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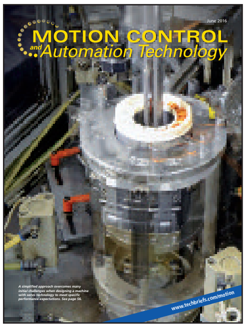

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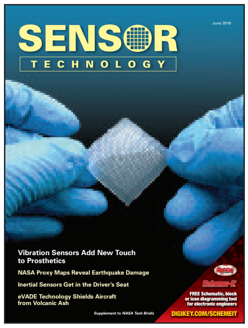

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June 2016 www.techbriefs.com Vol. 40 No. 6

TECH BRIEFS®

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

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Advanced Coating Technology at NASA Goddard

NASA Technology Converts Plastic Waste to Energy

Motion Control and Automation Technology

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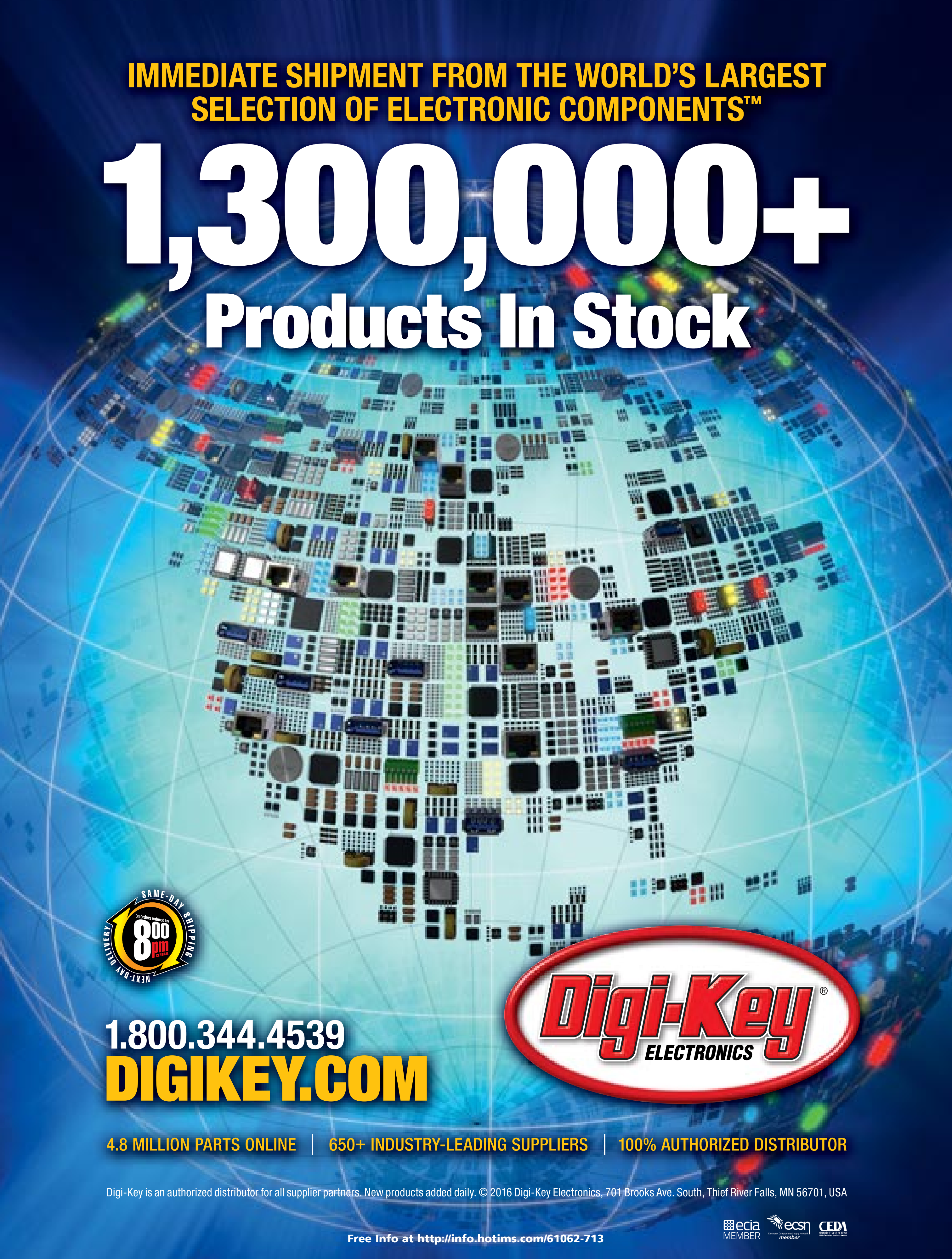
Intro Cov ToC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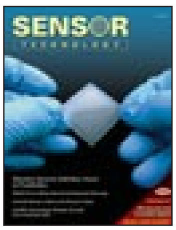

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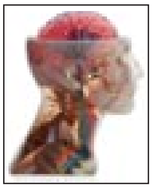
Product of the Month



Stratasys (Eden Prairie, MN) introduced the J750 3D printer that produces full-color, multi-material prototypes and parts in a single 3D print without post-processing.

66

On the cover

The 18 mirrors that make up the primary mirror of the James Webb Space Telescope (JWST) were assembled on the telescope structure in NASA's Goddard Space Flight Center's cleanroom in Greenbelt, MD. A very fine film of vaporized gold coats each segment to improve the mirror's reflection of infrared light. Goddard's Contamination and Coatings Engineering Branch has developed coatings like this for many NASA missions, including the Hubble Space Telescope, satellites, and the Mars 2020 mission. Find out more in a behind-the-scenes look at Goddard's Thermal Coatings Lab beginning on page 12.

(NASA image by Chris Gunn)

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UP FRONT

Linda Bell
Editorial Director

Editor's Choice

A small, metallic thermometer is hermetically sealed, has an essentially unlimited shelf-life, is insensitive to radiation, has no electronics or mechanisms, can operate in any orientation or gravity, and provides good thermal conductivity. It features an off-the-shelf ultra-high vacuum flange and permanently records temperatures in extreme environments. The low-cost device is read by visual inspection after opening the seal. Find out more on page 49.

Last Chance to Create the Future!

If you haven't already submitted your new design idea, you only have until July 1, 2016 to enter the 14th annual Create the Future Design Contest at **www.createthefuturecontest.com**. Sponsored by COMSOL and Mouser Electronics, along with Analog Devices and Intel, the contest provides global recognition and a Grand Prize of $20,000, in addition to other prizes. Entries can be submitted in seven categories. Don't miss your chance to "create the future." Visit **www.createthefuturecontest.com** to submit your entry today.

Next Month in NTB

The July issue of *NASA Tech Briefs* will include a special feature on NASA's newest robotic technologies, including rovers such as the Resource Prospector, the next generation of humanoid robots, Valkyrie, and advances in robotic arms.

NASA Public Domain Patents Benefit U.S. Industry

NASA has released 56 of its formerly patented technologies into the public domain, making them freely available for unrestricted commercial use. In addition, a searchable database is now available that catalogs thousands of expired NASA patents already in the public domain.

