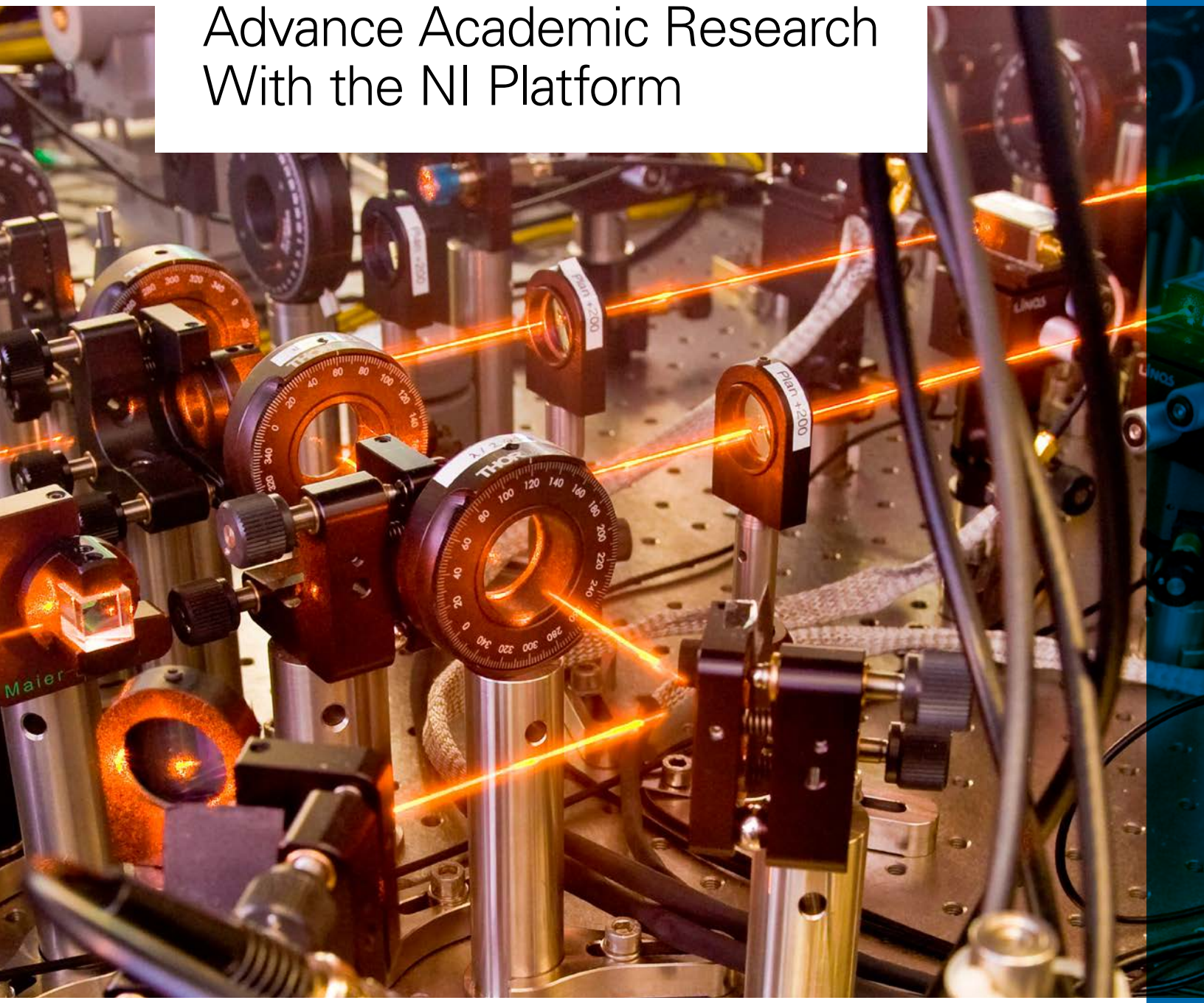
Advance Academic Research With the NI Platform



