ENGINEERING **RESEARCH** REVIEW 2021

South Dakota State University

Office of Engineering Research

Dear colleagues and friends,

I arrived at SDSU during interesting times—uncertain what the future would hold, but certain, in the abilities and talents of this college and its people. A year has passed and as the clouds recede, I stand with greater conviction that our college can soar higher.

I believe in the power of teams, of true collaboration and developing a shared vision—crafted with passion and purpose to propel our college into the future. The stories you're about to read only mark the beginning of such a vision, a coming together of talent aimed at solving some of the grandest, challenging and defining issues of our times spanning energy, control, sensing, automation, materials, bioinformatics and infrastructure. There are formidable intellectual challenges in these areas that can be surmounted only through genuine collaborative efforts. As we advance, I will continue these efforts and strive for deeper and intentional intersections, both within the college and across campus.

Thanks to your efforts and hard work, we closed FY21 just shy of $6M in awards. With the institutional vision of Imagine 2023, there is a greater calling for our college to achieve higher, develop a stronger identity and rise in stature nationally. As we open a new year, I'm ready to make strategic investments to grow our doctoral programs, catalyze ongoing efforts and cultivate a vibrant culture of scholarship to fuel our growth. I'm confident that if we can work collectively, aided with modest resources and unfettered by some of our self-imposed assumptions, we can not only meet, but surpass our goals.

Yes, the recent past will remain seared in our collective conscience for years to come, but if anything it has taught us the power of resilience. So, colleagues, much like our mascot, the Jackrabbit, let's surge ahead with renewed optimism and grit, with greater energy and persistence to herald a new chapter for our college.

Rajesh Kavasseri, Ph.D.
Associate Dean for Research

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About the cover

The PowerJacks research group in the Department of Electrical Engineering and Computer Science seeks to maintain the reliability and stability of the electric grid while integrating renewable energy into the mix. (See stories on pages 3-8.)

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1,000 copies | Printed on recycled paper | Office of Engineering Research | $1.90 each | EG056 | 07/21

Kavasseri **launches** new **research initiatives**

When Rajesh Kavasseri became the associate dean for research last summer, he went on a "discover SDSU" campaign to become familiar with what faculty researchers were doing.


Rajesh Kavasseri

"We've got one mouth and two ears, so we need to listen twice as much as we talk," Kavasseri said, with a smile. His goal is to grow research, measured both in external funding and in academic prestige, and to help the college expand its economic development activities.

Through that fact-finding mission, he discovered what he calls "pockets of excellence that have great potential and are nearly maxed out to capacity within SDSU." Then he set out to determine how to intersect those pockets.

"The very nature of academic research is to delve deeply into problems within a focused area. That depth can make you forget about other possibilities. My job is to give things a slight tilt, to shift those vantage points," said Kavasseri.

"These intentional intersections lead to synergies through which the net effect exceeds what these pockets could do by themselves. Those sort of gains are what I want to set in motion in the college and for SDSU as an institution," Kavasseri said.

Forming collaborative groups

To create those synergies, Kavasseri is forming research groups. The first three—PowerJacks, sustainable and resilient civil infrastructure/SARCI and control automation and navigation/CAN—were organized during the 2020-2021 academic year (see stories on pages 3-8 and 10-13). He plans to form three more groups—applied materials and sensors/AMS, advanced technologies for modeling and simulation/ATOMS and precision/digital agriculture—in the coming year.

The increasing complexity of the problems engineers are tackling demand collaborative and multidimensional solutions. "These research groups are coming together purposefully in a way that amplifies their research capabilities to meet the needs of sponsors external to SDSU and to address research needs in the state, region and nation," Kavasseri said.

He also wants to build similar collaborative groups among universities, research groups and corporations along the I-29 corridor. Many of these entities are engaged in exciting areas, such as precision agriculture, energy and cybersecurity, Kavasseri explained. "If we can bring these groups and talent pools together, we can integrate them into an ecosystem that can be far more effective than individuals sitting in their offices trying to solve problems by themselves."

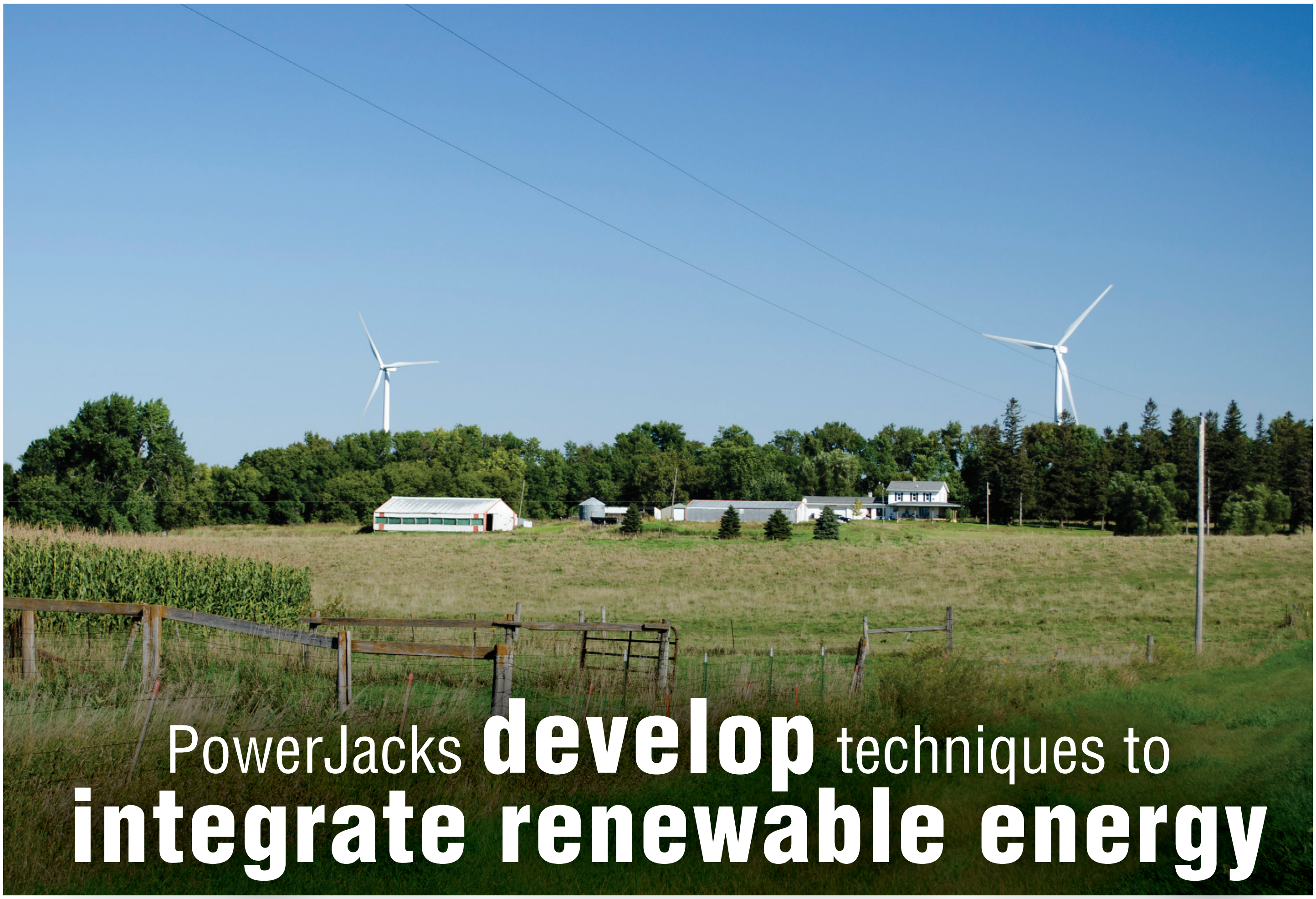
Bringing technologies to market

Another Kavasseri initiative, Imagine SD, seeks to catalyze the formation of startup companies and commercialize university-developed technologies. "Once we develop these innovative technologies, we need to take them to the market. That's not an easy job," he said. Kavasseri sees the need for a concerted effort from the universities to form these groups and start new companies in partnership with the Research Park at South Dakota State University, which seeks to develop and attract technology companies aligned with the talent and sponsored research conducted at SDSU.

