU. It will be exciting to see the opportunities that present themselves in the upcoming years. The best is yet to come.

**Stephen P. Gent, Ph.D.**

Interim Associate Dean for Research

Professor of Mechanical Engineering



# ENGINEERING RESEARCH REVIEW 2020



## About the cover

Variables, such as soil chemistry and topography, along with application of chemicals can impact agricultural production. Assistant mathematics and statistics professor Hossein Moradi is developing statistical models to estimate how these variables impact corn yields in specific fields. (See story pages 14-15).

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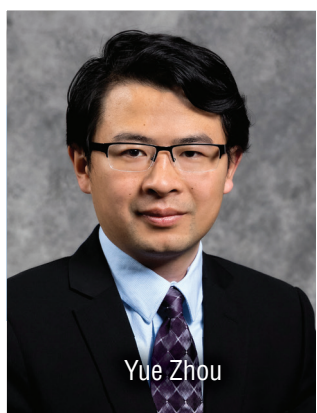
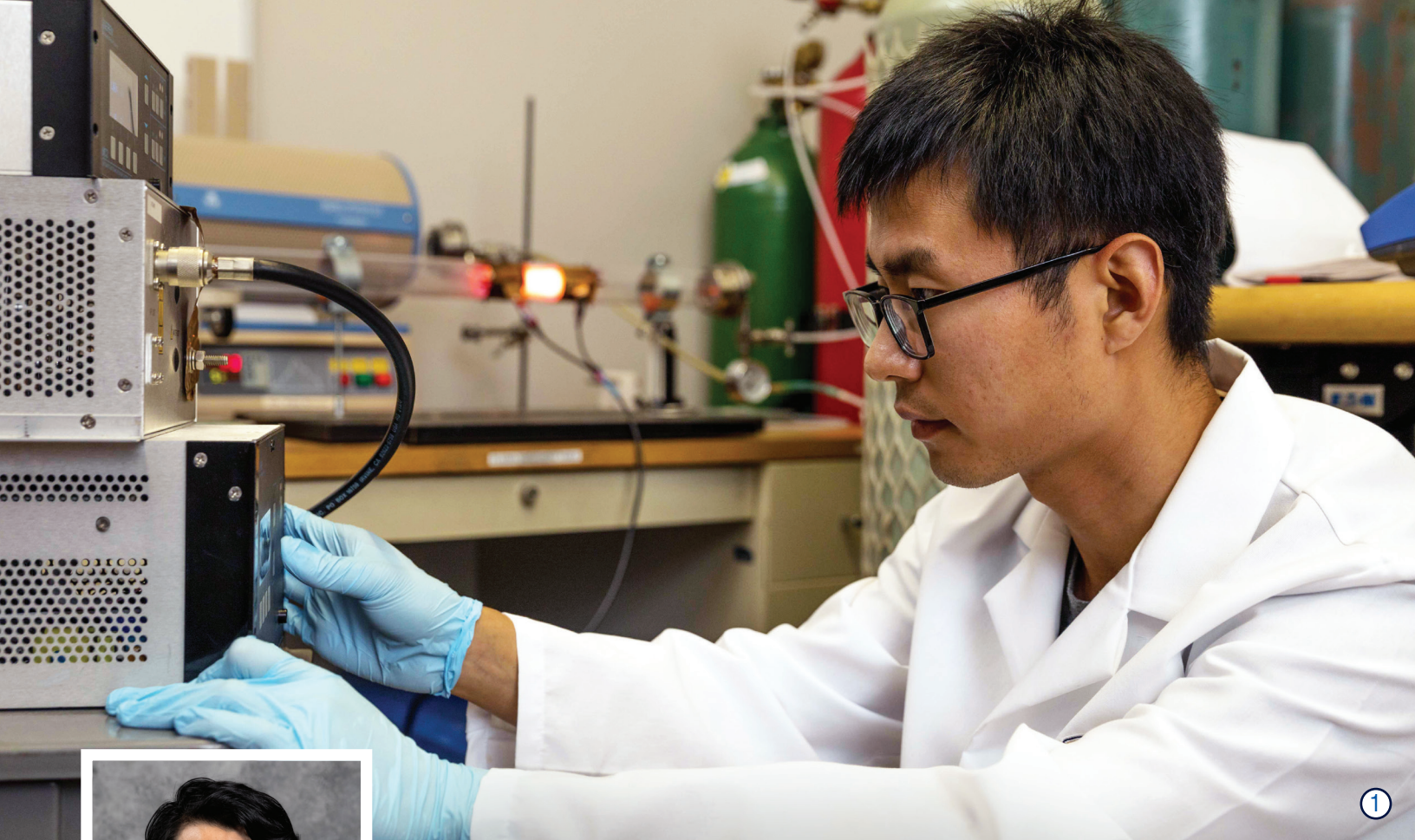
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Yue Zhou

## New materials **improve** performance of **lithium-ion batteries**

**M**ore power, longer life and lower costs—that's what people want from the rechargeable batteries that power their cellphones, laptops, wearable devices—and their electric cars.

Assistant professor Yue Zhou of the Department of Electrical Engineering and Computer Science is developing materials that will increase the capacity and energy density of the lithium-ion batteries that power these devices.

The research, which began in August 2018, is supported by more than \$150,000 in funding from the South Dakota Board of Regents. Two doctoral students are also working on the project.

"Because renewable energy generation fluctuates depending on the time of day and the weather, high-density energy storage devices are also important for the wind and solar energy industries," Zhou

noted. In South Dakota, for instance, more than 30% of electricity comes from wind energy.

Zhou, whose expertise is in energy storage and nanocomposite manufacturing, came to SDSU in January 2018 after doing postdoctoral research for two years at the Massachusetts Institute of Technology. He earned a doctorate in electrical engineering from Pennsylvania State University in 2015.

A traditional lithium-ion battery consists of two electrodes—a cathode and an anode—an electrolyte and a separator. When the battery is charged, lithium ions generated from the cathode move through a separator moistened by an electrolyte, to the anode. The electrolyte enables ion movement, and the separator prevents contact between the cathode and anode. When the battery is discharged, the process is reversed.