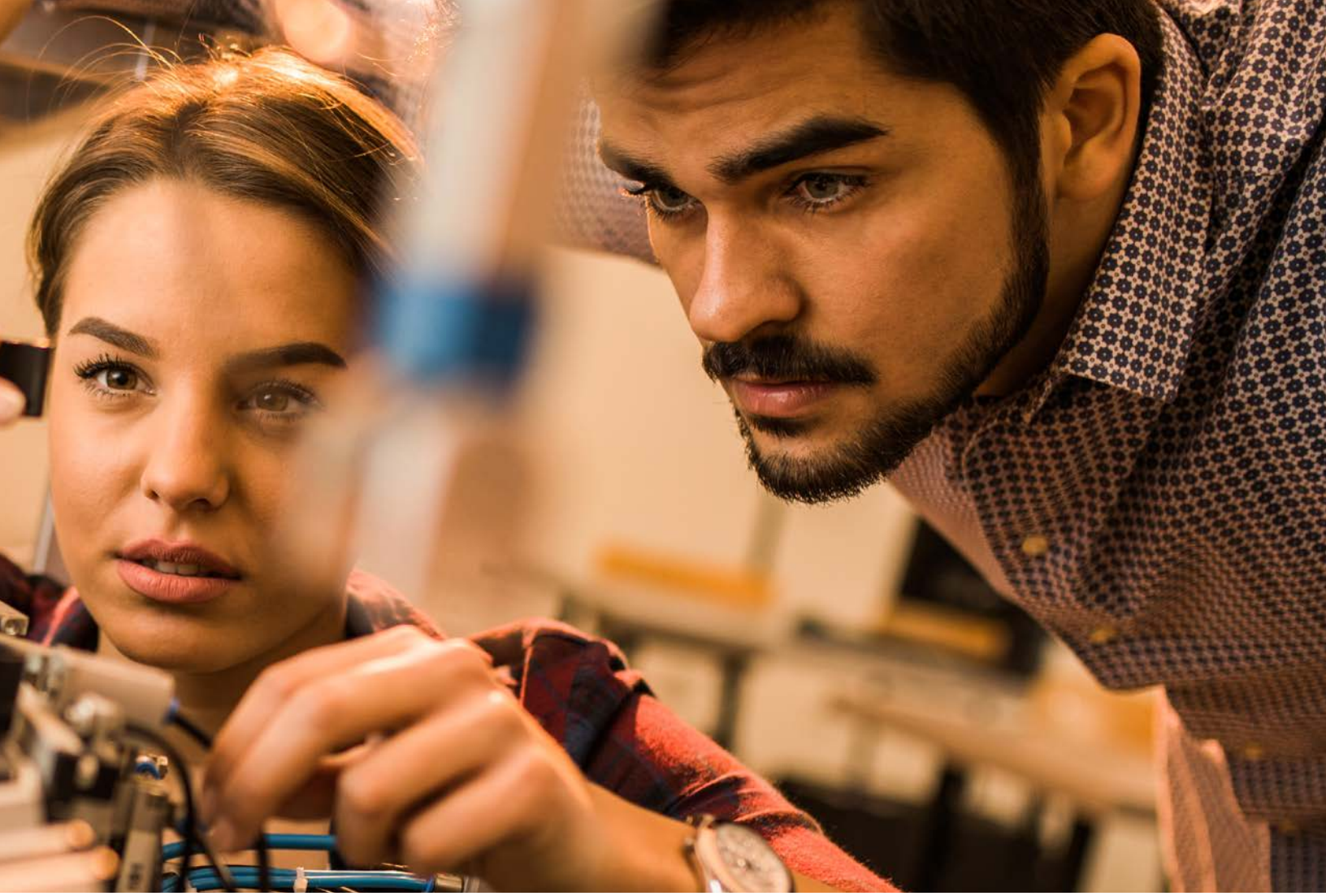
A Note to Academic Researchers

Every day, researchers use the NI platform to push the boundaries of discovery. They are driven by the grand challenges humanity faces and the economic and technical trends that are revolutionizing wireless communications, transportation, and energy. The ideas, theories, and prototypes that start in academic research labs scale to ever more complex applications and eventually impact all our lives in the form of commercial technology.

As varied as their research focus areas might be, academics face similar challenges regardless of domain. The goal of NI has always been to help scientists and engineers spend their time on the novel and the innovative by providing a platform with the accuracy, repeatability, and scalability they need to validate and prototype research.