To help students and faculty teams interested in commercialization, Kavasseri has assembled an Entrepreneurial Advisory Board to evaluate their ideas and provide feedback and direction in organizing that effort. He is bringing seasoned entrepreneurs together with engineering faculty interested in launching companies in the Research Park.

"Not everyone should be doing this," he cautioned. "It's only for those who have an innovation that serves an unmet market need."

Kavasseri hopes to have EAB members shepherding startup companies and even serving as CEOs or directors to help launch those enterprises at the Research Park. "Through these efforts, we can fuel economic development," he concluded.



PowerJacks **develop** techniques to **integrate renewable energy**

When we flip a light switch or plug in an appliance, we take for granted the electricity that powers these devices will be there—that's how reliable our electrical power grid has become. The PowerJacks research group seeks to maintain the reliability and stability of the electric grid while integrating renewable energy into the mix.

"We are a group of experts in different areas related to electric power systems," said professor Sid Suryanarayanan, head of the Department of Electrical Engineering and Computer Science. He uses his experience in systems engineering to manage energy within the power grid.

"Energy management is the coordinated performance of different assets in the electricity grid to deliver a certain kind of service," he explained. This includes everything from the high-voltage transmission lines to the utility companies and their customers.

Associate professor Reinaldo Tonkoski, the Harold C. Hohbach Endowed Professor in Electrical Engineering, develops novel ways of integrating renewable energy generated by wind turbines and solar panels into the electric grid. In particular, Tonkoski, who is the PowerJacks group coordinator, works with microgrids, which are self-contained local power systems that can disconnect from the larger grid and operate autonomously.

"My area is power electronic systems and controls. I make sure the system is stable and the controls work properly," Tonkoski explained. "Control decisions must occur in milliseconds, so I work with fast dynamics."

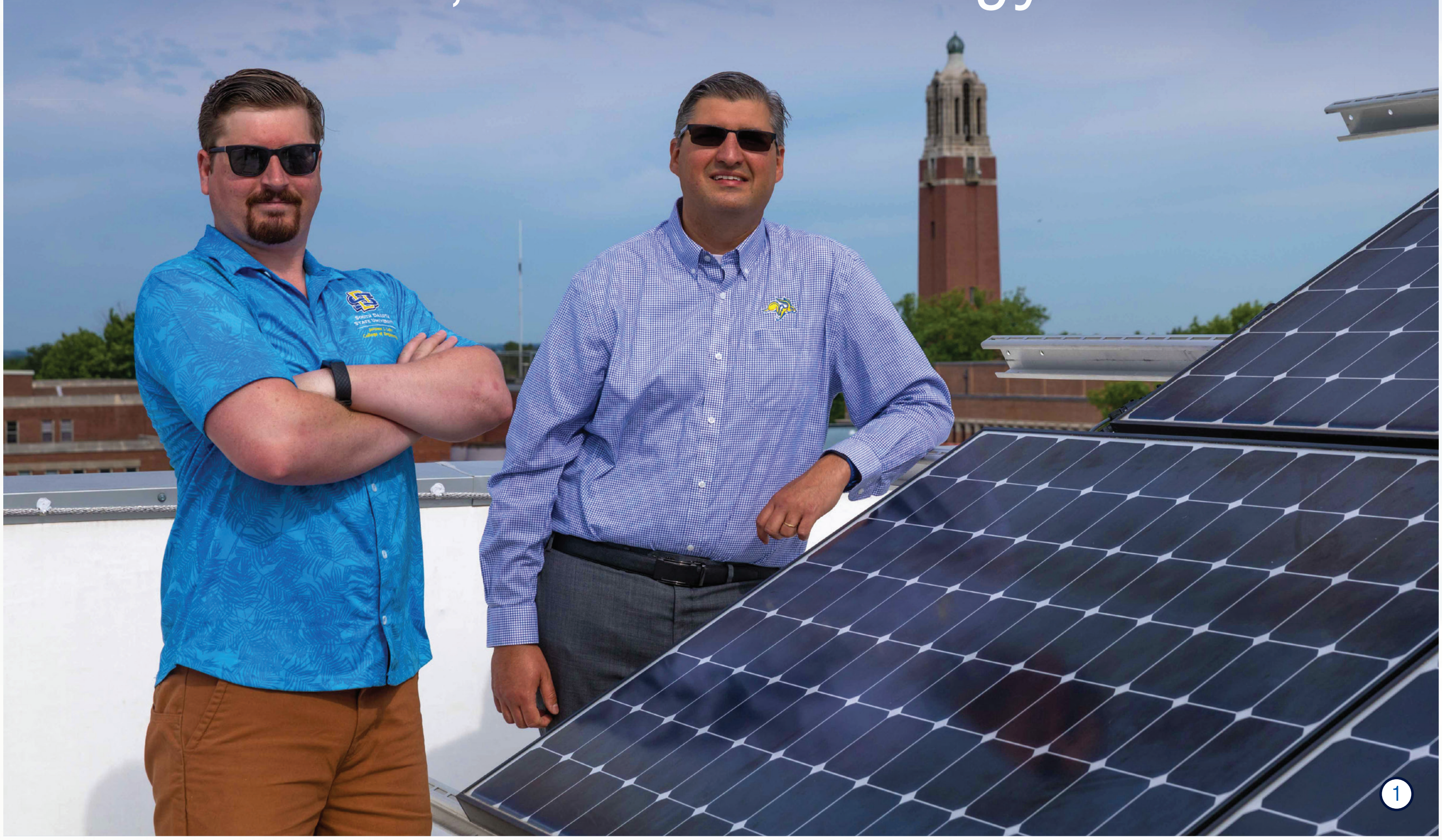
Associate professor Tim Hansen specializes in computer and data applications for power systems. He uses SDSU's high-performance computing cluster to "solve power system problems efficiently and quickly that were previously unsolvable because the computational resources were not adequate."

Hansen develops computer algorithms to determine how offering incentives for users to shift low-priority activities to nonpeak times can save energy for utility companies and consumers. For a U.S. Department of Energy Established Program to Simulate Competitive Research project, Tonkoski and Hansen developed a data-driven model to help integrate renewable energy into power grids.

"Our group is involved with creating cost-effective, sustainable ways to power your homes and to power the future of America and the world," Hansen said.

In addition, Suryanarayanan said, "We are bringing this research into our classrooms, so students gain not only traditional textbook knowledge, but also learn about fresh new topics that are coming out of research."

Data-driven model helps mix renewable, traditional energy sources



Two PowerJacks researchers are developing statistical models that will help orchestrate the integration of renewable energy into the electricity grid.