Using lithium metal in place of graphite as the anode material can increase

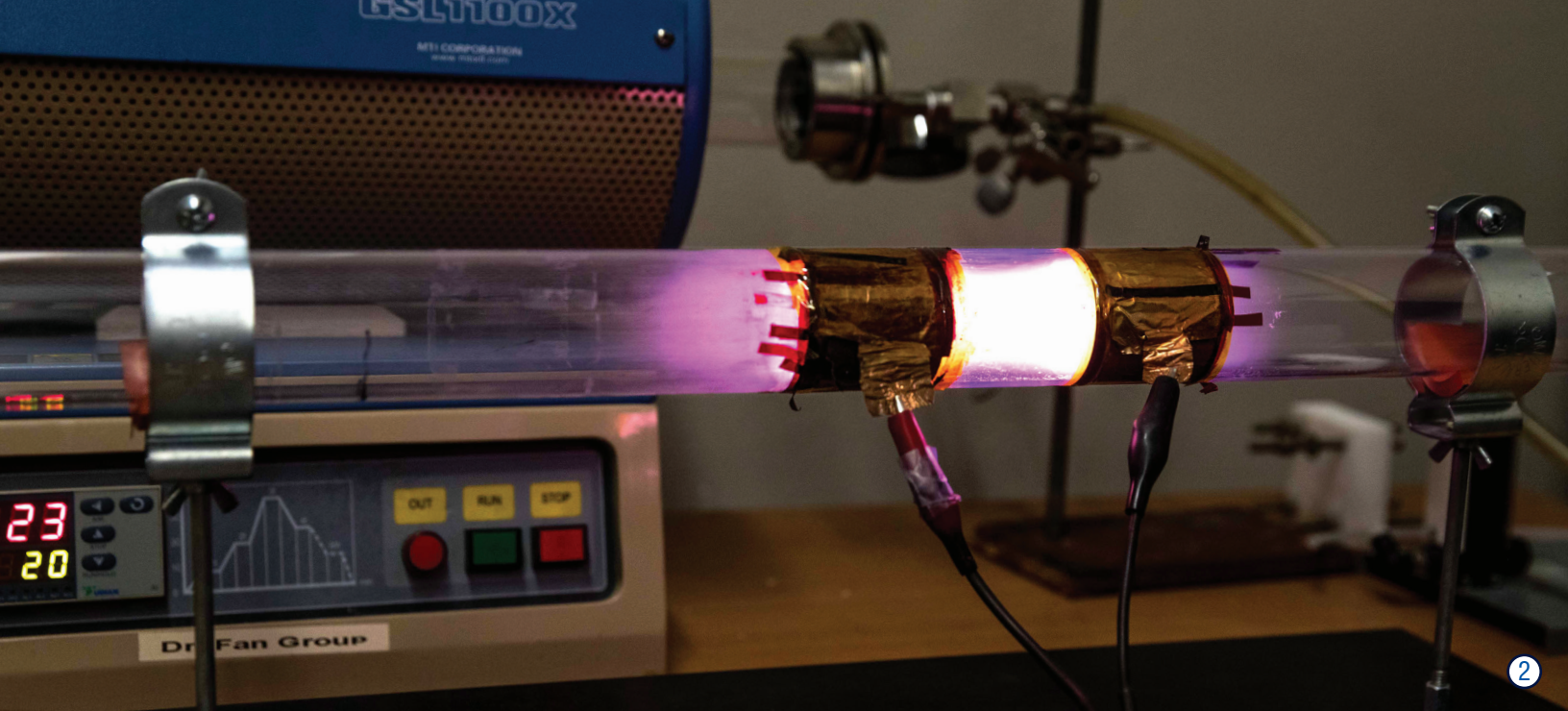
the battery's energy storage capacity. However, over time, the lithium foil tends to form needlelike dendrites. These tiny metal particles can pierce the separator, causing a short circuit, Zhou explained. "The electrolyte solvent is flammable so if it short-circuits, it will catch on fire."

### **Applying protective coating**

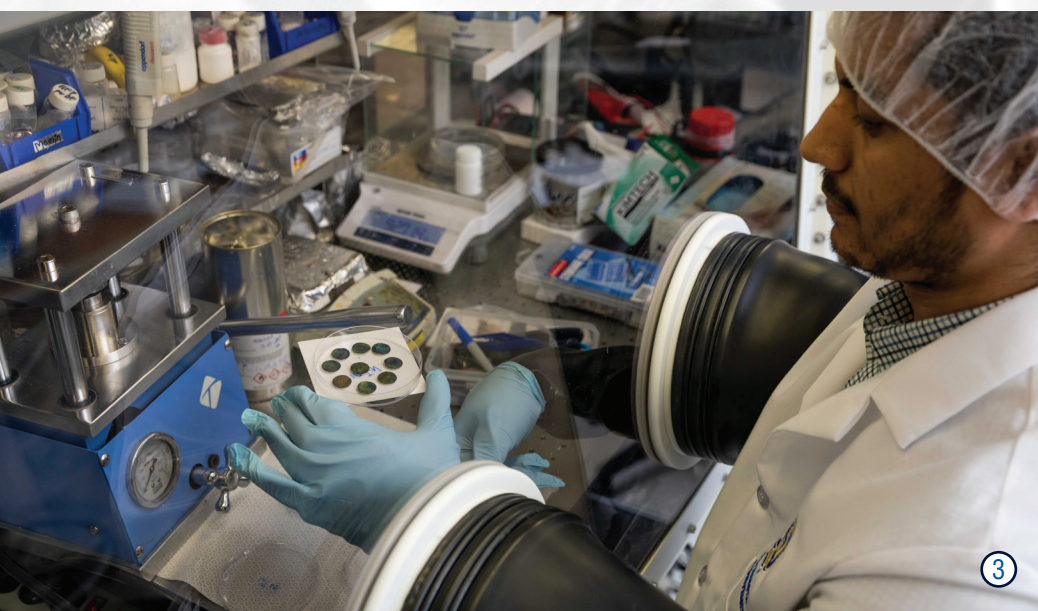
One of the factors contributing to dendrite formation is that the lithium metal is not uniformly deposited on the anode. To overcome this, Zhou and doctoral student Ke Chen applied an additional coating to protect the lithium metal anode and thereby prevent dendrite formation.

The researchers used plasma processing to deposit a thin coating on the anode. The process, which takes less than five minutes, uniformly distributes a protective layer of lithium nitride between the anode and the separator. "This artificial layer can stop or limit dendrite growth," he explained.





2



3

1. Doctoral student Ke Chen uses plasma processing to apply a thin coating of lithium metal nitride to the graphite anode. This uniformly deposited protective layer limits the formation of needlelike dendrites and remains stable for 500 hours.

2. The lithium sample is positioned in the tube under a vacuum. Nitrogen gas is released and power applied at various frequencies to apply a protective coating of lithium nitride on the lithium anode.

3. Doctoral student Rajesh Pathak keeps the lithium metal anodes inside the glovebox. He has used radio frequency sputtering to apply ultrathin layers of silicon oxide and graphite to the lithium metal surface.

In addition, this layer results in high ionic conductivity and high mechanical strength. The flower-shaped lithium nitride layer, which fully covers the anode, has a capacity retention of more than 96% after 100 cycles in a full cell with lithium cobalt oxide as the cathode.

"The ions go through faster and improve the chemical performance of the cells," Zhou said. Furthermore, the lithium nitride layer remains stable for 500 hours. Results were published in the February 2019 issue of *Energy Storage Materials*.

#### Developing interfacial layer

Zhou and doctoral student Rajesh Pathak also combined graphite and silicon oxide to make an ultrathin film that

prevents dendrite growth and enhances ion transport. This creates an artificial interfacial layer between the electrolyte and the lithium metal electrode.

The researchers used radio frequency sputtering to apply the graphite and silicon oxide layers to the lithium metal surface. "We use the synergistic effect of these layers," Zhou said. The researchers found a 20-nanometer-thick layer of silicon oxide on top of a 20-nanometer-thick layer of graphite produced the optimum interfacial layer.

The resulting battery cells had higher capacity retention and higher charge/discharge capacity than those with anodes made of lithium metal alone. The study was published in the August 2019 issue of *Advanced Energy Materials*.

Based on this work, Zhou and his team plan to incorporate inorganic nanofibers into the polymer matrix to develop a solid electrolyte that will replace the separator.

"Typically, solid electrolytes have lower conductivity," Zhou explained. However, the nanofibers will create a vast network of channels that will further facilitate ion transport. In addition, the nanofibers are like a binder, reinforcing the polymer to increase the mechanical strength of the solid electrolyte matrix.

Within the next few years, Zhou anticipates these new materials could be used to develop lithium-sulfur batteries, which have three to five times higher energy density than lithium-ion batteries. That greater storage capacity makes them suitable for powering electric cars and storing renewable energy.



# Aerosol modeling helps **trap coronavirus,** deliver medications



1

**E**xperience modeling aerosol sprays to treat chronic sinus problems has helped assistant mechanical engineering professor Saikat Basu secure funding for COVID-19 research. He is part of a multi-institutional team of researchers who will design and develop a mask with a reusable respirator that captures and kills the novel coronavirus.