This handbook serves as a space for us to share insights and best practices from a global research community through showcases of novel research conducted using the NI platform.

David Wilson
Vice President of Product Marketing for Software,
Academics, and Customer Education



Contents

Automating Industrial Measurements With the IoT at Trinity College Dublin

The Challenge

Ceramicx Ireland, a global leader of infrared heating technologies and services, recently faced a significant challenge in testing its varied product portfolio of more than 150 different part types while maintaining a high-processing speed for consistent and accurate measurements. This multidimensional challenge required collaboration with academia to harness the power of Industry 4.0 and the vision of the smart factory of the future.

The Solution

Project CIRCLE, including researchers from Ceramicx and Trinity College Dublin (TCD), developed a fully automated and reconfigurable product test and validation system. The devices under test (DUTs) included ceramic and quartz heating elements, which vary in size, shape, mechanical, and electric properties. Project CIRCLE emphasized an Industrial Internet of Things (IIoT) infrastructure to decentralise test operations into dedicated test stations that use NI CompactRIO Controllers for real-time control. Each test station features unique test and actuation equipment, for example, high-potential testers, thermal cameras, and motor drives.

Creating a Decentralized IIoT Architecture

A decentralised architecture requires a fog- or cloud-based supervisor to unite the stations in achieving a singular goal. The supervisor in Project CIRCLE is a communication hub that monitors, configures, and manages test stations over a network. The engineering research team at TCD developed the supervisor, programmed it with LabVIEW, and released it as a Windows OS executable. The supervisor identifies which program to run for each DUT at each test station (considered the edge node). It uses a software plug-in portal, so other developers from both academia and industry can integrate custom software applications and data services.

"We can seamlessly integrate future tests with the development of new test stations. Modifications in test stations do not affect the operation of other test stations," said Dr. Jeff Morgan at TCD. "Each connected test station's CompactRIO Controller can communicate with the other CompactRIO Controllers and the system supervisor using the software we wrote in LabVIEW. This creates a fully connected and interoperable system that is capable of true parallel processing through decentralised CPUs."

Defining the Cutting Edge

Industry 4.0 will be possible only through the convergence of high-power, low-cost computation and communication. To stay competitive in the marketplace, manufacturers need to be flexible so they can quickly react to rapid changes in market demands. Project CIRCLE researchers believe decentralised control and collaboration can meet the requirements of a progressive manufacturing enterprise. The underlying architecture is characterised as a Smart

Reconfigurable Test EXecution (SR-TEX) platform. This is a universal decentralised monitoring, control, and management platform that can be used to create any automated test line for parallel product test and validation.

Building Partnerships to Win Funding

Strong partnerships such as Project CIRCLE occur only when academia and industry come together to achieve common goals. Innovative research has a greater chance of improving the world when it is backed by global thought leaders from academia and knowledgeable experts from industry who can deliver technology to market.

The traditional letter of support in a research proposal is only one contribution an industrial partner can make to drive the success of academic research. The right industry partner can help researchers gain access to the expertise, insight, technology, and skills that heavily contribute to the credibility of a research plan. An approach that focuses on prototyping toward technology readiness and new product development, such as the solution used by TCD and Ceramicx, can benefit some of the most impactful areas of current research such as Industry 4.0.

To learn more about Project CIRCLE, read the full case study on ni.com.

Validating Enhanced Cancer Intervention Research at Worcester Polytechnic Institute

The Challenge

The number of people worldwide who will develop cancer during their lifetimes is steadily increasing. Advanced treatments and surgery are possible by combining MRI 3D intraoperative imaging and robotics to enable precise closed-loop instrument delivery. However, MRI is highly sensitive to electromagnetic interference (EMI), so a low-noise, modular control system for use with MRI-safe surgical robots needed to be designed and rigorously prototyped.

The Solution

Worcester Polytechnic Institute (WPI) prototyped a custom multiaxis piezoelectric motion control system that incorporates the NI CompactRIO System on Module (SOM) into a custom-designed backplane. This backplane interfaces with up to 10 actuator-specific daughtercards over FPGA-based multichannel SPI. WPI used LabVIEW for reliable, real-time motion control software, communication, and web-server-based user interfaces for remote access.