Associate professors Reinaldo Tonkoski and Tim Hansen have developed a data-driven model to determine the output of inverter-based renewable energy sources, such as wind turbines and solar panels, and subsequently a control system that helps them "play well" when mixing with traditional power sources.

For the U.S. Department of Energy project, Tonkoski and Hansen are collaborating with researchers from the University of Alaska Fairbanks and the University of Puerto Rico Mayagüez. Their objective is to ensure voltage and frequency stability in the grid while utilizing more environmentally friendly energy sources.

The project, which began in fall 2019, is supported by a two-year, $3 million Established Program to Simulate Competitive Research Implementation Grant. The EPSCoR project supports the DOE's mission of ensuring America's security by addressing its energy challenges. It also helps improve the host institutions' research capabilities, thereby increasing their ability to compete for federal funding.

This spring, the multi-institutional team applied for Phase 2 funding to continue testing the data-driven models. Five doctoral students also worked on the project at SDSU. Much of the data used to develop the model came from the Alaska grid and the Alaska Center for Energy and Power, which combines traditional and nontraditional energy sources.

Challenges integrating renewable energy

In general, things happen very quickly in the electrical network, Hansen explained. "When you turn on a light or plug in your cellphone, the power has to be generated at the same time that it is used." Although energy storage systems are improving, they are too small yet to make a significant difference.

Electricity generation and demand must be equal at all times to maintain a frequency of 60 hertz, meaning the signal oscillates 60 times per second. "It's pretty much always at exactly 60 Hertz," Hansen said.

Traditional generators, such as steam turbines and hydroelectric plants, produce electricity using a spinning mass and therefore resist a change in frequency due to rotational inertia. “If you have large changes in the demand for electricity, known as the load, this rotating mass will not let the frequency dip too low,” Hansen said. Furthermore, these traditional energy sources are connected directly to the power grid through transformers—those green boxes along streets and roadways.

Energy generated by solar panels and wind turbines is variable by nature and interfaces to the grid using power electronic inverters. “It’s a bunch of switches turning on and off very quickly using a given control strategy to turn direct current into alternating current at the 60 hertz wavelength,” Hansen explained. However, this power electronic interface decouples the energy from the power grid, thus leading to changes in system dynamics.

Controlling frequency, voltage

“When it comes to controlling frequency and voltage, we need to organize the time constants of the system so all of these energy sources play well together to deliver good power quality reliably,” Tonkoski said. He compared controlling the flow of power to conducting an orchestra.

“Frequency is like the beat of the music that keeps everybody synched, while voltage is the intensity with which each instrument is played,” he explained. Each musician must play the correct notes at the same tempo with the required dynamics to make beautiful music.

“Each generation source has a different response time,” Tonkoski continued. Traditional generation methods, such as coal or gas, maintain a steady beat with only slight variations in intensity, while solar and wind can respond very quickly. Therefore, “the decision-making or switching within the control system must occur in milliseconds,” he said.

When responding to major events, such as an earthquake or hurricane, which cause large deviations in system frequency, inverter-based energy sources are advantageous because their power output can change near-instantaneously, Hansen explained. They can help maintain stability and prevent systemwide blackouts.

Developing data-driven model

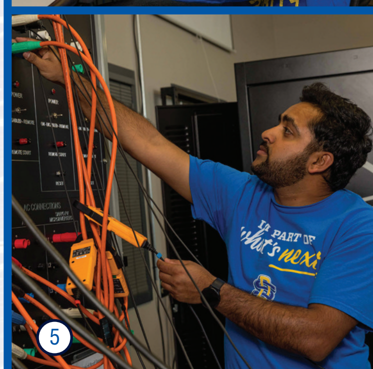
Power systems engineers are experienced at modeling power systems with traditional electricity sources. “This dynamic is well known,” Hansen explained.

However, that is not the case for inverter-based resources. Each company develops its own inverters, but the details about the switching mechanisms, or algorithms, are proprietary, Hansen explained. Consequently, the researchers must model “how that box responds to the power grid without knowing what’s inside.”

To overcome that challenge, the SDSU researchers developed a data-driven model that essentially measures what is coming out of the box. “We used the data response within that model as opposed to a detailed inverter model,” Hansen said. For each inverter, the researchers run tests to determine its output and produce a new version of the data model.

When comparing their model with the North American Electric Reliability Corporation model, the researchers found “the data-driven model is not only more accurate but more computationally efficient,” Hansen said.

During Phase 2, the research team will test its model with an additional 12 to 15 inverters to see if the methodology developed for several inverters holds true for other manufacturers. That may lead to changes in the standards for modeling inverter-based energy sources.



1. Associate professors Tim Hansen, left, and Reinaldo Tonkoski of the Department of Electrical Engineering and Computer Science are modeling power systems that integrate large amounts of renewable energy from sources, such solar panels, for a U.S. Department of Energy project.

2. Doctoral students Saima Ishaq, front left, and Nischal Guruwacharya use the OPAL-RT simulator to test a data-driven inverter model. Guruwacharya’s research adviser is Tonkoski and Ishaq’s adviser is Hansen.

3. Doctoral student Niranjan Bhujel, whose research adviser is Tonkoski, connects an inverter to collect output data with which to build the data-driven model. During Phase 1 of the Department of Energy project, the research team developed and tested the model with two inverters. During Phase 2, it will test the model with an additional 12 to 15 inverters.

4. Doctoral student Manisha Rauniyar models grid support functions using a data-driven inverter model. Her research adviser is Hansen.

5. Doctoral student Sunil Subedi connects the renewable energy sources to the grid after converting the direct current to alternating current using a data-driven inverter model. His research adviser is Hansen.

National laboratories **fuel technology commercialization,** student success

U.S. Department of Energy national laboratories play a key role in commercializing new power technologies and providing internships for high-performing graduate students.

"The national laboratories are a unique resource that help bridge the chasm between academia and industry," said professor Sid Suryanarayanan, noting that the PowerJacks group interacts with at least five national laboratories.

The PowerJacks researchers use modeling and simulation to see how different energy management strategies affect the electrical grid at different scales. Associate professor Reinaldo Tonkoski, the Harold C. Hohbach Endowed Professor in Electrical Engineering, refers to the national laboratories as "an important part of the innovation ecosystem."

A state-of-the art real-time digital simulator, purchased in 2017 through National Science Foundation funding, along with the university's high-performance computing cluster make the PowerJacks' research capabilities well aligned with the national laboratory initiatives, Tonkoski explained. However, companies must know a new technology is safe before they will invest money in it.

"National laboratories provide unbiased technical expertise to make sure these systems are safe to operate on the grid," he said.

Tonkoski spent summer 2019 and spring 2020 as a visiting scientist at Sandia National Laboratories developing new operation and controls systems to perform voltage and frequency control in microgrids. "It's an amazing environment in which you can engage in deep technical discussions with a large group of researchers working in the same area," said Tonkoski, who continues collaborating with Sandia scientists.

Doctoral student Ujjwol Tamrakar, who accompanied Tonkoski for a three-month SNL internship, stayed on as a postdoctoral researcher after completing his Ph.D. Furthermore, all of the students working with Tonkoski now have Sandia scientists on their graduate committees. "We are developing those synergies, in part, because of common interests. We have a very good research alignment."

Associate professor Tim Hansen was an intern in the Distributed Energy Systems Integration Group at the National Renewable Energy Laboratory while completing his doctoral degree at Colorado State University. "Because I was brought up in that research community, my research aligns well with what NREL is doing," said Hansen, who was offered a postdoctoral position but opted to start his career at SDSU.