These technologies were developed to advance NASA missions, but may have non-aerospace applications and can be used by commercial companies free of charge, eliminating the time, expense, and paperwork often associated with licensing intellectual property. The technologies include advanced manufacturing processes, sensors, propulsion methods, rocket nozzles, thrusters, aircraft wing designs, and improved rocket safety and performance concepts.

"By making these technologies available in the public domain, we are helping foster a new era of entrepreneurship that will again place America at the forefront of high-tech manufacturing and economic competitiveness," said Daniel Lockney, NASA's Technology Transfer program executive. "By releasing this collection into the public domain, we are encouraging entrepreneurs to explore new ways to commercialize NASA technologies."

This patents release is the latest in NASA's long tradition of extending the benefits of its research and development into the public sector, where it may enhance the economy and quality of life for more Americans. NASA's patent portfolio includes more than 1,000 technologies available for industry use through licensing agreements.

Visit http://technology.nasa.gov/publicdomain.

NASA and FAA Demonstrate Wireless Communication with Aircraft

For the first time ever, engineers at NASA's Glenn Research Center conveyed aviation data — including route options and weather information — to an airplane over a wireless communication system for aircraft on the ground. The demonstration, conducted in collaboration with the Federal Aviation Administration and Hitachi, demonstrated two technologies that could change airport operations worldwide.

The FAA Bombardier Global 5000 test aircraft used in the wireless communication system demonstration. (NASA)

The team used an Aircraft Access to System Wide Information Management (SWIM), or AAtS, prototype technical solution to convey the aviation information to an FAA Bombardier Global 5000 test aircraft taxiing 60 to 70 miles per hour. They sent the information over a new wireless communication system called Aeronautical Mobile Airport Communications System (AeroMACS), which is based on WiMAX wireless communication standards, but uses different frequencies to enable connectivity on the ground.

Until now, pilots have relied on voice communication with air traffic control or their airline operations center for this type of information because traditional wireless technologies don't support high data throughputs.

Visit www.nasa.gov/topics/aeronautics.

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Products of Tomorrow

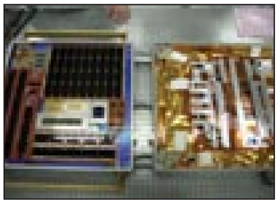
The technologies NASA develops don't just blast off into space. They also improve our lives here on Earth. Life-saving search-and-rescue tools, implantable medical devices, advances in commercial aircraft safety, increased accuracy in weather forecasting, and the miniature cameras in our cellphones are just some of the examples of NASA-developed technology used in products today.

This column presents technologies that have applications in commercial areas, possibly creating the products of tomorrow. If you are interested in licensing the technologies described here, use the contact information provided. To learn about more available technologies, visit the NASA Technology Transfer Portal at http://technology.nasa.gov.

▶ Drain System for Pools, Spas, and Tanks

Marshall Space Flight Center developed a system that reduces the entrapment risks associated with a pool or spa's recirculation drain. The technology prevents hazards caused by suction forces on the body, hair, clothing, or other articles. It uses a novel configuration of drainage openings along with parallel paths for water flow, redistributing force over a much larger area, and minimizing suction force at any localized area. With more efficient drainage and recirculation, the device improves performance, increases safety, and decreases operating costs. All of these benefits come without a protrusive drain cover, leaving the area safe and aesthetically pleasing.

Contact: Marshall Space Flight Center
Phone: 256-544-5226
E-mail: sammy.nabors@nasa.gov



▶ Specular Coatings for Composite Structures

Goddard Space Flight Center developed a method for bonding dissimilar materials using an elastic adhesive that permits the bond to withstand variations in temperature and pressure. The new method uses a combination of thermally and chemically stable materials to withstand large thermal shock loads. This innovation makes use of aluminized Kapton film that is normally used in fabricating thermal blankets for spaceflight hardware. The smooth finish and aluminum coating of the Kapton film provides the specularity. The coating method can be used in any application requiring lightweight mirrors or reflectors.

Contact: Goddard Space Flight Center
Phone: 301-286-5810
E-mail: techtransfer@gsfc.nasa.gov

▶ The Vibration Ring

Originally designed to reduce helicopter cabin noise, Glenn Research Center's vibration ring provides damping of rotors, gears, bearings, and fans within the driveline without disrupting the operation or position tolerance of a mechanical assembly. Besides significantly attenuating vibration-induced noise, it also reduces overall wear and tear, and the ring can generate electrical energy to power sensors on rotating machine parts. The ring-shaped mechanism reduces the effect of machine vibrations by converting applied vibratory energy into electricity. The mechanism is self-contained and requires no external wiring.

Contact: Glenn Research Center
Phone: 216-433-3484
E-mail: ttp@grc.nasa.gov

Who's Who at NASA

Joe Munchak, Research Meteorologist, Goddard Space Flight Center, Greenbelt, MD

Using the Global Precipitation Measurement (GPM) Core Observatory satellite, launched in 2014, NASA and Japan Aerospace Exploration Agency researchers have taken the first 3D images of raindrops and snowflakes. The GPM snapshots will help research meteorologist Joe Munchak determine precipitation rates and support the improvement of weather models.

NASA Tech Briefs: What can raindrop size tell us?

Joe Munchak: It tells us a lot about how the raindrop formed, and the type of storm that produced it. Very large raindrops have to form from melting snowflakes or hailstones. There's simply no other way to grow them from just a collection of water; they would break up hydrodynamically.

NTB: Why is a three-dimensional image so valuable?

Munchak: One of the capabilities we have with the Global Precipitation Measurement (GPM) radar is to actually probe into storms and get very fine vertical details. The vertical component really matters because we can see, at the top of the storm cloud, how the particles start to form and how they grow. Are they collecting other particles by collisions? Are they shrinking due to evaporation? Where do they melt and become rain? Or [are the particles] falling on the ground as snow?

NTB: How can that improve forecast models?

Munchak: By knowing the size of the raindrops, we actually get a more accurate measurement of the amount of rain that's falling. This is the first time we've had the technology to observe this on a global scale. With more accurate numbers, we can now determine whether or not a particular storm is likely to produce a flash flood. As we collect this data on the micro-physical properties of the storm — as well as environmental parameters such as the humidity and temperature, and where they vary regionally — we start to build a global picture.

NTB: How are these images taken?

Munchak: The Dual-frequency Precipitation Radar (DPR) was provided and built by the Japanese Space Agency. The two frequencies determine the raindrop size. The way that the radar energy reflects off of the raindrops is very dependent on both the wavelength of the radar signal and the size of the raindrop. When you have two different wavelengths for the same raindrop size, you'll get two different reflectivities. From that, you can back out the two pieces of relevant information: the average size of the raindrops and the overall number of raindrops.

NTB: What's next for the GPM mission?

Munchak: This is the first time we've had this capability in space. We need to spend some time in the next few years to understand all the potential sources of error that come from these spaceborne measurements. Once we get a handle on those, I think we'll have global maps of raindrop size, and we'll start to understand the variable processes that cause those to change globally.