About the AIM Lab

The Automation and Interventional Medicine Robotics Research Laboratory (AIM Lab) at WPI was founded in 2008 to enhance healthcare through smart medical robotic systems.

The AIM Lab's capabilities range from low-level embedded system hardware and software development to robot design and fabrication to high-level visualization and control software. A primary focus area is image-guided intervention, for which intraoperative medical imaging (primarily MRI) is used to provide "closed loop" surgical interventions. The AIM Lab has strong collaborations with several clinical sites including UMass Medical School, Albany Medical Center, and Brigham and Women's Hospital.

The AIM Lab is also affiliated with PracticePoint, which is an alliance of academic, industry, and healthcare providers to evolve innovative medical technologies. This unique facility at WPI embeds clinical suites in an engineering environment to co-locate advanced manufacturing and test equipment with clinical settings that replicate point-of-practice healthcare scenarios including surgical imaging, rehabilitative care, controlled care, and residential suites.

The Importance of Prototyping

Using surgical robots inside the bore of an MRI machine presents a two-way challenge: the MRI machine injects strong electrical noise into sensors and actuators, but it is highly sensitive to the electrical noise produced by those same devices.

Due to the MRI machine's intense and fast-changing magnetic fields, careful design is required for any systems that operate in or near it. The sensitivity to electrical noise in the megahertz range requires surrounding systems to

produce clean signals that do not overlap the frequency band used by the MRI for imaging. Furthermore, a surgical robot requires precise coordination among all its motion axes so that paths are followed as precisely as the surgeon intends.

The safety-critical nature of surgical applications means that thorough testing and prototyping are necessities for any new designs. Performance and behavior must be verified by repeatable data from experiments conducted in real-world conditions.

Taking the Burden Out of Building Prototypes

"Our first prototypes used a SOM and met most of our needs. However, the lack of an integrated programming environment significantly increased prototyping time," said Paulo Carvalho, doctoral candidate at WPI.

"As a result, we redesigned our system to incorporate the NI CompactRIO SOM solution that uses a developer-friendly FPGA hardware description graphical programming language in LabVIEW and exports a C API in easy-to-use header files," Carvalho said. "This enabled faster software development, which allowed our team to focus on our core value proposition instead of infrastructure work."

WPI's use of an established development environment and commercial off-the-shelf (COTS) hardware allowed the researchers to not only rapidly prototype and validate the system but also easily scale their innovation toward commercialization. It also helped them improve transparency by enabling easily replicable experimental setups across similar laboratories globally.

Defining the Future of Travel at The University of Texas at Austin

The Challenge

Growing urban populations are increasing the strain on traditional transportation links, and innovative solutions are needed to achieve fast, safe, and reliable travel in the future.

The Solution

The Texas Guadaloop team based at The University of Texas at Austin is designing a Hyperloop pod system to travel at transonic speeds. With the help of a control system based on NI's user-programmable FPGA instruments, the team developed a prototype of an air-bearing levitation system that allows a pod to achieve transonic speeds.

Creating an Initial Solution

A vehicle capable of traveling beyond the speed of sound must have a responsive control system. When Texas Guadaloop team members built their first designs of the air-bearing control system, they used two open-source embedded boards: the first one handled communication, calculation, automation, and other high-level tasks while the second one handled both digital and analog I/O.

This solution was satisfactory for basic use cases but was not scalable from the initial experiment to a more robust implementation. Team members discovered a significant bottleneck for a single pod was the communication between the boards, which required the processor to spend cycles waiting for off-board I/O processes to finish. Though team members could accommodate this during basic validation, future scenarios involving multiple pods would require more boards, which would lengthen idle processor cycles and slow down access times. That would lead to slower indeterministic subsystem updates, which is a significant issue in a control scenario for a transonic Hyperloop pod. The subsystems require control inputs and outputs to be updated on the order of milliseconds to maintain a levitation accuracy of a 1200 lb vessel to within 1 mm. Any issues would cause potentially catastrophic overshoots and undershoots within the control algorithm.