Four SDSU alumni who did their graduate work under Hansen's tutelage now have full-time positions at national laboratories—three at NREL and one at Pacific Northwest National Laboratory.

"We are proactively sending our students to do internships in the national laboratories," said Suryanarayanan. He and doctoral student Tanveer Hussain have been working on research funded by the Idaho National Laboratory for three years.

"We prepare our students with the background knowledge needed to succeed in their internships and then put them in touch with researchers there who need interns. Many return to the national laboratories to begin their careers after finishing their degrees."

1. Ujjwol Tamrakar, who completed his Ph.D in 2020 under the direction of associate professor Reinaldo Tonkoski, checks the connections on the OPAL-RT Technologies real-time digital simulator. After doing an internship at Sandia National Laboratories, he is now a postdoctoral researcher there.

2. Kapil Duwadi, who completed his master's degree in 2019, adjusts the control of solar energy output to regulate the voltage of the power grid. He is now a researcher-II in the Electrical Power Distribution Systems Group at the National Renewable Energy Laboratory in Golden, Colorado.

3. Shuva Paul, who completed his doctoral work in 2019 under the tutelage of former assistant professor Zhen Ni, works on research to protect the smart grid from cyber-security attacks. After doing an internship with the power group at the National Renewable Energy Laboratory in Golden, Colorado, Paul is now a postdoctoral fellow at the Georgia Institute of Technology.

Graduate student	Adviser	Degree/Completion date	Internship	FT Position
Venkat Durvasulu	Hansen	Ph.D./2019		Researcher-III Grid Systems Group, NREL
Prateek Munankarmi	Hansen	M.S./2019	NREL	Researcher-II Residential Buildings Research Group, NREL
Kapil Duwadi	Hansen/Fourney	M.S./2019		Researcher-II, Electrical Power Distribution Systems Group, NREL
Fernando Bereta dos Reis	Hansen	Ph.D./2020	PNNL	Engineer-III, Electricity Infrastructure, PNNL
Ujjwol Tamrakar	Tonkoski	Ph.D./2020	SNL	Postdoctoral researcher, SNL
Shuva Paul	Ni	Ph.D./2019	NREL	Postdoctoral fellow Georgia Institute of Technology
Priti Paudyal	Ni	M.S./2019	NREL	Research Engineer, Grid Automation and Controls Group, NREL
Rylee Sundermann*	Kimn/Hansen	M.S.	SNL	
Tanveer Hussain*	Suryanarayanan	Ph.D.	INL	

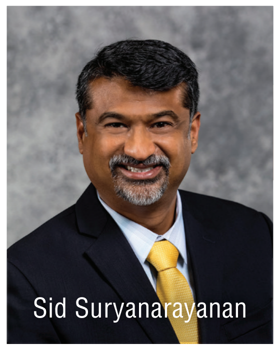
Argonne National Laboratory - ANL
Idaho National Laboratory - INL
National Renewable Energy Laboratory - NREL
Pacific Northwest National Laboratory - PNNL
Sandia National Laboratories - SNL
* Current graduate students

Energy management algorithms improve grid resiliency

Wildfires, hurricanes and ice storms can down transmission lines, leading to regional power outages. Professor Sid Suryanarayanan is developing ways to manage energy that will reduce the number of customers who lose power.

"What I want to do is minimize the impact catastrophic events have on customers by designing systems that are more robust than the ones available today," explained Suryanarayanan, who has been head of SDSU's Department of Electrical Engineering and Computer Science since June 2020. Prior to that, he was a faculty member and director of the Advanced Power Engineering Laboratory at Colorado State University for 10 years.

"One of my main contributions to power research is developing and applying mathematical algorithms to different computer systems for energy management," he said. While at CSU, Suryanarayanan and doctoral student Tanveer Hussain began working on a project with the Idaho National Laboratory to increase the resiliency of the electricity grid. They are continuing that research at SDSU using the high-performance computing cluster.



Sid Suryanarayanan

Dropping loads to balance supply

"The power supply must be equal to demand at all instances—if one goes in one direction, the other must follow," Suryanarayanan explained. "When a transmission line goes down, electrical loads (consumer demand) must be dropped to match the (reduced) supply, resulting in rolling blackouts."

The researchers came up with the idea of "turning off a few more lines, but doing this very carefully, knowing certain mathematic aspects of the system to bring those loads back up. It's counterintuitive because what you do not want to do is what we are doing, but we are doing it based on science, math and engineering."

However, he pointed out, "This idea is not new—it's been around since the 1980s. What has stopped the industry from doing this is determining which lines to remove to obtain a solution really fast." Previously that meant checking the balance each time a line was removed—and by that time, the system had already gone down.

"We sped things up," Suryanarayanan said. Working with INL, Hussain "came up with a cool idea that localizes the problem. Knowing a set of things about the system before this happens speeds up (the decision-making process) through the use of high-power computing."

In April, CSU filed a nonprovisional patent based on what the researchers accomplished there and Suryanarayanan anticipates filing an invention disclosure at SDSU soon. "What we patent is the algorithm, the steps that are unique in analyzing the problem and getting a solution in a very fast timeframe," he said. The collaboration with INL resulted in "not just one algorithm, but a suite of algorithms."

Dealing with predictable events

Through a National Science Foundation-funded project, Suryanarayanan seeks to minimize power disruptions due to hurricanes, in particular. To do this, he is collaborating with CSU and the city of Tallahassee, Florida. He was a scholar scientist at the Center for Advanced Power Systems at Florida State University for two and a half years before moving to Colorado.

"We want to harden the grid with assets, systems and philosophies of working that currently are not there but can be developed and deployed on the Eastern Seaboard to mitigate the effects of hurricanes," Suryanarayanan explained. He proposes using historical data, projected load and available resources to develop a plan to allocate certain assets, thereby circumventing a situation in which rolling blackouts might take effect for a particular group of loads.

"We have very good hurricane forecasting models. Based on those models, we can increase the resiliency of the grid by pre-allocating certain assets in certain areas and thereby decrease the overall vulnerability of critical infrastructure like the electricity grid," Suryanarayanan said.

His long-term goal is to develop energy management systems that are "proactive rather than reactive, to sense things that could happen before they happen and adjust for those in such a way that the end user is largely insulated from something like a blackout."

1. Doctoral candidate Tanveer Hussain develops resilient energy management algorithms. In his research, Hussain uses smaller-sized test systems on computers to perfect his algorithms before quantifying them on larger, life-sized computer models on SDSU's Roaring Thunder high-performance computing cluster. His research adviser is professor Sid Suryanarayanan.

SDSU engineers use **satellite images** to **protect national security**

The South Dakota State University Image Processing Laboratory is helping intelligence agencies use images from remote-sensing satellites to protect national security.

The work is part of a potential four-year Intelligence Advanced Research Projects Activity, or IARPA, contract awarded to Accenture Federal Services, which has expertise in artificial intelligence and machine learning. SDSU is one of seven universities, including Boston University, Cornell University and Massachusetts Institute of Technology, and two companies that received subcontracts to work on the project.

The contract supports IARPA's new Space-based Machine Automated Recognition Technique, or SMART, program, which seeks to automatically search images from multiple satellites to monitor changes stemming from natural events, such as forest fires, insect infestations and crop disease outbreaks and flooding, as well as human activity, such as large-scale construction projects.