*To learn more about the mission, read a full transcript, or listen to a downloadable podcast, visit **www.techbriefs.com/podcast**.*

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Advances in Coating Technology Take Shape at NASA Goddard

The Contamination and Coatings Engineering Branch at NASA's Goddard Space Flight Center in Greenbelt, MD, provides system-level support in contamination engineering and thermal coatings engineering from concept to mission end of life. This includes development, implementation, and management of instrument and spacecraft contamination control programs, technical consultation on contamination and coatings issues, thermal coatings applications, material property characterization, and coatings flight qualification.

Led by Randy Hedgeland, the branch maintains specialized laboratories for thermal coatings characterization and environmental testing, molecular kinetics testing, and surface effects measurements. Additionally, the branch designs and builds flight experiments, molecular adsorbers, custom thermal control materials, and protective coatings for astronaut visors. In support of current NASA initiatives, the branch also performs research and technology development in the areas of coatings development, extraterrestrial dust mitigation, planetary, laser damage, and advanced cleaning and verification techniques.

Recently, *NASA Tech Briefs* was given a behind-the-scenes tour of the branch's Thermal Coatings Laboratory to find out how these coatings are developed, implemented, applied, and flight-qualified for NASA missions.

Two technologies for thermal control are featured in the lab: thin film coating technologies and spray coating technologies. The lab provides the coatings that provide thermal protection for the outside of the spacecraft.

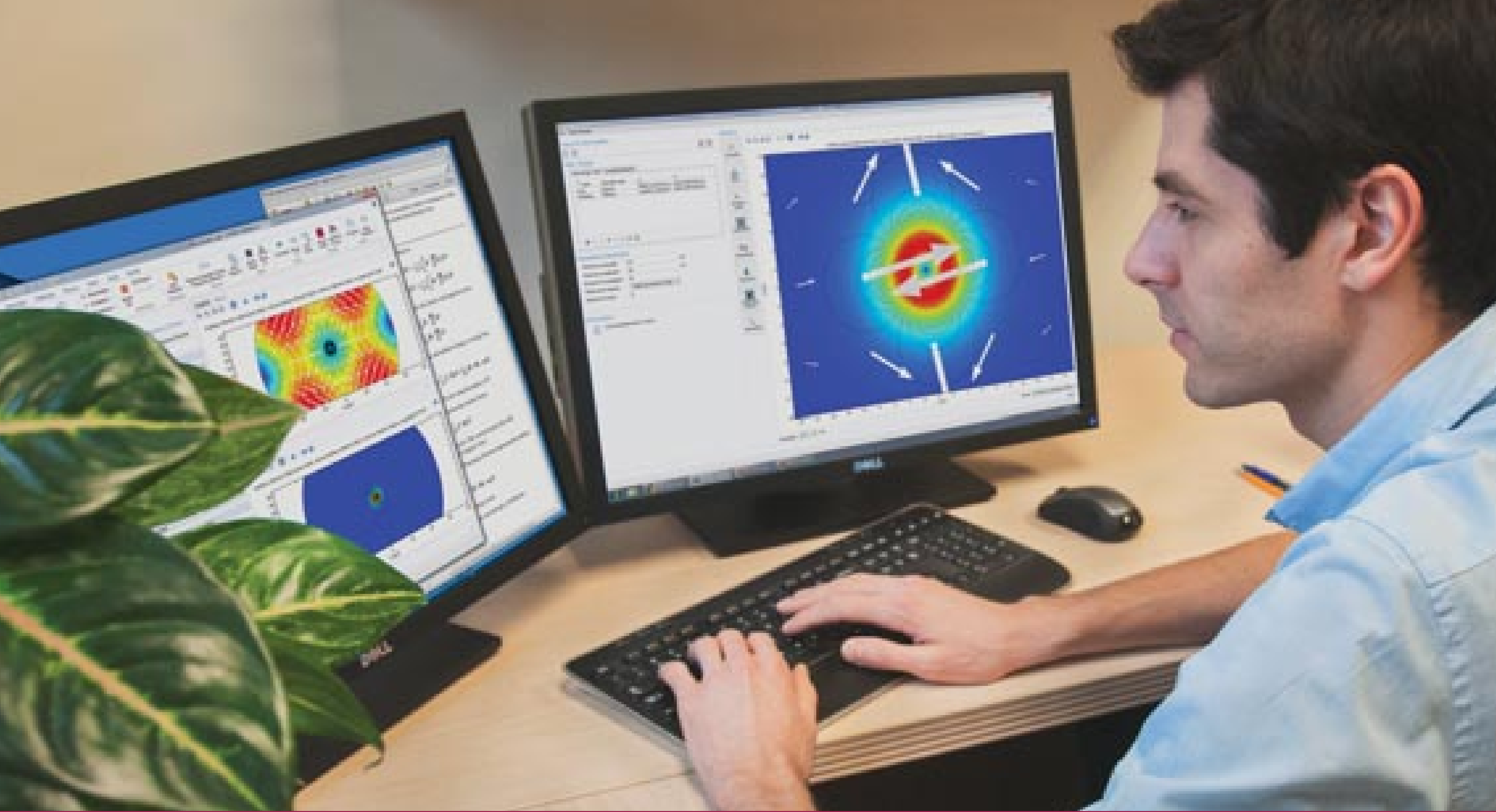
"When you look at a spacecraft, you may see five surfaces: blankets, solar arrays, antennas, instrumentation, and then the exterior coatings that are on the spacecraft. That's what we do inside this laboratory," explained Mark Hasegawa, Thermal Coatings Application and Development Group Lead.

Materials are evaporated onto spaceflight hardware, blanket material, or other surfaces that require exterior passive thermal control.

Spray Coatings

If you take a regular automotive or house coating and send it into orbit, it would darken very quickly because of particle radiation that you don't see on Earth. The ultraviolet radiation is far more intense, and the ozone in the atmosphere stops that. Most of the stable spray coatings used at the lab are silicate-based. "It's a very brittle coating," said Hasegawa. "A lot of preparation is required. You can't spray it on the way you spray an automotive coating."

The coatings developed and used in the lab must be vacuum-stable. If not, they become a contamination hazard. "You don't want optics fogging up because of contamination from coatings or materials," added Hasegawa.



In addition, the spray coatings do not outgas or transport materials out. The silicate-based materials only transport out water, which usually is not a hazard. And since space is a very cold environment, the coatings will be subjected to very cold temperatures, and then be exposed to warm bodies such as the Sun. They need to be able to survive these extreme thermal cycles. Materials on the International Space Station, for example, go through 90-minute orbits of repeated hot and cold, for thousands of thermal cycles, so the coatings must bond well and adhere well.

Thin Film Coatings

The lab is responsible for environmental testing as well as thin coating deposition via vapor deposition chambers that are used to evaporate materials onto spaceflight hardware, blanket material, or whatever surface requires passive thermal control on the exterior of the satellite.