Basu was the first South Dakota State University faculty member to receive a grant for COVID-19 research through NSF's Rapid Response Research funding mechanism.

To develop the new respirator, Basu will be collaborating with associate professor Sunghwan "Sunny" Jung of Cornell University and associate professor Leonardo Chamorro of the University of Illinois Urbana-Champaign. The project,

which began in May, is supported by a one-year, \$200,000 NSF grant.

Since April 2016, Basu has been modeling aerosol sprays designed to help patients with chronic sinus problems with a research group at the University of North Carolina Chapel Hill Medical School. He began working on the National Institutes of Health project as a postdoctoral researcher and has continued collaborating with the UNC group since coming to SDSU in January 2019.

Basu has published nearly a dozen journal papers on intranasal transport and topical drugs. He is also working on an NIH pilot grant to determine whether adjusting the droplet size can help deposit aerosol medication into the trachea to treat benign tumors in the voice box or larynx.

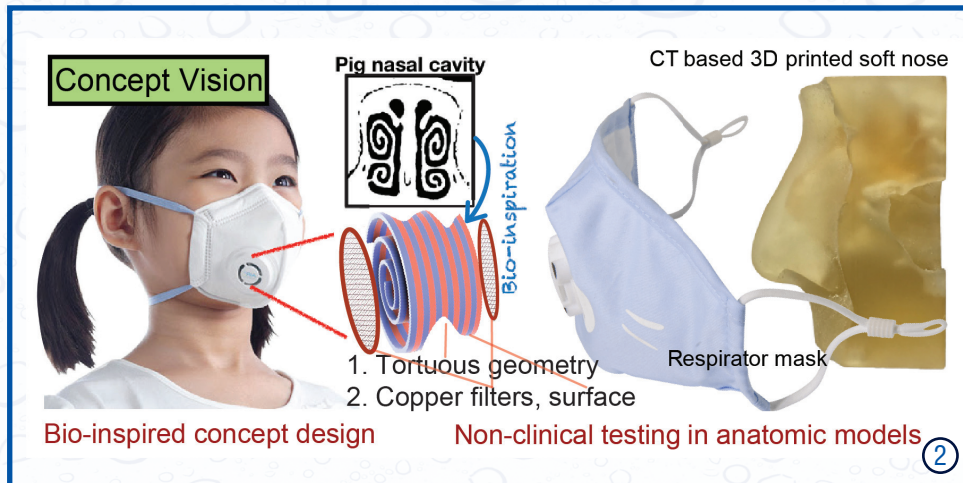
## **Developing virus-killing respirator**

The new respirator will filter the air a wearer breathes, Basu explained. As the wearer breathes, the new respirator will actively capture virus-carrying aerosol droplets and then inactivate them.

In contrast, N95 respirators use passive filters to prevent the wearers from inhaling airborne particles. "They do nothing to kill the virus," he pointed out.

The new respirator will have an internal structure modeled after the complex nasal passages of animals, such as pigs and dogs, which have a very sensitive sense of smell. This unique design will help isolate the droplets and embed them in the respirator. Basu will do 3D modeling of aerosol droplets to figure out the best possible respirator design. One doctoral student will also work on the project.





In addition to its unique structure, the new respirator design will use a combination of copper-based filters and temperature changes to help the droplets adhere to the respirator walls and to kill the virus.

“Both the geometry and a cold temperature on the surface walls will help the droplets condense,” Basu said. The combination of raising the temperature of the walls and the effect of ions generated from copper wires will help inactivate the virus. Recently published studies have supported the use of these two mechanisms on earlier and current strains of coronavirus.

“It takes about 50 minutes to inactivate the virus,” he said. “We envision the respirator will be a removable piece that can be washed each day and then reused.” Once the prototype has been completed, the researchers will collaborate with a biosafety level 3 laboratory to test their design using live virus.

### Optimizing nasal spray delivery

More than 14% of Americans have chronic sinusitis—and those numbers are increasing, according to a July 2019 article on Medscape.com. Treatment for the condition, which involves inflammation of the sinuses, costs an estimated \$3.4 to \$5

billion annually. That treatment includes the use of steroid nasal sprays.

By modeling the distribution of the spray in the sinus cavities, Basu is helping revise the treatment protocol on how to use these topical sprays. To do this, he is working with associate professors Julia S. Kimbell and Dr. Charles Ebert Jr. of the UNC Department of Otolaryngology.

To determine how to get the steroid spray to the affected sinus cavities, the research team uses CT scans from chronic sinusitis patients to build 3D models. Basu then computationally integrates the 3D models into ANSYS software to simulate inhaled airflow and drug transport.

The researchers found the spray nozzle should be inserted 5/8 of an inch into the nostril and be held at a 35- to 45-degree angle. This is a deeper insertion and a steeper angle than the current nasal spray guidelines and will result in an eight- to tenfold greater chance the medicine will reach the desired site, Basu explained. “When more drug reaches those critical areas, the effect should be better.”

The next step will be to recruit patients for clinical trials. To do this, Basu and the UNC researchers will apply for a continuation of the NIH RO1 grant this fall that will include collaboration with Duke University and the University of Wisconsin.



1. Assistant professor Saikat Basu of the Department of Mechanical Engineering uses a speculum to examine the nasal cavities in a flexible model of a human nose. He is using the model to determine how to get a steroid spray to the affected sinus areas. This research may also be useful for development of an intranasal coronavirus vaccine.

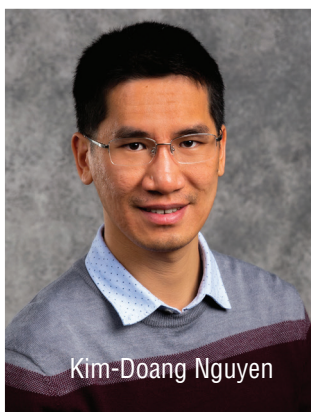
2. The internal structure of a new respirator mask designed to trap and kill coronaviruses will be modeled after the nasal passages of animals that have a sensitive sense of smell. Basu is part of a multi-institutional team that will be designing and developing the new respirator.

3. Basu is using this 3D model, which has the mouth, nose and sinus cavities and throat to the base of the trachea, to figure out how to deposit medication in the laryngeal area to treat benign tumors. The interchangeable cartridges represent how the area changes when tumors are present.





# Robot helps patients perform rehabilitative exercises



Kim-Doang Nguyen

reducing health care costs.