The Benefits of Industry-Grade Hardware

By adopting NI's user-programmable FPGA instruments that are often applied in industry, team members fundamentally simplified the Hyperloop pod control system and decreased the time they needed to iterate on designs. They streamlined the controller architecture from a system that used multiple embedded controllers and a mess of wires to a single

embedded controller that had more processing power, onboard I/O interfaced directly to processors, and greater reliability. For their unique signal conditioning needs, team members moved from three custom printed circuit boards (PCBs) to one, which refined the prototype and removed vulnerabilities from the system. NI's user-programmable FPGA instruments also helped team members effectively scale from their current implementation to more complex implementations and even to commercialization.

In addition, Texas Guadaloop team members reaped time and effort benefits. "We went from spending 80 percent of our development time trying to resolve communications issues between systems to 100 percent of our development time focused on the new sensors, the architecture, and testing the system," said Sahar Rashed from The University of Texas at Austin.

Gaining an Edge From Industrial Platforms

These academic researchers face the same technical challenges that many of their peers in industry face, so they can gain the same benefits that industrial leaders see by using the right solutions in the design and validation of transportation and aerospace applications. Adopting an industrial platform enabled Texas Guadaloop team members to resolve issues caused by a DIY approach and focus on their research. An additional benefit is that sharing a platform used by industry offers young innovators a simpler path to collaborate in commercial ventures that can strengthen funding proposals and lead to a shorter time to market.

To learn more about Texas Guadaloop, read the full submission to the 2018 Engineering Impact Awards.

Evaluating the Possibility of Surgery in Space at the University of Louisville

The Challenge

In the history of space flight, neither a surgical procedure nor immediate surgical treatment of an accident has been required in space. Despite the technological advances that allow humans to live for extended periods of time just outside Earth's atmosphere, if a medical emergency does arise, the patient would need an emergency capsule to travel back to Earth for treatment. As we make plans for sending missions to the Moon, Mars, and beyond, medical complications are an absolute certainty, and appropriate treatment at the time of injury is vitally important.

The Solution

The conceptualization and development of a surgical isolation dome offer the possibility of surgery in space. To function, the dome requires a fluid management system (FMS) and multifunctional surgical wand (MFSW) to contain and control the site of surgery and work in the absence of gravity. NI's user-programmable FPGA instruments are used to automatically trigger the experiments when microgravity conditions are met, as validated on test flights in the famous Vomit Comet test aircraft.

Surgery in Microgravity

The University of Louisville and the Cardiovascular Innovation Institute have partnered to conduct exploratory research for eventual use in surgical operations that support long-term space flight and to develop instrumentation for possible use in general laparoscopic surgeries.

In fall 2018, researchers are planning to use the NASA-supported project to run an experiment on an unmanned flight campaign on SpaceShipTwo (Virgin Galactic). This requires the development of a fully automated system to support the FMS and MFSW components.

Automating Control, Measurements, and Validation

During the early stages of development, researchers manually manipulated fluids with a push-button technique to fill and empty the dome. A second-generation prototype provided semiautomatic and timer-based control. But neither of these approaches could address the challenge of running the experiment onboard an unmanned flight.

The FMS and MFSW were designed to run in an automated control configuration programmed to conduct a specific set of steps based on precise timing without the need for any manual operation.

Data from an onboard accelerometer was used to initiate the experiment upon the detection of microgravity (<0.02 G). Software was developed to trigger high-resolution data capture upon entering microgravity. That microgravity was achieved at the NASA Glenn Research Center's 2.2-second drop tower, where the system was loaded into an experimental drag shield device and raised to 24 m (79 ft) before being dropped.

"These validation tests are critical considering the experiment ultimately will be performed in near-zero gravity —for approximately two minutes of zero G conditions— and the entire experiment must be triggered automatically because the flight is unmanned," said Christopher Higginson from the University of Louisville.

Far-Reaching Opportunities of Experimental Research

A fully functional FMS and a collection of appropriately sized surgical domes will provide a compact, efficient technique to perform surgical operations during space travel. The FMS will manage the infusion of all necessary fluids to protect the spacecraft and patient, and the MFSW will act as a helping hand for the limited number of personnel that will populate an extended-flight spacecraft (four to six crew members).