"We coat hardware as it's rotating under vacuum with a coating developed in this lab in the 1970s, and we're still the only ones who do it," said George Harris, manager of thin film coatings technology. "It's a silver sapphire quartz coating that reflects the vast majority of the Sun's energy and also emits in the infrared interior energy created by the electronics going up in the satellite."

The coating was used in a Hubble Space Telescope repair mission after astronauts reported that the existing thermal blanket material on the exterior of the telescope was falling apart. The silver Teflon material was degrading under the combination of ultraviolet and atomic oxygen. "We coated 30 sheets of stainless steel foil with this silver composite coating, and they made blankets out of it and put them on the Hubble," explained Harris.

The silver sapphire quartz coating is being used in a robotic servicing mission to refuel on-orbit satellites in low Earth orbit for the Satellite Servicing Capabilities Office (SSCO) at Goddard. The mission satellites will experience heat from the Sun and some atomic oxygen and radiation, so the danger will be the fuel line overheating. Harris's group will be coating the exterior conduit around the fuel line. "The shuttle tiles were made out of the same material, but they were much thicker," he said. "Our coating is only about a couple of microns thick."

George Harris, manager of thin film coatings, with hardware coated with a silver sapphire quartz coating that reflects the vast majority of the Sun's energy.

Harris explained that the lab previously coated all of the astronaut visors prior to the end of the space shuttle program. But before the program shut down, they had the coating "stockpiled" so that they could continue to make visors for the astronauts for the remainder of the flights.

Additive Manufacturing

While additive manufacturing or 3D printing may not be a technology that comes to mind initially when you think of making coatings, the lab is using the technology in a number of ways. For example, additive manufacturing is being used to reduce masking and structural loading. There are multiple composite units that are circular, so only the outside can be coated, leaving the inside without coating. In order to coat the entire unit, 3D printed parts were made and the composites were stacked on top of each other to coat multiple parts in one run, as opposed to doing one at a time. This cuts down the masking requirements, along with touch time on the parts, by a factor of ten. So instead of having to mask each part, a number of them can be stacked together with minimal masking, and then they can be sprayed together.

According to Hasegawa, "For a program with 64 parts that are all the same size, it would require many hours of labor for masking and unmasking. We're trying to use additive manufacturing for automated masking to reduce the touch time."

Additive manufacturing also can be used to manufacture replacement parts for equipment used in the lab. Older spray guns, for example, require replacement parts that may be hard to obtain. By manufacturing functional parts in-house using 3D printers, the lab is able to keep the spray guns working.

Innovative Coatings

Research and development has resulted in a number of innovative coatings being created at the lab that have both current and potential future uses on a number of NASA missions. The Molecular Adsorber Coating (MAC) was developed to mitigate outgassing concerns. When you buy a new car, that "new car smell" is actually from chemicals outgassing from materials in the car. In spacecraft, those outgassed molecules can deposit on sensitive surfaces like telescopes and mirrors. MAC captures those molecules and prevents them from depositing on those sensitive surfaces.

MAC is also being used on the Ionospheric Connection Explorer (ICON) mission in the the Far Ultra-Violet (FUV) instrument to mitigate molecular outgassing. The FUV captures images of the upper atmosphere in the far ultraviolet light range. MAC can also be used inside vacuum chambers for testing, and is planned for use on the inside of the Mars 2020 rover.

Lotus Coating is a hydrophobic and dust-mitigation coating for planetary missions that prevents dirt and bacteria from sticking to and contaminating the

The lotus plant has inspired materials engineers to create a coating that mimics the plant's unusual self-cleaning capabilities, and has led to investigation of whether materials treated with these coatings could survive the harsh space environment. (Flickr Creative Commons/Liangjinjian)

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surfaces of spaceflight gear. The need for the technology arose when astronauts came back covered with lunar dust that damaged their suits.

The name for the coating comes from the method it uses to prevent contamination from sticking. It mimics that of a lotus plant shedding water. Although the lotus leaf appears smooth, under a microscope, its surface contains innumerable tiny spikes that greatly reduce the area on which water and dirt can attach. This special quality is what the NASA team is attempting to replicate to prevent dirt from accumulating on the surfaces of spacesuits, scientific instruments, robotic rovers, solar array panels, and other hardware. The coating's potential uses on Earth include car windshields, camera lenses, and eyeglasses — almost anywhere a need exists to repel dirt.

Mark Hasegawa (left) is the Thermal Coatings Application and Development Group Lead. Grace Miller is a coatings engineer at NASA Goddard who is world renowned in her field, and has worked on coatings development for virtually all NASA missions dating back to the 1960s. She recently celebrated 50 years of service at Goddard. Alfred Wong (right), a contamination engineer in the Coatings Lab, is applying additive manufacturing techniques to reduce masking steps.

Metallurgy and Material Selection

For metallurgy and material selection for projects at Goddard, Tim Stephenson, Senior Metallurgist in the Materials Engineering Branch, focuses on three major technology aspects. The first, and most recent, is the athermalization of optical structures, part of which has been inspired by the James Webb Space Telescope (JWST). The low-expansion alloy used to maintain alignment of the optical structures — the four instruments that sit inside the JWST Integrated Science Instrument Module (ISIM) — was Invar, which was discovered 100 years ago. Invar is a dense, heavy iron material, and there is almost half a ton of it on JWST. "Since mass drives launch cost, the idea was to try to lightweight this material in any way possible and still have it behave the way we want it to behave — in other words, not change dimensionally with temperature," said Stephenson.

Thermal coatings engineer Nithin Abraham applies a spray coating in the Contamination and Coating Lab.

A second aspect of his work is tailoring thermal expansion. Stresses developed in structures as temperatures change are minimized if they move in lockstep with each other. "We have an active effort in developing silicon optics using single crystal silicon. I can match thermal expansion to zinc solenoid, beryllium, and Schott glasses that were going to be used for x-ray optics, and that's shifted back to silicon. That's all part of the athermalization to minimize the distortion that occurs when we change temperature," Stephenson explained.

The third area is tailoring the geometry of structures to select a natural frequency response; materials that will null out low-frequency vibrations and tolerate high-frequency vibrations. "This has a lot to do with sensitive instruments on the top of a rocket. We can put more sensitive instruments into space if we can tailor the materials around them to null out the damaging frequencies," he said.

The promise of additive manufacturing technology also is evident in metallurgy. One of the challenging issues with additive manufacturing as far as making structural components, according to Stephenson, is trying to understand their damage tolerance — what is the critical flaw size? "In raw materials, that's pretty easy to do. It's more of a challenge with metal matrix composites and ceramic matrix composites," he explained. "But with additive manufacturing, you're essentially building things up using the material almost as if it's a continuous weld. That's a challenge. There's a whole non-destructive evaluation staff that's making rocket components using additive manufacturing.

"Once you look at the cost from idea to actual implementation, about 10% of the cost is in the development of the concept, and about 90% is in the scale-up to actually make it useful. There are a lot of custom things we can do in additive manufacturing that aren't done in the commercial sector that are driven specifically to cut cost — mixing and matching materials, developing functional structures for natural frequency tailoring," Stephenson said.

"A lot of the things I've worked on have been in response to the science people saying, 'I wish we had a material that would …,' and I say, 'I can help you out with that.'"