“Structured, repetitive exercises can help activate skeletal muscles and thereby help patients recover functional motor skills,” said Nguyen, noting that back pain is a leading cause

**P**hysical therapy can help those suffering from back and neck pain, but the sessions can be quite expensive.

Mechanical engineering assistant professor Kim-Doang Nguyen is designing a robot that assists patients in performing certain rehabilitative exercises. As a result, the patient will require fewer physical therapy sessions, thus

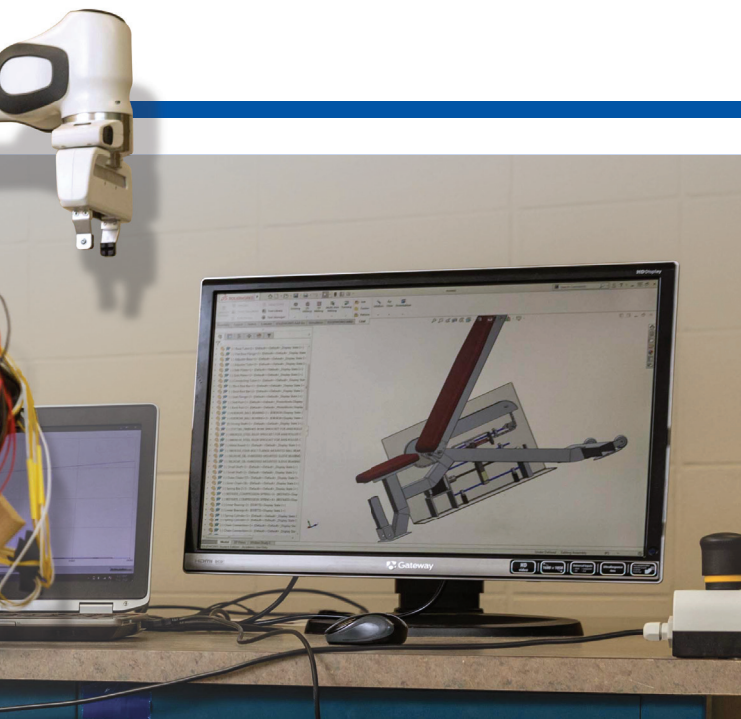
of disability. An estimated 8.4 million Americans experience limitations in their daily living activities due to chronic back pain, according to the U.S. Bone and Joint Initiative. The rehabilitative robot can also be useful for patients recovering from a stroke or a spinal cord injury.

The human user and robot are partners, cooperating to achieve a shared objective—to complete a therapeutic exercise, Nguyen explained. “When a patient performs the movement as expected, the rehabilitator does not intervene. However, when the patient fails to perform the desired movements, the robot adjusts to safely guide the motion of the user.”

Development of the rehabilitation robot and control system is supported by a one-year, \$24,000 grant from the South Dakota Board of Regents and additional funding from the SDSU Research and Scholarship Support Fund. Graduate student ElHussein Shata, who completed his master’s degree in May, also worked on the project.

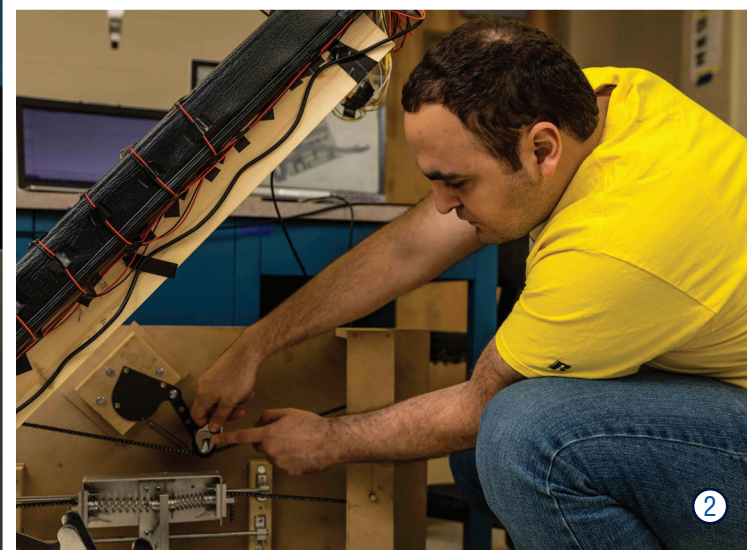
Nguyen spent one year as a postdoctoral fellow in the Centre





1. Doctoral student Praneel Acharya, right, performs a situp with assistance from the rehabilitation robot that master's student ElHussein Shata, left, designed. As he performs the movement, the sensors capture data on the laptop. The screen on the right features the 3D model of the apparatus.

2. Shata adjusts the tension on the chain and sprocket of the rehabilitation robot.



In addition, Nguyen said, “Signal transmission through the robot’s electrical circuits and forces produced by the motors is virtually immediate, while sensing and action in a human body are the results of complicated biomechanical and biochemical processes.” These human processes do not happen immediately—there are time delays in the human control pathway known as neuromotor delays.

The researchers aim to compensate for the effects of these delays in the robot control system. “The control algorithm analyzes the data from the force sensors to make decisions about when and how to assist the patient,” Nguyen explained. For instance, the spring and damper in the elastic joint of the rehabilitation robot can assist the patient through small muscle spasms. If these spasms are large, the robot control system will trigger an emergency stop. Details on their delay-compensation method were published in the July 2020 *Automatica* journal.

for Autonomous Systems at the University of Technology in Sydney, Australia, before coming to SDSU in 2017. He earned his doctorate in 2015 from the University of Illinois at Urbana-Champaign, where he was also a postdoctoral scientist in the Applied Dynamics Lab.

For a previous project, Nguyen developed a wearable sensor device that recorded a patient’s arm movements while doing rehabilitative exercises at home. The low-cost sensing module helped caregivers track a patient’s progress. In the last decade, Nguyen has published or presented more than 30 papers on robotics and control systems.

### Balancing human, mechanical movement

The main challenge in developing a robotic rehabilitator is to make sure that the bio-assistive device interacts safely with the user. “Because of differences between the human musculoskeletal system and a robotic mechanism, the two don’t naturally work together,” he said. A robot is made of rigid links and joints, while the human body has soft, elastic muscles and tendons that move the joints.

### Developing, testing prototype

Shata designed and built a rehabilitation robot prototype that assists the user in performing either a situp or a knee extension. The mechanism, which utilizes a stepper motor and a pair of springs, operates much like the antagonistic muscles that move a human joint. As the user moves through the motions of a situp, for instance, one spring is under compression while the other is in tension.

Part of the testing involved collecting and analyzing data regarding the amount of force needed to assist a human performing a situp. This analysis validated the robot was able to provide enough assistance for the patient to perform the exercise. Eventually, patients will be able to vary the stiffness or resistance as their muscle tone and range of movement improve. The results were recently published in the *International Journal of Control, Automation and Systems*.





Anamika Prasad

# Prasad develops biomaterials using cellulose fibers

**C**ellulose, the organic material that provides plants with their shape and structural integrity, may one day be incorporated into new composite materials.

These bio-based materials can be used to build structural components, such as beams and columns, to make plastic and even to repair damaged bones, according to assistant professor Anamika Prasad of the Department of Mechanical Engineering. Her research focuses on bio-based material design and manufacturing, as well as biological materials for tissue engineering applications.

She is developing the infrastructure to incorporate cellulose nanofibers into structural engineering materials and biomaterials for medical applications.

Cellulose is a natural polymer that is extracted from crop residues, such as corn stalks and leaves as well as wheat, oats and barley straw. While scientists develop more efficient,

economical methods of extracting the cellulose, Prasad and other researchers in the Jerome J. Lohr College of Engineering and the College of Agriculture, Food and Environmental Sciences are determining how to integrate these fibers into new materials.

"We can create value-added products from agricultural biomass," Prasad said. These products have the potential to be degradable in the environment and absorbable in the body.

However, working with biomaterials, such as cellulose, is challenging.

Unlike plastic polymers, "the cellulose fibers cannot be melted and reheated," Prasad explained. To overcome these challenges, Prasad and her team are building the tools they need to work with biomaterials. One doctoral student, a master's student and several undergraduates are also involved in the research.

## Electrospinning fibers

A single-nozzle electrospinning machine costs at least \$20,000, but Prasad built one for \$4,000. She purchased the parts in summer 2017 through new faculty incentive funding from the Surface Engineering Research Center, a state-funded collaboration involving researchers from South Dakota State University, South Dakota School of Mines and Technology and the University of South Dakota. An undergraduate student assembled the electrospinner, completing it in fall 2018.