SDSU has earned an international reputation for its expertise in calibrating images from remote-sensing satellites, according to Larry Leigh, director of the image processing laboratory. It is one of only three university laboratories doing this type of work. "Simply put, we make sure the pictures from the satellite sensors accurately capture what exists on the Earth's surface."

Ten years ago, scientists were solving problems using hundreds of satellite images, but now there are close to 500 satellites collecting millions of images, Leigh explained. "We are overloaded with data."

Accenture Federal Services has experience analyzing large amounts of data, but has tapped SDSU "to bring data from many different satellites together and to fuse that data into a seamless measurement that can drive the downstream decision-making process," he explained. "This project involves something we've been doing for many years, but now we can start doing it in a different world," said Leigh, pointing out that this is their first project interacting with IARPA—and one that helps fulfill his goal of diversifying the lab's research funding sources.

"What makes this interesting is each satellite measures things a bit differently," Leigh continued. "If you take images from the U.S. Landsat satellite series and the European Sentinel satellites, you need to understand those differences to be sure that when you stack them together in a time series the changes you see represent what is happening on the ground, rather than differences between satellite measurements."

To do this, Leigh and his team will collaborate with Mississippi-based Innovative Imaging and Research, I2R, which also does remote sensing geospatial and optics-based work, to harness the data from remote-sensing satellites. "We've worked a lot with I2R because they do similar remote-sensing work," he explained.

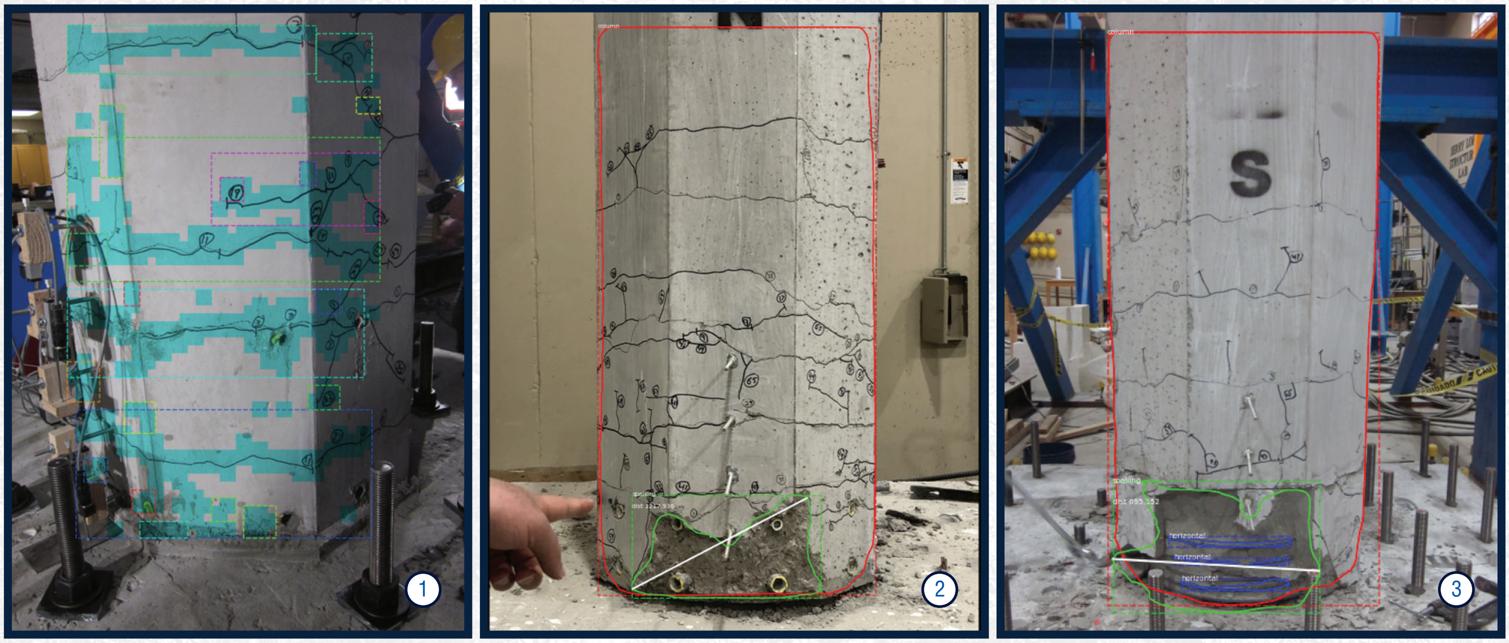
SDSU imaging engineers Morakot Kaewmanee and Cibele Teixeira Pinto, assistant professor Hankui Zhang of the Geospatial Sciences Center of Excellence and four to five graduate students will work on the project. The full four-year contract would bring more than $1.8 million in research funding to SDSU.

"I2R and SDSU will provide an interface, a system that will be able to handle the input and bring it together into one continuous cross-validated and harmonized stream of data that scientists and intelligence agencies can use," Leigh explained. The team's current focus is looking for large-scale construction projects. "For instance, we can look at a site in Dubai to see how many buildings are being erected, monitoring the construction of those structures and doing so in an automated way."

The project involves developing systems in the cloud that store petabytes—1,000 terabytes—of data, Leigh explained. "We will also be examining the data sources, assigning certainty and quality statements to the data and making decisions on the confidence levels regarding the data."

Once completed, this project will not only give intelligence agencies the information they need, but provide a data stream with which scientists can detect diseases, such as white mold in a soybean field, and can spot changes in the landscape, such as erosion on a coastline.

1. The SDSU Image Processing Laboratory is helping intelligence agencies use remote-sensing satellite images to protect national security through an Intelligence Advanced Research Projects Activity, or IARPA, contract awarded to Accenture Federal Services. Pictured, from left, are imaging engineer M. M. Farhad, lab director Larry Leigh and imaging engineers Morakot Kaewmanee and Cibele Teixeira Pinto.



Computer vision may **revolutionize** structural inspection

Inspecting structures after an earthquake, hurricane or flood is essential to saving lives, but that can be difficult to accomplish in a timely manner.

"Trained inspectors need to decide whether to keep a bridge open, to restrict traffic to first responders only or to close it—and this must happen within a short time," explained associate professor Mostafa Tazarv of the Department of Civil and Environmental Engineering. "After an earthquake, you need an army of structural engineers to quickly assess and comment on the serviceability of bridges and buildings in the affected area."

Tazarv, who is coordinator of the Jerome J. Lohr Structures Laboratory, does research on the structural behavior of buildings and bridges and how they behave during catastrophic events, specifically earthquakes. He also leads the Sustainable and Resilient Civil Infrastructure, or SARCI, research group.

Tazarv is working with another SARCI member, assistant professor Kwanghee Won of the Department of Electrical Engineering and Computer Science, to develop artificial intelligence software that scans and pinpoints cracks and other damages in support columns and other structural components. Won's expertise is in computer vision, neural networks, deep learning and intelligent systems.

The software has the potential to revolutionize how buildings and bridges are inspected—and save both time and money.

Developing vision capabilities

During Phase 1 of the project, the researchers have been developing the software's capability to visualize various types of damage in a concrete column. "Bridge columns are usually made with concrete," Tazarv pointed out. "From there, we can expand to different bridge components and maybe other types of structures."

This vision-based software can expedite the inspection process. "It can see concrete damages, including cracking, their angles, spalled area and exposed rebar," Tazarv said. "Once the program is refined, we can examine the structural components from all angles and even use color coding to categorize the severity of the damage and report that information to the inspector."