RESOURCES

For more information, contact Dennis Small in Goddard's Strategic Partnerships Program Office at 301-286-5810, or email techtransfer@gsfc.nasa.gov.

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Large NASA production facilities, such as the Michoud Assembly Facility (MAF) in New Orleans, are among the largest manufacturing facilities in the world, with more than 1,870,000 square feet of floor space for assembly and manufacturing space that NASA shares with commercial aerospace and U.S. government contractors. A major activity at MAF is the assembly of core stage components for NASA's Space Launch System (SLS) rocket program. The most powerful rocket ever built, the SLS will be capable of carrying the highest payload mass in history. When fully assembled, the SLS measures 322 feet high with a launch weight of 5.5 million pounds, and a payload capacity of 77 tons. NASA uses Wheelift® Self-Propelled Modular Transporters (SPMTs), manufactured by Doerfer Companies of Waverly, IA, to move the rocket components.

Key components in the assembly include the liquid oxygen and liquid hydrogen tanks. Representing comparatively smaller rocket components, intertank manufacturing is also handled at MAF. Large sections of the various tanks must be moved throughout assembly and manufacturing processes; when the tanks are complete, they are moved out of the manufacturing facility via SPMT equipment and cranes to be packed and shipped to the launch site, typically by sea on a barge.

Operator control of the Wheelift is handled primarily through an intuitive radio interface. While one Wheelift is more than enough for most applications, NASA applications are much more elaborate. Multiple Wheelift vehicles must work together to pick up large loads and even pick up multiple points of especially heavy loads. In order to safely move such large pieces of equipment over distances as far as 1 to 2 miles, four separate Wheelift SPMTs are coordinated together, holding large fixtures to cradle the NASA rocket components. This required Doerfer to gather continuous feedback from the fixture that supports the various tanks to maintain precise alignment of the load.

Four Wheelift SPMTs are each rated for up to 100-ton load capacity, and together move the rocket stage equipment onto a public road, over a levee, and onto a barge. The Wheelift SPMTs and rocket components then travel by barge to the next NASA facility. Wheelift transporters integrate Uniload® fluid-equalizing suspension technology across every axle in the system, increasing capacities to a virtually unlimited weight. Each of the wheels on the Wheelift automatically holds their own share of the load, and permits omni-directional movement for limitless options for steering and positioning.

It is challenging to maintain coordination of multiple SPMTs balancing a support fixture over difficult ground conditions such as bumps and other elevation changes in plant floors and pathways. Managing these loads also requires heavy-duty servomotors and tires, as well as an advanced automation and control system that can keep up with constantly changing conditions. Through an advanced PC-based control platform from Beckhoff Automation, the engineers at Doerfer ensure that the Wheelift can compensate for this according to feedback from the support fixtures, and reposition SPMTs as needed.

Doerfer dynamically sets the SPMTs to work together and share load or torque in different groups within a synchronized system. Hundreds of tons of rocket components must travel over production floors and pathways without damaging the surfaces, as these are likely not reinforced for such extremely heavy loads. The Wheelift system addresses this and other issues, designed such that it does not apply excessive force underneath the SPMTs or across the support fixture. This avoids imbalances and potential damage to the fixture and the fuel tank components in transport. The four SPMTs, working in tandem, must constantly maintain safe velocity and steering centers.

Leveraging TwinCAT 3 automation software from Beckhoff, Doerfer has designated one SPMT that works as the "master" for the vehicle group with the others following as slaves in an object-oriented control architecture. Each of the Wheelift SPMTs oper-

Since January 2014, Wheelift Self-Propelled Modular Transporters (SPMTs) have been used by NASA to transport SLS rockets and components from site to site.

A PC-based control platform from Beckhoff Automation ensures that the Wheelift can handle changing, frequently uneven terrain, and reposition SPMTs as needed.

Motion control for the Wheelift wheels is handled by Beckhoff AX5000 servo drives and AM3000 servomotors.

ates via the TwinCAT 3 PLC runtime, loaded on Beckhoff CP6201 Panel PCs with Intel® Core™2 Duo processors. The newest generation of Wheelift SPMTs accomplishes this via DIN rail mounted Beckhoff CX2030 embedded PCs. The HMI devices mounted directly on the Wheelift are Beckhoff CP29xx series multi-touch control panels. EtherCAT serves both as the I/O and drive bus in Wheelift SPMTs for sub-millisecond communication times and flexible connectivity to other bus systems. The terminals are connected to hardware e-stop buttons, and also activate with any loss of radio communications.

The automation system on the Wheelift, which can have as many as 24 axes per vehicle, must handle highly advanced positioning algorithms to successfully compensate for the movement of extremely heavy loads. Motion control for Doerfer's heavy-duty Uniload wheels on the Wheelift is handled by AX5000 EtherCAT servo drives and AM3000 servomotors from Beckhoff.

For the support fixtures that cradle the rocket sections, the Doerfer team was required to control rotation at ±4 degrees, and the Wheelift held that to ±0.25 degree. Doerfer held the maximum distance between the two fixtures to about 3/8".

Since NASA began using the Wheelift vehicles, which measure less than 22" high, the Agency has successfully avoided major new infrastructure investments at their manufacturing sites. Doerfer is able to prepare the Wheelift SPMTs, load them, and run them on the plant floor for NASA in a week or less.

For Free Info Visit http://info.hotims.com/61062-115

 Free Info at http://info.hotims.com/61062-726

Predicting Magnetospheric Relativistic >1 MeV Electrons

NASA's Jet Propulsion Laboratory, Pasadena, California

There is an association between High-Intensity Long-Duration Continuous AE (HILDCAA) activity intervals and the acceleration of relativistic >1 MeV electrons in the magnetosphere. All of the HILDCAAs that occurred in solar cycle 23 (SC23) from 1995 to 2008 led to the acceleration of E>0.6 MeV, >2.0 MeV, and >4.0 MeV electrons in the Earth's outer radiation belts. What is particularly noteworthy is that the E>0.6 MeV electron acceleration was delayed ~1.0 day after the onset of the HILDCAA event, the E>2.0 MeV electrons delayed ~1.5 days after the onset of the HILDCAA event, and the E>4.0 MeV electrons delayed ~2.5 days after the onset of the HILDCAA event.

Because relativistic electrons can be damaging to spacecraft in Earth orbit, knowledge of future enhanced radiation will allow spacecraft engineers to "safe" their spacecraft from the upcoming radiation. The investigators worked to understand if it was solar and interplanetary forcing that was causing the radiation near Earth. A likely scenario is that high-speed solar wind streams come from coronal holes on the Sun. The embedded Alfvén waves in the solar wind plasma cause reconnection of magnetic fields on the dayside of the Earth's magnetosphere, and the solar wind convects the fields and plasma to the tail. After the magnetic fields reconnect in the tail, the plasma is heated as it is injected into the nightside region of the magnetosphere. The energetic ~10 to 100 keV electrons generate electromagnetic waves called chorus waves, which interact with the ~100 keV electrons to accelerate them to ~MeV energies. Interplanetary space data and solar information gathered from NASA, ESA, and NOAA satellites were used to solve the problem.