To produce electrospun fibers, the cellulose must be dissolved in a solution, which is pumped through a syringe at a particular feeding rate. High voltage is then applied to create an electrical field that draws the solution from the syringe tip to a collector plate. The solution dries as it emerges from the tip into aligned nanofibers that accumulate on a vertical surface. These lint-like fibers can be integrated into composite materials.





Students in Prasad's lab have continued to work with and modify the electrospinner, adding a spinner drum as a collector in addition to the vertical plate.

Graduate students Marco Castro and Ruhit Sinha created polyvinyl alcohol and cellulose-based fibers as binders in asphalt construction. Prasad collaborated with assistant professor Rouzbeh Ghabchi in civil and environmental engineering on the one-year North Central Regional Sun Grant Center project.

For his thesis, Sinha, who completed his master's degree in May, used the electrospinner to produce a cellulose-based biomaterial designed to repair bones. Though the material is in the early stages of development, Sinha said, "We got good results." In particular, he developed a technique to adjust the stiffness of the electrospun fiber material.

"Bone has a wide range of mechanical properties, which change based on the bone's location and the patient's age, for instance," Sinha explained. "We can tune the stiffness based on those needs."

In many instances, bone cement is used to repair damaged bones and secure joint implants; however, Prasad pointed out, "that material is passive—it sits there and does not encourage cell growth."

A matrix that includes cellulose fibers could be a better option because the fibers are "similar to what is inside our bodies. It's a bioactive material that encourages cells to grow and will allow bone to heal in the long term." That is important when treating younger patients whose bones are still growing.

As part of Prasad's Mechanical Behavior of Biomaterials course, senior Zachary Dorn of Litchfield, Minnesota, is working on a material that combines fiberglass resin and cellulose fibers to create a lightweight material to replace plaster casts. Dorn, who is minoring in biomedical engineering, will continue his work this fall "to get more conclusive, verifiable results."

### Using cellulose for 3D printing

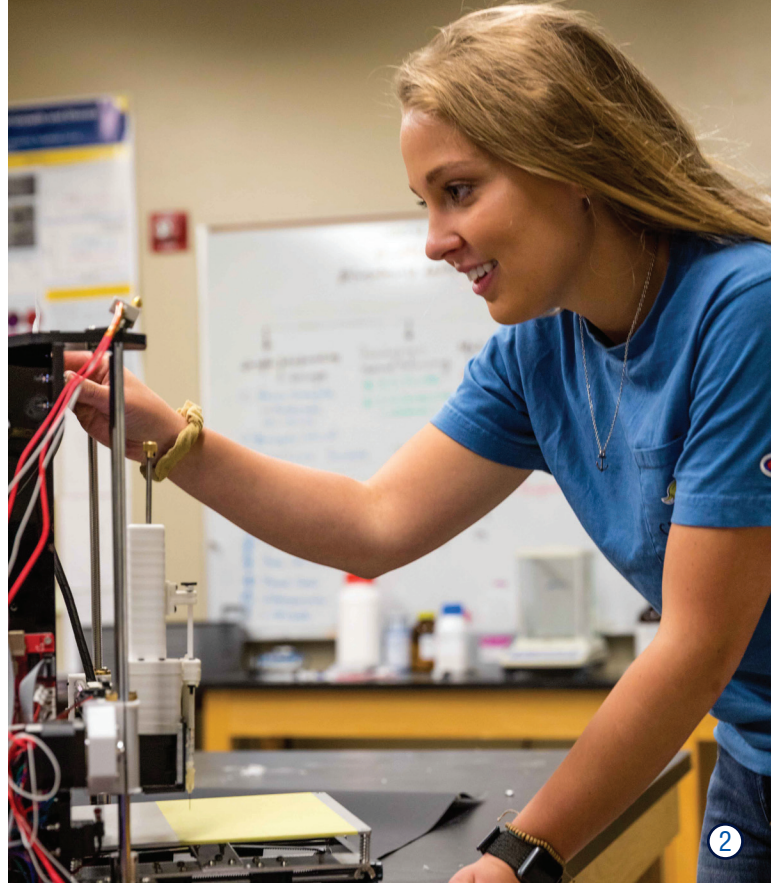
In traditional 3D printing, plastic is melted and shaped to create the filament. "That will not work for cellulose and a whole host of bio-based materials," Prasad said. This spring, as part of the biomaterials class, Katelyn Hillson used a do-it-yourself kit to build a 3D bioprinter for only \$500.

"This is a new challenge," Prasad said, noting that a commercial 3D bioprinter costs anywhere from \$20,000 for a basic unit to more than \$100,000.

Hillson, a senior from Austin, Minnesota, became interested in biomaterials and biomedical engineering when she learned about 3D printing of organs in an ethics class. She modified the 3D printer's extruding mechanism, replacing it with a syringe that can handle hydrogels and other biomaterials.

Once the students are back on campus, Prasad plans to improve the newly developed bioprinter, adding more sensors to increase its functionality and efficiency. Two student teams will modify the current bioprinter, build another bioprinter and use these units along with the electrospinner. The hands-on biomedical experience is supported by a \$10,000 NASA Project Innovation Grant, which Prasad and associate professor Stephen Gent secured.

"The students are learning manufacturing skills by making these devices, which will allow them to work with a range of bio-based materials," Prasad said.



1. The fiberglass resin in senior Zachary Dorn's hands forms the basis for a lightweight composite material. In the specimen on the table, left, he has combined the fiberglass resin and cellulose fibers to form the composite material. The white material in front of him is composed of cellulose nanofibers.

2. Senior Katelyn Hillson of Austin, Minnesota, examines the 3D bioprinter she built from a do-it-yourself kit. She replaced the extrusion mechanism with a syringe that can handle hydrogels and other biomaterials.

3. Graduate student Ruhit Sinha loosens the electrospun fibers from the vertical collector plate.





## Study examines **degradation of plant-based plastics**

**P**lastics made from fermented plant starch, known as polylactic acid, have been touted as an eco-friendly, biodegradable alternative to petroleum-based plastics. However, researchers are just beginning to determine their impact on the environment.

“PLA plastic is degradable only under very specific conditions, which are not necessarily ones we find in the general environment,” explained professor Suzette Burckhard of the Department of Civil and Environmental Engineering. Degradation should take place at an industrial composting facility where the waste can be heated to 140 degrees Fahrenheit. “It can be composted but needs elevated temperatures,” she noted.

Burckhard examined the extent to which PLA plastic degrades in soil and water through funding from the North Central Regional Sun Grant Center. Starch from corn, sugar beets, sugar cane and wheat can be used to make PLA, which is used in 3D printing material, shopping bags, transparent cups and other packaging materials.

The study showed that elements from the plastic were leaching into the water and soil, but only had a minimal short-

term impact on the environment. “PLA plastic does degrade or, in some manner, dissolve in water, but at the end of the 30-day batch experiments there were still plastic pieces similar to what we started with,” Burckhard said.

### Testing microplastics

For the project, the researchers immersed tiny pieces of PLA plastic, known as microplastics, in lake water from the Dakota Nature Park, sludge from the Brookings Wastewater Treatment Plant, and soil from SDSU-owned farms. Postdoctoral research associate Sepideh Sadeghi also worked on the project.

The researchers tested three microplastics sizes—2.36 millimeter, which is about the width of a spaghetti strand; 2 mm; and 1.18 mm, about the size of a pinhead—at temperatures ranging from 68 to 140 degrees Fahrenheit.





### Interacting with water, soil

As the PLA plastic degrades, the long-chain carbon polymer comes off in fragments, Burckhard explained. “It’s like a set of Legos. You put the pieces together in a long chain. When it comes apart, it is not just a single piece, but different lengths of carbon chains.”