He envisions integrating the software in a mobile app, which would make it possible for an untrained individual to use the software to scan bridges and transmit the images to a central inspection office. Using that knowledge, trained personnel can then determine whether a bridge, for instance, can be opened or not, Tazarv explained.

Another possibility is to incorporate the software into a drone, for which Tazarv will rely on the expertise of another SARCI researcher, assistant mechanical engineering professor Marco Ciarcià, who specializes in controls, robotics and multirotor vehicles (see story page 12-13).

Mostafa Tazarv

Kwanghee Won

A software-equipped drone could fly around structures and send the information to the transportation office to expedite inspections. "We could send a fleet of drones to pinpoint cracks in structures," he said.

Collaboration key to success

"We are collaborating to develop a product that neither of us could achieve individually," Tazarv said. "I cannot do it myself because I do not have the computer vision knowledge and same for Dr. Won because he does not have a bridge engineering background."

Won said, "Being part of the SARCI group gives me a unique opportunity to apply artificial intelligence and machine learning to help solve problems in the civil engineering field."

That's the advantage of an integrated research group, Tazarv noted. He sees great potential in developing projects utilizing the skills of other SARCI members. The group also includes assistant professor Rouzbeh Ghabchi in road and highway construction, associate professor Guanghui Hua in water and wastewater management and assistant professor Michael Pawlovich, who works with traffic safety and operations.

"We have only scratched the surface in terms of what the SARCI team can accomplish, Tazarv said.

1. This image shows how the vision software automatically detects cracking in a reinforced concrete bridge column.

2. The vision software scans a bridge column for concrete spalling and determines the spalled area.

3. The vision software being developed can also identify exposed steel bars within the spalled area of reinforced concrete columns.

4. Assistant professor Rouzbeh Ghabchi tests the indirect tensile strength of a compacted asphalt specimen as part of the American Association of State Highway and Transportation Officials T-283 standard, through which he can determine its susceptibility to moisture-induced damage, which often results in potholes.

4

Two transportation centers support infrastructure research

Participation in two U.S. Department of Transportation centers makes the Sustainable and Resilient Civil Infrastructure group ideally positioned to improve serviceability and increase the life span of bridges and buildings, as well as roads and highways.

Associate professor Mostafa Tazarv and assistant professor Rouzbeh Ghabchi are developing innovative techniques to repair and construct bridges and roadways through the National Center for Transportation Infrastructure Durability and Life-Extension. Begun in 2019, the research center, known as TriDurLE, involves 11 universities and 30 researchers who are addressing issues related to protecting transportation infrastructure against multiple hazards and improving system response and resilience.

Tazarv, who is coordinator of the Jerome J. Lohr Structures Laboratory, examines ways to enhance the performance of bridges and bridge components by using innovative materials that reduce damage due to severe events, such as earthquakes and flooding. Ghabchi, who oversees the asphalt and concrete laboratories, focuses on improving the durability of roads and highways.

In addition, professor Nadim Wehbe, head of the Department of Civil and Environmental Engineering, is the site director for the Mountain Plains Consortium. The regional DOT center is composed of eight universities in five states— Colorado, North Dakota, South Dakota, Utah and Wyoming.

"Both centers allow us to perform collaborative, multidisciplinary research that will improve the transportation infrastructure in the state, region and nation," Tazarv concluded.

Senior design teams build **human-carrying rotorcraft**

A personal automated flying vehicle in every driveway. That's the future assistant professor Marco Ciarcià of the Department of Mechanical Engineering envisions when he describes a multiyear senior design project to build an electric-powered rotorcraft large enough to carry a human being. Rotorcraft refers to an aircraft with rotary wings to generate lift.

"One of the main limitations of an airplane or a standard helicopter for personal transportation is that it is an extremely complex machine that requires a lot of training to fly," said Ciarcià, who specializes in robotics, mechatronics and nonlinear and optimal controls. From 2010 to 2014, he worked on spacecraft guidance systems at the Spacecraft Robotic Laboratory in the Naval Postgraduate School in Monterey, California.

When he came to SDSU in August 2016, Ciarcià began the Aerospace Robotic Testbed Laboratory, which gives students hands-on work in robotics. He is also coordinator of the recently formed control, autonomy and navigation, or CAN, faculty research group.

"These days, you see small multirotor drones being used for a variety of tasks. We are trying to see if it is possible to use the technology developed for these smaller drones to develop an autonomous human-carrying rotorcraft," Ciarcià said. The personal vehicle will be equipped with GPS navigation, so a passenger can simply tell it where to go and it will fly automatically to that location, eliminating the need for a trained pilot.

Record-setting funding for senior design project

To begin the project in 2019, Ciarcià and associate professor Todd Letcher, who teaches the senior design class and also oversees the rotorcraft team, secured a nearly $80,000 grant through NASA's University Student Research Challenge. The ATLAS (Advanced Transportation through Leading-edge Aerial Systems) project to build an autonomous aerotaxi responded specifically to NASA's air transportation initiative, which seeks to encourage innovation and inspire young engineers.

"Never before have we had an $80,000 senior design project," Letcher said. "This is such an incredible opportunity for our students."

To claim the full amount of the NASA grant, the first senior design team used crowdsource funding to raise $2,590, thanks to 16 private and corporate donors. A second design team completed its work in May. The ATLAS project also received $1,200 in college funding.

Recently, the researchers received a two-year, $63,000 South Dakota Space Grant Consortium Project Innovation Grant. These funds will help improve the technology of the rotorcraft,

ATLAS ALBATROSS SPECIFICATION

Take-off weight:	Empty weight:	Payload:	Flight time (hover mode):	Flight time (cruising mode):
660 lb.	**440 lb.**	**220 lb.**	**18-19 min.**	**14-15 min.**

Range:	Cruising speed:	Maximum speed:
8-9 miles	**30-40 mph**	**~65 mph**

Manual and autonomous flight modes

decreasing its weight by using composite materials and improving its performance by using more efficient motors as well as propeller size and configuration. The funds will provide summer salaries for students working on the project. The grant will support senior design teams for the next two academic years.

In addition, the funding will also support two summer internships on multirotor design at SDSU. This summer, undergraduates from other South Dakota universities can learn to build a small multirotor vehicle. Next summer, the boot camp will be for high school students.

Challenging, interdisciplinary teamwork

"The human-carrying rotorcraft project is an amazing opportunity for undergraduate students to get their feet wet with a very complex design," Ciarcià said. "They have the opportunity to learn how to work on an interdisciplinary team and how to deliver important tasks in a timeline."

The first senior design team was composed of four students majoring in mechanical engineering, one majoring in electrical engineering and two majoring in business and entrepreneurial studies. The second team had two electrical engineering students and three mechanical engineering students.