This work was done by Bruce T. Tsurutani of Caltech; Rajkumar Hajra, Ezequiel Echer, and Walter D. Gonzalez of Institute Nacional de Pesquisas Espaciais, Sao Jose dos Campos, Brazil; and Ondrej Santolik of the Institute of Atmospheric Physics and Charles University, Prague Czech Republic, for NASA's Jet Propulsion Laboratory. ***This software is available for license through the Jet Propulsion Laboratory, and you may request a license at: https://download.jpl.nasa.gov/ops/request/request_introduction.cfm.*** *NPO-49852*

Optimal Prioritized Actuator Allocation

This allocation could improve the safety and autonomy of missions where it is critical to match torque first to minimize disturbances to spacecraft pointing.

NASA's Jet Propulsion Laboratory, Pasadena, California

For formation flying, rendezvous and docking, and proximity operations with small bodies of the solar system, spacecraft require simultaneous translational and rotational agility. The necessary agility is generally provided by combinations of multiple small thrusters and torque-only actuators. To use these actuators, an onboard control system first calculates desired forces and torques that cause a spacecraft to follow a desired trajectory. Then the commanded forces and torques are turned into individual commands to specific actuators such that the combined action of all the actuators realizes as closely as possible the commanded forces and torques. This problem is referred to as actuator (or control) allocation.

Actuator allocation is fundamentally a constrained optimization problem: given the actuator configuration, find individual actuator commands that minimize the difference between the desired force and torque, and the total force and torque resulting from the individual actuator commands. Mission constraints and in-flight failures limit the configuration of actuators on a spacecraft, in turn limiting the ability to achieve the commanded forces and torques. Further, off-nominal situations can result in commands that require more agility than the actuators can provide. When a desired maneuver exceeds the capabilities of the actuators, it is often more important to maintain pointing — that is, prioritize torques — so translational engines stay pointed in the correct direction and appendages do not strike other bodies.

Prioritized allocation is achieved by solving three or more successive optimization problems instead of the standard two. This approach extends Bodson's framework, where the principal novelty is to explicitly prioritize — rather than weight the force and torque components — by introducing additional, successive optimization problems. The new approach consists of solving each level of prioritization with a constraint that ensures the performance of the preceding optimizations is maintained. For example, first match the commanded torque as closely as possible. Then a second optimization problem is solved that minimizes the error between desired and allocated force with an additional constraint that maintains the optimal torque-matching performance from the first optimization problem. In this way, torque is prioritized over force. Finally, the overall actuator command vector is minimized as in the standard approach. In all optimizations, the maximum impulse constraint is also enforced.

The explicit prioritization developed here is different than weighting. Weighting will not give best torque followed by best force, but rather, 99% best torque and conceivably very poor force matching since it is de-weighted. Further, the approach is generalizable to any prioritization of the six degrees of freedom; for example, when near the surface of a small body matching

tip/tilt torque, then axial force, then twist torque, and finally lateral forces.

The main application is attitude and position control of spacecraft. A prioritized thrust allocator is directly applicable and could improve the safety and autonomy of the proposed Asteroid Redirect and Return Mission (ARRM), asteroid/comet sample return missions, autonomous and piloted rendezvous and docking, and precision formation flying missions concepts such as Exo-S, where it is critical to match torque first to minimize disturbances to spacecraft pointing.

This work was done by Daniel P. Scharf, Milan Mandic, and Jordi Casoliva of Caltech for NASA's Jet Propulsion Laboratory. ***This software is available for license through the Jet Propulsion Laboratory, and you may request a license at: https://download.jpl.nasa.gov/ops/request/request_introduction.cfm.*** *NPO-49675*

Terrain Model Registration

Model registration solves target tracking and target handoff problems.

Ames Research Center, Moffett Field, California

This technology is a method for registration of terrain models created using stereovision on a planetary rover. Most 3D model registration approaches use some variant of iterated closest point (ICP), which minimizes a norm based on the distances between corresponding points on an arbitrary 3D surface where closest points are taken to be corresponding points. The approach taken here instead projects the two surface models into a common viewpoint, rendering the models as they would be seen from a single range sensor. Correspondence is established by determining which points on the two surfaces project to the same location on the virtual range sensor image plane. The norm of the deviations in observed depth at all pixels is used as the objective function, and the algorithm finds the rigid transformation, which minimizes the norm. This recovered transformation can be used for visual odometry, rover pose estimation, and feature handoff.

Single cycle instrument placement (SCIP) is the single greatest autonomy need for the next generation of Mars rovers. The goal of SCIP is to enable a planetary rover to approach and place an instrument on a scientifically interesting point on the terrain from a distance of ten meters. This must happen within one command cycle, so that after an operator selects a science target and uploads a command, the next response from the rover is the requested science measurement from the target.

The first step in SCIP is the navigation of the rover to a location that places the point of interest within the workspace of the arm that carries an instrument. Uncertainty about the exact target position and accumulated rover localization errors requires that the rover actively keep track of where the target is in relation to itself as it navigates towards it. Once positioned, the rover evaluates the target to ensure the instrument can be safely placed, and then moves it into place with the arm.

Terrain model registration can solve both the target tracking and target handoff problems. Tracking is done by registering successively acquired terrain models of the target area to the initially acquired model of the target. Tracking also provides information about rover motion between views. Handoff is done by registering the target models from two sensors.

Registration of 3D surface models is an attractive approach for rover localization. As long as the lighting conditions permit the acquisition of images for stereo, the resulting 3D surface models are independent of the lighting conditions. This is attractive compared to 2D approaches that might have difficulty with tracking features or recognizing places when lighting conditions change.

During testing, surface models were not "cleaned" in any way, and the results are still promising. Other reported approaches require mesh regularization and cleaning in order to ensure that there are no outliers before minimizing a norm that is sensitive to large deviations. These steps may improve the results achievable using robust estimation, but empirically are not required for it to work.

This work was done by Matthew Deans, Clayton Kunz, and James Sargent for Ames Research Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact David Morse at david.r.morse@nasa.gov or 650-604-4724.*** *ARC-15432-1*

Error Budget for Pointing at Surface Features From Close Range

NASA's Jet Propulsion Laboratory, Pasadena, California

Traditional error budgets that characterize pointing capability in terms of a single radial angle lack sufficient information to support analysis of pointing error in terms of distance along a nearby surface.

This work characterizes all sources of angular pointing error in terms of the traditional radial angle, plus a distance from the source of the error to the surface. Translational errors (which don't apply for celestial pointing distances) were added to the error budget.

The novelty here is the introduction of the concept of an "effective origin of error" and inclusion of translational error, and the derivation of a new mathematical formulation. This innovation is useful for calculating error for any spacecraft pointing at a nearby surface.