Though dissolved organic carbon levels increased during the first week, the microorganisms in the water and soil consumed the carbon. This led to dissolved organic carbon levels decreasing as much as 80% after four weeks. Furthermore, the microbes were most efficient at doing so at the lowest temperature.

This is good news when it comes to PLA’s impact on wastewater treatment plants, Burckhard said. However, the same microbes that consume the carbon in lake water may also be using oxygen fish and other organisms need to survive.

Overall, PLA leaching led to a more acidic environment in the surface water; however, after four weeks, the pH returned to a normal level.

Conductivity increased for all microplastics sizes, but was highest for the smallest microplastics. As the temperature increased, the conductivity also increased.

“Conductivity is a measurement of electrical activity,” Burckhard explained.

“Measuring how much current a solution can carry indicates the concentration of ions in a solution and that gives us an idea of how many other constituents in the water could actively be participating in chemical reactions.”

In addition, the amount of plastic remaining after the experiments



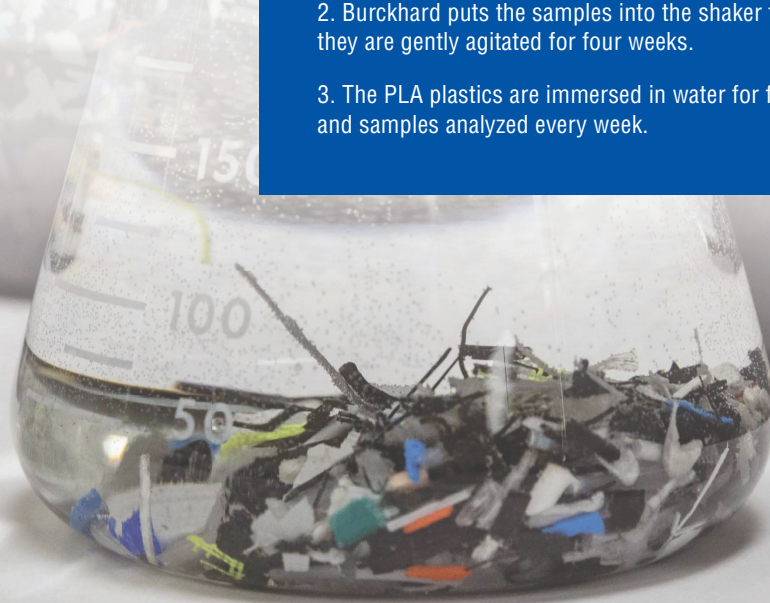
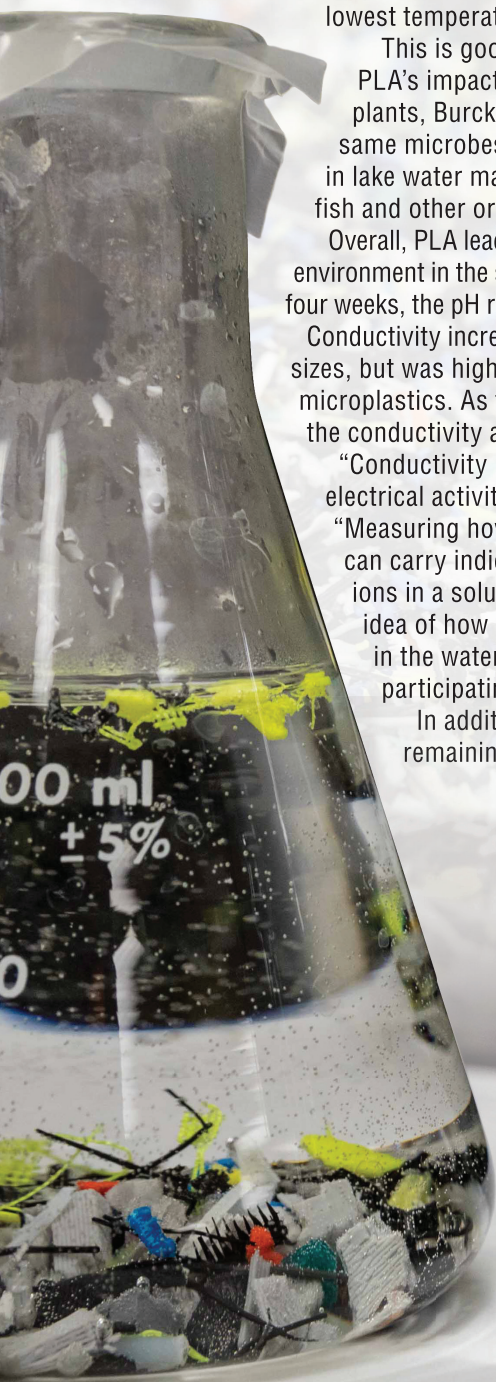
raised concerns. “We assumed the smaller microplastics would dissolve more quickly, but that is not necessarily true,” Burckhard said. Surprisingly, the smaller pieces did not break down as much as the larger pieces.

“These tiny plastic pieces act like a sponge, absorbing and transporting both nutrients and contaminants in water and soil,” she explained. These findings will be used to apply for federal funding to help determine the long-term environmental impact of PLA plastic.

1. Professor Suzette Burckhard prepares samples with which she will determine the extent to which polylactic acid plastic degrades in water.

2. Burckhard puts the samples into the shaker table, on which they are gently agitated for four weeks.

3. The PLA plastics are immersed in water for four weeks and samples analyzed every week.







## Underwater drone expands water quality testing capabilities

**A**n underwater drone that can measure multiple water quality parameters across a water body is increasing research capabilities at the South Dakota Water Resources Institute. However, the sampling capabilities are not what make it unique.

“What’s new is the ability to revisit a specific place multiple times over a season,” explained assistant professor Aaron Franzen. His research in the Department of Agricultural and Biosystems Engineering focuses on emerging precision agriculture technologies, including drones, electronics, diagnostics and control systems.

Undergraduate student Alex Masloski, who is from Blaine, Minnesota, built and tested the drone last summer under Franzen’s supervision. The drone, which will be used for education, research and outreach, was built through department funding.

Franzen and Masloski equipped the remotely operated underwater vehicle with a 3D locator that allows the researchers to create a 3D map of water quality parameters.

“Normally, sensors are suspended in one place in the water, and left over a long period of time to collect data in a single location,” Franzen explained. Using this new technology, researchers can “plan a path and then repeat it, taking repeated measurements at the same spots along the path, weekly, biweekly or whatever is necessary.”

The 50-pound drone is about the size of a 2-foot cube, has eight thrusters and operates on a tether that is a little less than a quarter-mile long. The 3D locator is necessary because “GPS does not work underwater,” Franzen explained. The locator uses ultrasonic technology via a beacon on the drone and four receivers on the surface of the water connected to GPS. This then provides a historical record of where the drone was when it collected each measurement.

“This greatly increases our capacity to do water quality research in both time and space,” said Franzen, who is seeking to partner with engineering firms and state agencies to utilize this new technology.





Aaron Franzen

### Combining drone with sensors

To begin exploring the drone's research potential, Rachel McDaniel, then an assistant professor in the Department of Agricultural and Biosystems Engineering, purchased an array of sensors to gather parameters, such as oxygen, chlorophyll-a, nitrate, phosphate, pH, temperature and salinity. In addition, the drone has a gripper that allows

researchers to take vegetation and soil samples.

Once on-campus research work resumes, the sensor array will be mounted on the drone. In addition, Franzen explained, "All control signals, telemetry from the drone and sensor readings will eventually be transmitted through the same tether cable to the top-side computer." This portion of the work was also supported by department funding.