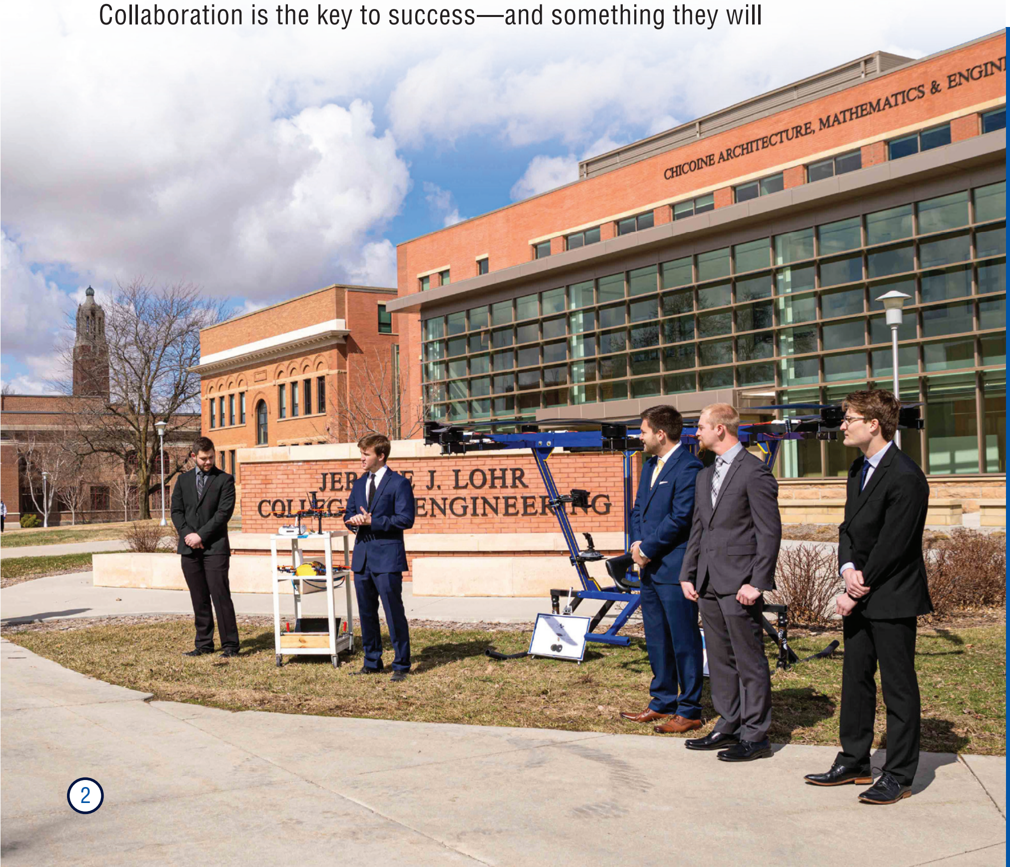
"This type of aircraft has a lot of components and subsystems related to electronics and electrical parts," Ciarcià explained. Collaboration is the key to success—and something they will experience in their careers as well. "This is good incentive and motivation for them to work well together."

The first team built the Hummingbird, a small-scale drone, using off-the-shelf components to validate their design and began assembling a large-scale prototype, the Albatross. The second senior design team completed the Albatross, which is now ready to fly. The students applied for Federal Aviation Administration airworthy certification and Ciarcià hopes to get flight approval this fall.

Ciarcià is pleased with the progress. "Todd is doing a fantastic job of finding the right students for this project," he said.

"Companies and research groups are developing multirotors, so the time is right, and we want to be among the first team to develop this," he said. To further that effort, Ciarcià, with support from Rajesh Kavasseri, associate dean for research in the Jerome J. Lohr College of Engineering, and Dwaine Chapel, CEO/executive director of the Research Park at SDSU, plans to launch a startup company called Aerofly.

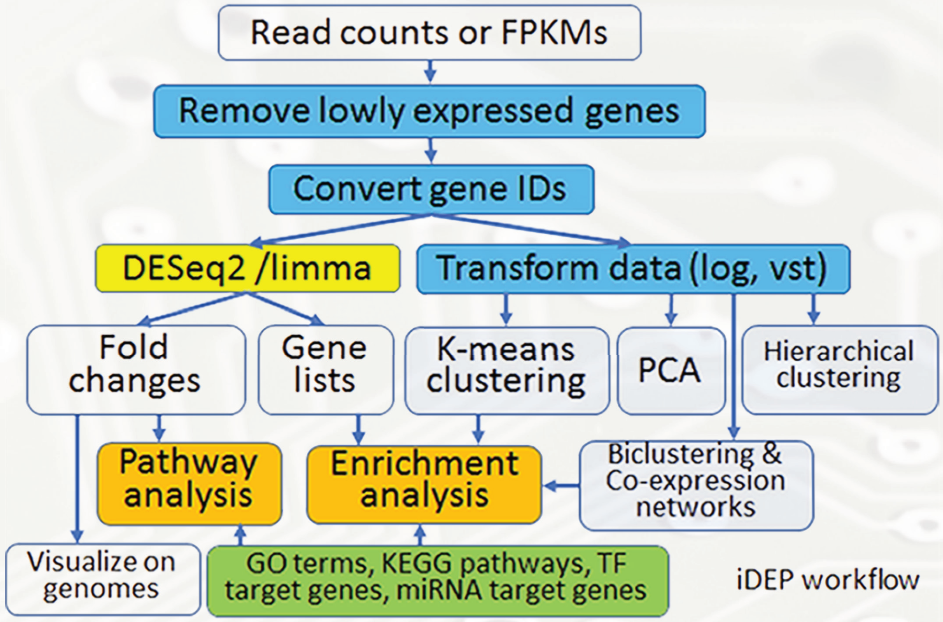
"The goal is to commercialize the electric rotorcraft for human transportation and other heavy-lift applications," Ciarcià explained. "It will take few years, but if we think big, one day people will have affordable electric rotorcraft parked next to their cars."



1. Mechanical engineering major Josh Gross of Marshall, Minnesota, sits in the large-scale human-carrying multirotor vehicle prototype dubbed the Albatross. It is ready to fly and will be tested once it receives Federal Aviation Administration airworthy certification and flight approval.

2. Members of the senior design team that worked on the Advanced Transportation through Leading-edge Aerial Systems project to build an autonomous aerotaxi during the 2020-2021 academic year explain their work to engineering faculty and university administrators outside Crothers Engineering Hall. The team members are, from left, Cody Blocker of Hosmer; Nathan Sydow of Dakota Dunes; Josh Gross of Marshall, Minnesota; Evan Steers of Miller and Andrew Hanshaw of Dakota Dunes. Sydow and Hanshaw are majoring in electrical engineering, while the others are in mechanical engineering.

NIH grant to **improve genomic analysis** website



iDEP workflow

A website used by more than 40,000 scientists to analyze their genomic data is getting a major upgrade, thanks to a four-year, nearly $870,000 National Institutes of Health grant.

Professor Xijin Ge of the Department of Mathematics and Statistics developed the integrated differential expression and pathway tool, known as iDEP, to help researchers decipher their RNA sequence data. The free website, http://bioinformatics.sdstate.edu/idep, has been available since 2017.

"I specialize in bioinformatics, a relatively new field focused on the analysis of genomics data," explained Ge. "Biologists today are flooded with data. Lack of access to bioinformaticians is a critical barrier for many researchers, especially those in institutions with limited resources."

Users can upload their data to the iDEP website and create anywhere from 30 to 40 different graphs to analyze their results. "What we did was simplify a complex analytics workflow. We made it very intuitive so people who are busy with their experiments can analyze their own data," Ge said. That saves the researchers both time and money.

"What once took scientists three months to do, they can now do in a day or two and get the exact same results," he pointed out. "Our goal is to empower biologists to analyze their own data, interactively and reproducibly."

For his work in bioinformatics, Ge received the outstanding researcher award for the Jerome J. Lohr College of Engineering at the university's March 25 Celebration of Faculty Excellence.