This work was done by Stephen F. Peters of Caltech for NASA's Jet Propulsion Laboratory. ***This software is available for license through the Jet Propulsion Laboratory, and you may request a license at: https://download.jpl.nasa.gov/ops/request/request_introduction.cfm.*** *NPO-49661*

Traceable Automation with Remote Display and Interruptible Scheduler Version 1.04.0

Many complex procedures can be completed more quickly, under controlled conditions, and without human intervention or error.

NASA's Jet Propulsion Laboratory, Pasadena, California

Traceable Automation with Remote Display and Interruptible Scheduler (TARDIS) is a software set designed for use in ground operations. TARDIS is a multi-mission automation framework that supports seamless integration of manual and automatic processing. It was developed to automate mission design and navigation (MDN) procedures, but is general enough to automate many other kinds of procedures as well. It allows users to define the tasks to run and the circumstances under which to run them. Thereafter, TARDIS watches the entire host computer and automatically runs the corresponding tasks as conditions change. It also watches the tasks as they run and logs their results. It provides a graphical user interface (GUI) front end, so users can monitor and control system state and task progress from any Web browser. As a result, many complex procedures can be completed more quickly, under controlled conditions, and without human intervention or error.

TARDIS allows users to define arbitrarily complex circumstances under which to run each task. These circumstances include (a) time-based events, e.g. twice per hour on every weeknight; (b) file-based events, e.g. whenever at least three new files appear with names matching some desired pattern; (c) task-based events, e.g. whenever another task named "XYZ" has completed; and (d) arbitrarily complex combinations of any or all of those kinds of events, e.g. whenever J and K both happen OR L and M both happen, OR three Ks and two Ms all happen.

It allows users to connect tasks together into higher-level procedures, running different sequences of tasks according to the actual state of the host computer, whether various tasks pass or fail, what inputs become available at different times, and more. It also allows users to intervene for any tasks in a procedure, e.g. to keep correcting errors and rerunning a task until it completes successfully. These manual interventions may occur at any time, after which the user may tell TARDIS to continue automatic processing from that point forward. All the while, TARDIS can perform automatic processing of other, unrelated tasks in any procedure.

It can salvage and optionally restart interrupted tasks, even if the entire host system crashes without warning and is rebooted later. Processing continues with whichever tasks were running when the host system crashed. In addition to its command line user interface (CLUI), TARDIS provides a GUI to allow users to monitor and control the state of the host computer and the progress of every task. Because its GUI is Web-based, users can run it in any browser from any computer.

This work was done by Richard M. Kelly, Ian M. Roundhill, Jae H. Lee, and Ahlam A. Attiyah of Caltech for NASA's Jet Propulsion Laboratory. ***This software is available for license through the Jet Propulsion Laboratory, and you may request a license at: https://download.jpl.nasa.gov/ops/request/request_introduction.cfm.*** *NPO-49507*

Java Pathfinder (JPF) Core System

Ames Research Center, Moffett Field, California

The JPF Core System is a framework to analyze and verify Java bytecode programs. The major component of JPF core is an extensible and runtime-configurable virtual machine (VM) that can be customized with runtime components such as specific instruction sets and plug-ins to observe program execution. The JPF core can store and restore program states, and comes with a configuration that constitutes a standalone software model checker that can be used to detect and analyze concurrency defects in Java applications like deadlocks or data race conditions.

The underlying key capability of the JPF VM is to execute the system under test in many alternative ways, thus achieving significantly better coverage than traditional testing, while providing better insight into execution details. The main design goal of the JPF core framework is its extensibility. It therefore is a suitable basis for creating specialized, runtime-configured verification tools that use the JPF core libraries to perform tasks such as test case generation or user interface model checking.

This work was done by Peter Mehlitz of SGT, Inc. for Ames Research Center. ***This software is available for use. To request a copy, please visit https://software.nasa.gov/software/ARC-17487-1.***

Single Doppler Retrieval Toolkit (SingleDop)

Marshall Space Flight Center, Alabama

Single-Doppler retrieval of low-level, two-dimensional winds is desired to compare ground radar wind retrievals to satellite scatterometer wind retrievals. This needs to be integrated within the growing collection of open-source radar tools maintained by the Python Atmospheric/Ocean Sciences (PyAOS) community. SingleDop is a software module written in Python that retrieves 2D, low-level winds from either real or simulated Doppler radar data.

It ingests Doppler radar data using the Department of Energy's Py-ART open-source radar software toolkit, or specifies synthetic wind data. After analysis, the user has options to either plot the retrieved 2D wind data or save them. It works using the IPython interactive command line interface, or the user can write a script that calls the module to do analyses and plots in batch mode. The interface is simplified to a single line of code in the end user's Python scripts, making implementation of the algorithm in research analyses very easy.

Simple visualization (including vector and contour plots) and save/load routines (to preserve analysis results) are provided.

This work was done by Timothy Lang of Marshall Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Ronald C. Darty at Ronald.C.Darty@nasa.gov.*** *MFS-33272-1*

Computing Efficient Onboard Analysis and Re-Scheduling

The objective is to speed up the responsiveness to onboard decision-making.

NASA's Jet Propulsion Laboratory, Pasadena, California

Prior space missions have not routinely used onboard decision-making. The Autonomous Sciencecraft (ASE), flying onboard the Earth Observing One spacecraft, has been flying autonomous agent software for the past decade that enables it to analyze acquired imagery onboard, and use that analysis to determine future imaging. However, ASE takes approximately one hour to analyze and respond.

A scheduling prototype was developed for the Earth Observing Autonomy (EOA) project to increase the responsiveness of spacecraft flight software for onboard decision-making, as well as to increase the capabilities of flight software. Specifically, onboard image analysis and response performance are estimated to be in the minutes range operating on standard flight hardware. This work focused on the re-scheduling of the future image acquisitions in the context of an existing set of requests, along with new requests based on onboard analysis of just-acquired imagery.

The software prototype of the EOA capability includes several autonomy components:

1. Onboard science processing algorithms. Science analysis algorithms process onboard image data to detect science events and suggest reactions to maximize science return. Specifically, the use of the Mixture-Tuned Match Filter (MTMF) for onboard spectral analysis of acquired imagery was investigated, but ASE has already demonstrated the utility of thermal analysis for volcanoes and wildfires, spec-

tral analysis for flooding, spectral analysis for cryosphere study, as well as spectral unmixing for mineralogical analysis.

2. Onboard planning and scheduling software. The Continuous Activity Scheduling Planning Execution and Replanning (CASPER), combined with the Eagle Eye Mission Planning Software system, generates a baseline mission operations plan from observation requests. This baseline plan is subject to considerable modification onboard in response to data analysis from step 1. The model-based planning algorithms enable rapid response to a wide range of operations scenarios based on models of spacecraft constraints.

3. Robust execution software. The JPL core flight software (CFS) expands the CASPER mission plan to low-level spacecraft commands, and includes a powerful and expressive sequencing engine. The CFS sequencing engine monitors the execution of the plan and has the flexibility and knowledge to perform improvements in execution as well as local responses to anomalies.