Last summer, the researchers deployed the sensor array and the drone separately as part of preliminary testing for a research project to gather 3D water quality data at Lake Mitchell, which has experienced challenges with algal blooms for decades. The project's long-term goal is to develop a model to predict level of risk for algal blooms in eastern South Dakota lakes two weeks in advance.

Assistant professor John McMaine, SDSU Extension water management engineer, is coordinating the project, which was begun by McDaniel. She will continue working on the project as an adjunct faculty member. The research is funded by the U.S. Geological Survey 104B Small Grants Program administered through the Water Resources Institute. One master's student and one doctoral student are also working on the project.

The technology's 3D capabilities will empower researchers to use geographic coordinates to track the exact position—vertically and horizontally—at which measurements are taken in the lake.

"We can have it automatically take a sample every couple of seconds to get really detailed

measurements," McDaniel said. Those geographic coordinates will allow the researchers to compare the Lake Mitchell surface data to those recorded by remote sensors.

### Developing a risk model

The South Dakota Department of Environment and Natural Resources reports chlorophyll-a, one of the primary indicators used to determine algal bloom intensity, is the second-most prevalent stressor in lake water bodies.

"Early prediction of algal bloom risk can provide critical information that has the potential to help water resource managers at state and federal agencies develop policies aimed at mitigating future occurrences of this hazard," explained doctoral student Kevin Brandt, who is also SDSU's director of research computing. He is in the early stages of developing an algal bloom risk prediction model based on a machine learning technique called deep learning using chlorophyll-a as a measure of algal bloom intensity.

"The deep-learning training algorithm is iterative, improving the accuracy of the prediction model with each pass by calculating errors and adjusting the connector weights until the prediction model reaches an acceptable margin of error," he noted.

Brandt plans to integrate 30 years of data into the deep-learning model training process. "I'm using an extensive amount of historical data to train the prediction model," he said. Data for this study has been collected from the underwater drone, the city of Mitchell, Mesonet at SDState, the U.S. Geological Survey and the National Water Quality Monitoring Council database.

In addition to chlorophyll-a concentrations, Brandt's work will incorporate other potential influencers of algal bloom growth, such as nutrient load, pH, salinity, temperature and oxygen in the lake water, air temperature, wind, rainfall event amounts and intensity, land use and topography. Once completed, the prediction model will classify algal bloom risk as high, medium and low for 19 lakes in eastern South Dakota, providing an essential tool for water resource management.



1. Senior Alex Masloski tests the underwater drone at the Dakota Nature Park. In summer 2019, Masloski built the drone and wrote an operator's manual under the direction of assistant professor Aaron Franzen.

2. The remotely operated underwater vehicle gives researchers the ability to create a 3D map of water quality parameters and revisit those specific locations multiple times.



# Statistician assesses agricultural data to **increase productivity**

**N**ew precision agriculture technologies generate a wealth of data that can help farmers make decisions that will improve their bottom line—and protect the environment.

However, the challenge is how to efficiently and accurately assess the variables affecting yield and thereby help researchers and producers pinpoint ways to increase productivity. That's where assistant professor Hossein Moradi of the Department of Mathematics and Statistics can offer valuable insight.

"Remote and onsite sensing technologies, such as satellite imagery and yield monitors, generate a wealth of data even for a single field," Moradi said. That data can be used to assess the effect variables, such as soil chemistry, topography and application of fungicides, herbicides and fertilizers, have on crop yield. "By estimating the effect of the variables, we can help farmers make more informed management decisions."

Moradi, who specializes in high-dimensional datasets correlated over space and time, came to South Dakota State University in August 2018 after completing his doctorate in system modeling and analysis at Virginia Commonwealth University. He also did postdoctoral work for the National Science Foundation-funded Statistical Methods for Atmospheric and Oceanic Sciences program through North Carolina State University and then VCU.

In 2018, Moradi began collaborating with Distinguished Professors Doug Malo, now retired, and David Clay of SDSU's Department of Agronomy, Horticulture and Plant Science. The soil scientists were modeling soil organic carbon in different corn and soybean fields using geospatial satellite images and soil samples from different farms. This then led to further collaborative research.

Precision agriculture research involves "statistical questions that I'm interested in," Moradi said. "As a statistician, I can help develop models that test their hypotheses," but the scientists must first explain what data they are using and what they want to do.

One doctoral student and one master's student are working with remote sensing and onsite agricultural data. Their work is supported by U.S. Department of Agriculture Hatch Act funding through the South Dakota Agricultural Experiment Station and the Department of Agronomy, Horticulture and Plant Science.

"Our collaboration with Dr. Moradi and other statisticians results in more expedient processing of large amounts of data and helps us train individuals to interpret data from digital agriculture," said professor David Wright, head of the Department of Agronomy, Horticulture and Plant Science.



1. To predict corn yield for a specific field, like the one pictured here, assistant professor Hossein Moradi and graduate student Shahrukh Khan are developing statistical models that combine data from Landsat 7 satellite images with climate data and 13 other indices, including soil characteristics.



## Evaluating effectiveness of fungicides

"We collect data from the field and store it in the computer," said lecturer Jiyul Chang, whose specialty in the Department of Agronomy, Horticulture and Plant Science is geospatial analysis of field variation and crop mapping using geographic information systems, including satellite and drone images. The satellite images can be combined with multiple years of yield data. "We give all that information to the statisticians and they make a program to automate the data analysis," Chang said.

"Big data analyses are time-consuming," said research associate Deepak Joshi, who captures field data to monitor white mold in soybean fields. The data he gathers helps determine the appropriate time to apply fungicide, test different products and subsequently evaluate their effectiveness.

Recently, Moradi and doctoral student Paul May developed an efficient means of analyzing data from a white mold study involving two fungicides. "Our job was to determine the impact of each fungicide and if that impact is statistically significant or not," Moradi explained. To do this, the researchers developed a model that "uses indicator variables for places where each fungicide was and was not applied."

The commonly used ordinary least square method requires a minimal amount of processing time, but it has a high margin of error. The maximum likelihood estimate, or MLE, approach that uses 50,000 data points could require 60 to 70 gigabytes of RAM and two hours of high-performance computing time. "Farmers do not have access to this type of computing power," Moradi noted.

"Our method takes only 10 to 15 minutes of computing time



Hossein Moradi

and the margin of error is nearly the same as the MLE approach," Moradi said. In addition, the analysis requires less than 2 gigabytes of RAM so the program can be run on a workstation or laptop computer.

## Predicting corn yield

Master's student Shahrulkh Khan is using satellite images from Landsat 7 to predict corn yield on a specific farm. To do this, the researchers developed

a deep-learning model that selects features from the Landsat data and combines them with 13 other indices as well as climate data to predict crop yield. Thus far, Moradi said, "we have enough evidence that our model outperforms some other traditional approaches, such as OLS and GLS (generalized least squares)."

Moradi's long-term goal is to launch a website that allows farmers to have a fast, accurate prediction of their expected crop yield using the field locations/coordinates and the last five years of crop yield data. The built-in statistical programming package in the website would then pull historical information about weather, precipitation and temperature and combine that with satellite images, such as those from Landsat, as well as the fields' soil characteristics.

The output would "tell the farmer a couple of months in advance to expect this much product out of the field," he said.