How iDEP began

Initially, Ge developed iDEP for SDSU researchers who wanted to analyze RNA sequence data from soybeans. To fulfill their request, he wrote code to do statistical analyses and produce visual interpretations of the gene expression data.

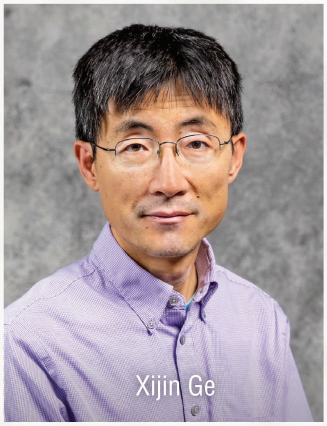
A few months later, he got a similar request from SDSU researchers working with mice. "I tweaked the code a little bit and gave the results to the second group of researchers," he said. That led to the realization that "the same code base could benefit many others—that was the starting point for this project."

Ge used Shiny, a software package in the statisticians' R language, to build the interactive webpages that deliver the data analytics. He then worked with the Office of Research Computing to transfer the code and host iDEP on the university server, using the high-performance computing facilities.

"We made it powerful yet easy to use," Ge said. "The site offers, not just analytics, but also precompiled annotation data, which is essential for the interpretation of genomic data." Through the web interface, researchers can access annotation data for more than 2,500 species of organisms.

Impacting worldwide research

Since the website's 2017 launch, Ge said, "I've kept adding to it." But even he was surprised at the impact iDEP has had on scientific research worldwide.



Xijin Ge

While Ge was preparing the NIH proposal, an influential blogger, who has no connection to SDSU or iDEP, started a campaign to “save this magical bioinformatics tool.” Within two days, Ge had received more than 100 emails from iDEP users describing how useful the tools are to their research and suggesting ways to improve it.

“I never imagined this would be that popular,” Ge said. Responses came from researchers in the United Kingdom, Spain, Germany, Canada, Poland, Belgium, Switzerland, Australia, Italy, France, Belgium and Japan as well as from scientists across the United States. He also received word from a Japanese research group that is using iDEP to do COVID-19 research.

Upgrading website

The SDSU team will make substantial improvements to the website through the NIH R01 grant, which allows it to apply for a continuation award during the project’s final year. “We will convert a prototype into a mature bioinformatics tool,” Ge said.

The team will hire a software developer to help rewrite the code and at least two graduate students will work on the project. Furthermore, Ge said, “In addition to user suggestions, we have many ideas, including local installation and automatic reports.”

Ge and his team will also increase the number of RNA sequence databases to which researchers can compare their results. In November 2020, research associate Jenny Qi joined the team to update and maintain the databases and provide customer outreach and support.

“I connected the two worlds to fill the gap and pulled the user into the driver’s seat,” Ge said. Soon researchers worldwide will be able to do even more analyses through the upgraded iDEP website.

1. This flowchart shows the functions scientists can perform using the iDEP website. Through a four-year, nearly $870,000 National Institutes of Health grant, professor Xijin Ge of the Department of Mathematics and Statistics will make improvements to iDEP that “will convert the prototype into a mature bioinformatics tool.”

2. Analyzing RNA expression in cells within the nodules on these roots will help advance research aimed at increasing the nitrogen-fixing power of soybeans.

Plant scientist uses iDEP for soybean research

Professor Senthil Subramanian of SDSU’s Department of Agronomy, Horticulture and Plant Science uses iDEP to analyze RNA expression in cells within soybean nodules. His laboratory will be one of nine laboratories nationwide doing beta testing of the website for Ge’s NIH project.

Subramanian emphasized the integral role iDEP can play in projects, such as his National Science Foundation CAREER award research, referring to it as a “one-stop shop for RNA expression analysis.”

Soybean nodules have two distinct zones—the central zone where the root cells host nitrogen-fixing bacteria and the periphery where they transport the nitrogen to the plant, he explained. “The goal of the NSF project was to find out, as the nodule is growing, how the cells know whether they are in the central or peripheral zone.”

Previously, graduate student Sunita Pathak would have had to learn to use six different programs to do the analyses. “With iDEP, the graduate student uploaded the data and performed all six analyses with one tool,” he explained.

The iDEP website “allowed us to look at how consistent data was among the replicates, and also told us how many and which genes were consistently different between the two nodule zones. It took all those consistently different genes between the two zones and looked at if there are any patterns within those genes, those that belong to one pathway in one zone versus the other. That was very powerful because it is nearly impossible to do that manually,” Subramanian said.

AWARDS

College, university honor Ge, Zhou

Xijin Ge
Associate Professor
Department of Mathematics and Statistics

Ge named outstanding engineering researcher

Professor Xijin Ge of the Department of Mathematics and Statistics has been helping biologists make sense of their genomic data for decades. However, his goal has now shifted to "empowering biologists to analyze their own data, interactively and reproducibly" through a free website that has been accessed by more than 40,000 scientists worldwide.

In recognition of his contributions to the scientific community, Ge was named the outstanding researcher for the Jerome J. Lohr College of Engineering at the university's Celebration of Faculty Excellence.

Ge began doing bioinformatics research with cancer genomics while pursuing his Ph.D. at the University of Tokyo. He continued to work on human genomics and breast cancer as a postdoctoral researcher at Northwestern University and NorthShore University HealthSystem before becoming an SDSU faculty member in 2007.

At SDSU, Ge has secured more than $2 million in research funding. His bioinformatics research has been supported by grants from the National Science Foundation, National Institutes of Health, South Dakota Experimental Program to Stimulate Competitive Research, U.S. Department of Agriculture Hatch funding through the South Dakota Agricultural Experiment Station and funding from Sanford Health and Avera Health.

Ge has received two NIH RO1 grants. These are unique because he can apply for continued funding during the final year of the research project.

His most recent NIH RO1 project is to improve the integrated differential expression and pathway tool, known as iDEP. The free website allows researchers to decipher their RNA sequence data (see story page 14). When Ge was preparing the NIH proposal, he received an outpouring of testimonials on the value of iDEP and suggestions for upgrading the website to make it even more useful to scientists.

Yue Zhou
Assistant Professor
Department of Electrical Engineering and Computer Science

Zhou receives Young Investigator Award

Research to improve the performance of lithium-ion batteries has earned assistant professor Yue Zhou of the Department of Electrical Engineering and Computer Science the Jerome J. Lohr College of Engineering's Young Investigator Award.

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

Using lithium metal in place of graphite as the anode material can increase the battery's energy storage capacity, but, over time, the lithium foil tends to form needle-like dendrites. These tiny metal particles can pierce the separator, causing a short circuit.

Through South Dakota Board of Regents funding, Zhou used plasma processing to apply an additional coating to protect the lithium metal anode and thereby prevent dendrite formation. In addition, he combined graphite and silicon oxide to make an ultrathin film that prevents dendrite growth and enhances ion transport. This also creates an artificial interfacial layer between the electrolyte and the lithium metal electrode that increases stability and improves battery cell performance.

Using these preliminary results, Zhou secured a three-year, nearly $450,000 National Science Foundation grant to examine how lithium metal improves battery performance. SDSU leads the project, which involves collaboration with the University of Texas at Arlington.

"We want to understand the physical and chemical factors that lead to these desirable properties," he said. This fundamental scientific knowledge provides guidelines that will help researchers use this material to develop next-generation batteries with increased storage capacity and stability to power electric cars and store renewable energy.

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