Time, money, and, most importantly, lives will be saved by giving crewmembers access to medical treatment without needing to return to Earth. This will increase the overall safety of space-based missions and will build confidence in long-distance space travel from Earth. The FMS not only facilitates space-based surgery but also offers the potential for fluid management in terrestrial-based surgery. This will eliminate the need for certain medical devices and extra personnel in Earth-based laparoscopic procedures.

Developing a Novel Millimeter-Wave Radar for Aerospace Applications at ENRI

The Challenge

The need to automatically detect foreign object debris (FOD) on airport surfaces has rapidly increased as airports become busier and require maximum possible uptime. Even if the FOD is small, it may cause catastrophic damage to an aircraft. After a small metallic plate on the runway caused the Concorde accident in 2000 at Paris Charles de Gaulle Airport, the detection of FOD became a key issue for airport administrators. The downtime needed to investigate possible FOD can cause expensive and inconvenient delays.

The Solution

The Electronic Navigation Research Institute (ENRI) in Japan is actively working to tackle this challenge as part of its mission to develop civil technologies for aviation surveillance and communication, air traffic safety, and efficient operation of air traffic routes. ENRI is developing millimeter-wave radar systems as part of its solution. Millimeter-wave radar enables high-performance detection, very detailed resolution, and weather robustness compared with camera systems.

Empowering Research by Innovating In-House

Runway radar systems require complex signal processing such as fast Fourier transforms (FFTs) and coherent signal integrations with trigger synchronization. Trying to outsource system development meant high costs and a long development period. In addition, experimenting with novel algorithms required the researchers to modify or add functionality, which wouldn't be easy if they outsourced the original design.

Choosing to keep development in-house had its own challenges. ENRI researchers were concerned about how much money and time they would need to acquire programming skills if they chose to use multiple programming languages, such as VHDL for FPGA and C for the host computer, alongside different communication interfaces. Using LabVIEW as a common programming language across the FPGA, real-time embedded processor, and host computer eliminated this challenge and allowed the researchers to develop their system quickly.

"The main signal processing algorithm was implemented in less than one month, which is one-tenth of the time the conventional programming method takes," said Shunichi Futatsumori from the Surveillance and Communications Department at ENRI. "Since we were not required to outsource the construction of the programming code, a low cost and rapid construction were possible."

Reusing Intellectual Property in New Projects

Since their initial work on the FOD detection radar, ENRI researchers have been developing a helicopter collision avoidance radar based on other NI solutions. Because of their decision to use the NI platform, the researchers can easily reuse the main algorithm containing the radar signal processing and port it to other NI hardware systems without any change. They can use LabVIEW to adjust the detailed FPGA clock timing as it scales to a different platform and avoid the extensive rewrites of VHDL code that are usually required.

Adopting a common platform makes research more efficient through intellectual property (IP) reuse and the transfer of common skills from one project to the next. ENRI is just one example of the time and resources researchers can save by not reinventing existing IP. A common platform can ultimately help researchers meet their publication deadlines and rapidly push their findings into new, novel directions.

To learn more about ENRI's use of the NI platform, read the full case study on ni.com.

US Corporate Headquarters
11500 N Mopac Expwy, Austin, TX 78759-3504
T: 512 683 0100 F: 512 683 9300 info@ni.com

ni.com/global–International Branch Offices
ni.com/research.

NI Services and Support

Hardware Services

Fix maintenance costs, improve uptime, and maintain traceability starting at only a fraction of the hardware price with NI service programs.

Training and Certification

Develop 50 percent faster and spend 43 percent less time on code maintenance with NI training courses. Also validate your expertise with NI certifications.

Technical Support

Get started with NI products faster or troubleshoot tough issues by contacting NI applications engineers who are ready to help via phone and email.

Consultation and Integration

Leverage our extensive network of Alliance Partners and NI systems engineers for assistance with prototyping, feasibility analysis, consulting, and systems integration.

Software License Programs

Streamline NI software management by accessing multiple levels of training, technical support, and tools through your software license.

Technical Resources

Access volumes of self-help information at **ni.com** including application tips, example programs, and developer communities.