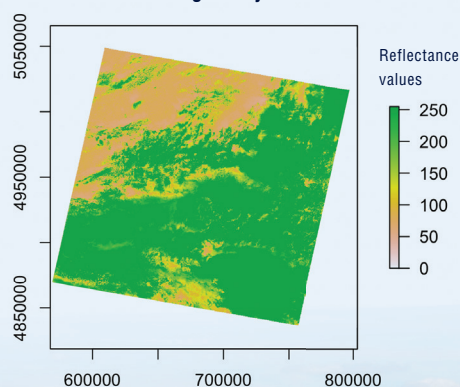
2. This Landsat 7 image shows the reflectance values in the bar, on the right, from one of the eight spectral bands which are being using to help predict corn yield in a specific field. The field's coordinates are on the x and y axes and the colors on the bar are the reflectance values.

3. This map shows soybean yields ranging from 70 to 30 bushels per acre (bar on right) across an 800-by-800-meter, or approximately 160-acre, field. The yield data is used to evaluate how effective two fungicides have been at reducing losses due to white mold.

4. This field of soybeans shows signs of damage from white mold, a fungal disease that develops when high humidity and moisture are combined with warm temperatures. Moradi and doctoral student Paul May of Vermillion developed an efficient means of analyzing data from a white mold study involving two fungicides.

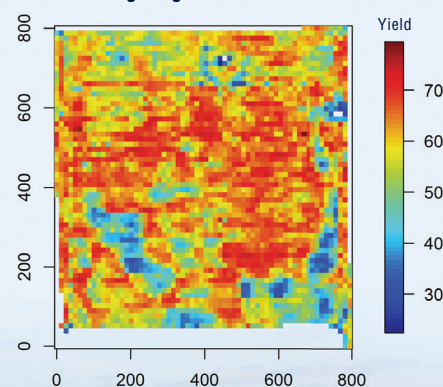
②

Predicting corn yield



③

Tracking fungicide effectiveness



④





# AWARDS

## Engineering researchers receive college, university awards



**Christopher Saunders**  
Associate Professor  
Department of Mathematics  
and Statistics

### Saunders named college's Outstanding Researcher

Using statistical probability to interpret crime scene evidence has garnered associate professor Christopher Saunders of the Department of Mathematics and Statistics the Outstanding Researcher Award for the Jerome J. Lohr College of Engineering.

While completing his doctorate in statistics at the University of Kentucky in 2006, under the direction of associate professor Constance L. Wood, Saunders was recruited to support the FBI and broader intelligence community as an Intelligence Community Postdoctoral Research Fellow in pattern recognition and forensic source identification problems related to handwriting.

Saunders then spent the next two years at George Mason University being trained in machine learning, statistical pattern recognition and the interpretation of forensic evidence under the tutelage of professor Donald Gantz, now retired, of the Department of Information Sciences and Technology; Kathryn B. Taylor, now retired, of the Office of the Chief Scientist, Intelligence Community Post-doctoral Research Program; and JoAnn Buscaglia, research chemist at the FBI Laboratory.

"These excellent mentors helped me discover how statistics can be applied to topics within the forensic field, and I want to thank them for putting me on this research path," Saunders said.

After the fellowship ended, Saunders continued as an assistant research professor in the document forensics lab at George Mason and Lead Signal Processing Engineer at The MITRE Corporation until coming to South Dakota State in 2012.

Saunders collaborates with forensic research scientists to develop ways to quantify impression, pattern and trace evidence with the majority of his funding for basic research coming from the National Institute of Justice and Oak Ridge Institute for Science and Education. Recently, he received a subaward in support of two projects at the Massachusetts Institute of Technology's Lincoln Laboratory related to developing methods of using residue from an explosion to trace where the components were manufactured and the quantification of touch DNA samples.





**Todd Letcher**  
Associate Professor  
Department of Mechanical  
Engineering

## Letcher receives Young Investigator Award

Graduate and undergraduate students have the opportunity to explore the virtually limitless applications of 3D printing, thanks to the work of assistant professor Todd Letcher. For developing additive manufacturing as a research area in the Department of Mechanical Engineering, Letcher received the Jerome J. Lohr College of Engineering's Young Investigator Award.

Letcher came to SDSU in 2012 after completing his doctorate at The Ohio State University, where his research focused on materials characterization and the mechanical behavior of materials related to fatigue. After a one-year stint as a postdoctoral researcher for the Materials Evaluation and Testing Laboratory, Letcher was a lecturer for a year before becoming an assistant professor in fall 2014. He was recently promoted to associate professor and granted tenure.

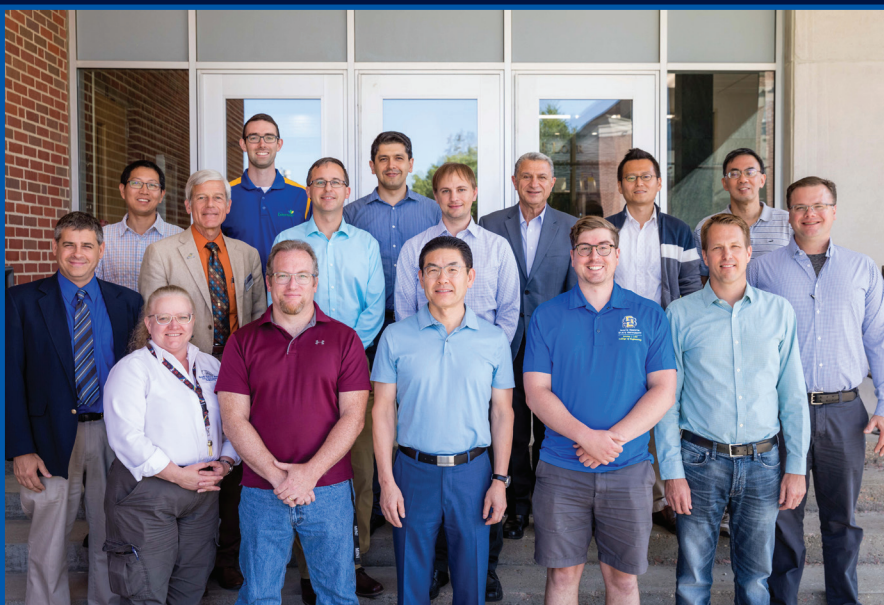
He purchased his first 3D printer in early 2014 through support from the university's

Scholarly Excellence Fund. That purchase has blossomed into an entire laboratory filled with 3D printers and an adjoining room in which his students can fabricate their own filament.

Though he explored 3D printing for biomedical applications, Letcher's research now focuses largely on in-space applications. Two years ago, a team of graduate and undergraduate students built a 3D printer that stands 10 feet tall and operates on a 14-by-21-foot base as part of NASA's 3D-Printed Habitat Challenge. The goal was to design and build shelters for astronauts on Mars.

Through a NASA grant, another senior design team developed and tested innovative materials to use for 3D printing at the International Space Station. The team published a paper in the September 2019 Journal of Composites Science about using basalt, which can be mined on Mars, as one of the components in the feedstock for in-space manufacturing applications.

## Grantwinship Awards



Faculty members in the Jerome J. Lohr College of Engineering who secured or had research expenditures of \$100,000 or more during the 2019 fiscal year are—front row, from left, Chris Schmit, Suzette Burckhard, Larry Leigh, Sung Shin, Tim Hansen, Jeffrey Doom and Stephen Gent; middle row, Rich Reid, Greg Michna and Todd Letcher; back row, Qiuan Qiao, John McMaine, Rouzbeh Ghabchi, Nadim Wehbe, Junwon Seo and Francis Ting. Not pictured are Greg Derynck, Xijin Ge, Dennis Helder, Cedric Neumann, Chris Saunders, Mostafa Tazarv, Reinaldo Tonkoski and Greg Vavra.





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