This work was done by Dero Gharibian and Steve A. Chien of Caltech for NASA's Jet Propulsion Laboratory. ***This software is available for license through the Jet Propulsion Laboratory, and you may request a license at: https://download.jpl.nasa.gov/ops/request/request_introduction.cfm.*** *NPO-49806*

libSPRITE

Marshall Space Flight Center, Alabama

libSPRITE is a set of software libraries used in the development of software applications. The libraries provide components for encoding engineering units, math functions, a task scheduler built on top of pthreads, a publish/subscribe data distribution system, and a Lua scripting language interface.

libSPRITE is composed of the following components: Base, Units (depends on Base), Utilities (depends on Base), Math (depends on Units), SRTX (depends on Units), and SCALE (depends on SCALE).

libSPRITE was specifically designed for real-time systems that operate on a single computational node, but may be multicore. Of primary importance was to systematically address common coding errors, provide for multi-threaded programming that produces the exact same results regardless of the number of cores on fee host compute node, and provide support for in-operation reconfigurability (parameter and control flow modifications).

libSPRITE was designed to host both flight software and simulations. The rationale for that decision was to enable application-level software development to take place on non-flight hardware thus reducing bottlenecks caused by limited access to flight hardware. To achieve this, it was important that fee code execute the same on fee multicore systems typically found on desktops and laptops, and single-core systems typically found on spacecraft. A side benefit of this approach is that simulations can also be developed on this framework and deployed on systems with varying numbers of processors/cores while achieving repeatable results.

The intent is to open-source the software to ease leveraging community-based development.

This software is available for use. To request a copy, please visit https://software.nasa.gov/software/MFS-33231-1.

Tool for Rapid Analysis of Monte Carlo (TRAM) Simulation Data

This tool can be used in any engineering industry that uses Monte Carlo simulations as part of a design and analysis process.

Lyndon B. Johnson Space Center, Houston, Texas

Spacecraft design is inherently difficult due to the complexity of the systems involved and the expense of testing hardware in a realistic environment. The number and cost of flight tests can be reduced by performing extensive simulation and analysis studies to understand vehicle operating limits and identify circumstances that lead to mission failure. A Monte Carlo simulation approach that varies a wide range of parameters is typically used to generate a large set of test scenarios. The results of these analyses bound the vehicle performance and eventually help certify a spacecraft for flight.

Identifying variables that drive the design is crucial to ensure safety and reliability of a spacecraft. The Monte Carlo simulation process is perhaps the most important, and also the most time-consuming, part of the design and analysis cycle of any space vehicle. Engineers seek to pinpoint influential variables that directly affect a particular system requirement in order to address the necessary changes in the design. The main objective of TRAM is to accelerate the data analysis process while providing engineers with more confidence in their analysis results than when the analysis process is done manually.

Monte Carlo data analysis for problems with a relatively small number of design variables has been addressed in a number of ways, but the analysis of data for fully integrated spacecraft has mostly been performed manually on an individual basis by a large number of people working simultaneously.

TRAM combines different pattern-recognition algorithms into an interactive analysis tool that allows a user to explore large data sets in a very efficient manner. TRAM automatically searches data sets for specific patterns and highlights critical design variables so engineers can focus their analysis efforts. This tool does not replace the analysts, but it can quickly point them to the design variables responsible for specific system failures. The tool streamlines the process of verifying performance requirements, making decisions on which design parameters must be updated, and reporting problems to other team members. Current results show that this tool can quickly and automatically identify individual design parameters, and most importantly, combinations of up to four design parameters that play a significant role in any specified system failures. TRAM was originally developed to analyze sets of flight dynamics Monte Carlo data, but the algorithms are applicable to any Monte Carlo data set. The inputs and outputs of TRAM have a very generic format, so the process can be applicable to any other engineering design problem with a large number of design parameters.

TRAM has two main pieces of code: A MATLAB graphical user interface (GUI) that contains some of the analysis algorithms, and a parallel code that runs on a graphical processing unit (GPU) located on a JSC server that contains the rest of the analysis algorithms. The MATLAB user interface takes the Monte Carlo data in the form of three MATLAB files. The GUI allows the analyst to select analysis variables and system performance metrics for a given analysis task. The MATLAB GUI sends the data to the GPU, where it runs through the analysis algorithms. The GPU sends the data back to the MATLAB GUI, where the user has the chance to display it graphically and further explore the results.

TRAM requires only three inputs in a very simple format so that any Monte Carlo data set can be quickly prepared for analysis. TRAM never manipulates the Monte Carlo data, it does not make any assumptions, it does not normalize the data, and it keeps original physical units throughout the analysis process. TRAM treats all design parameters as equals, and it does not require the analyst to categorize or group different types of variables. This allows a user to analyze a system as a whole rather than analyzing each subsystem separately.

The algorithms are based on two well-known pattern recognition algorithms: kernel density estimation and k-nearest neighbors. However, the results of these two algorithms are combined in a novel manner in order to rank the design variables and variable subspaces in order of importance. The cost function that represents the influence of a parameter on a specified failure was developed specifically for TRAM.

This work was done by Carolina Restrepo and Kurt McCall of Johnson Space Center, and James Garton of Texas A&M University. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact jsc-techtran@mail.nasa.gov.*** *MSC-25231-1*

Object-Oriented FITS File Interface for MATLAB

Goddard Space Flight Center, Greenbelt, Maryland

The ability to read complicated Flexible Image Transport System (FITS) files in MATLAB was required for analyzing data from the Integrated Science Instrument Module (ISIM) cryovac test campaign for the James Webb Space Telescope (JWST) project. This software was written to fill that specific need, but is more generally applicable.

FITS is the predominant file format for storing image data from astronomical telescopes, including ground test campaigns. This software provides an object-oriented interface for easily reading and writing FITS files in the MATLAB computing environment, and allows the user to more easily manipulate more complicated aspects of the standard, including header data and multiple header data units (HDUs).

Image data from the ISIM of the JWST is encoded in the FITS format. Portions of this data are analyzed using software written in MATLAB. While MATLAB does provide both high- and low-level interfaces for reading files in the FITS file format, those interfaces do not present a unified method for reading and writing header data and multiple header-data units. This software provides the user with a convenient interface for manipulating these more complicated aspects of the FITS file format in the MATLAB programming language.

This work was done by Thomas Zielinski of Goddard Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Scott Leonardi at Robert.S.Leonardi@nasa.gov.*** *GSC-17165-1*

Space Station Research Explorer

This program presents experiments, facilities, and research results from the International Space Station in formats that could be easily understood by a wide audience.

Lyndon B. Johnson Space Center, Houston, Texas

The Space Station Research Explorer provides current information on International Space Station (ISS) experiments, facilities, and research results through video, photos, interactive media, and in-depth descriptions on iOS and Android devices.

The Experiments section provides access to the six main experiment categories and their subcategories. Experiments are depicted as dots within the category system, and the stems connecting the dots to the system depict the length of time the experiment spent on orbit. Users can drill down to see specific experiments within the categories and subcategories, or search for a specific experiment or subject using the search option. Experiment descriptions consist of links, images, and publications if available. The Experiments section can be further narrowed by selecting a specific expedition and sponsor by using the dials at the top right of the screen.

The Facilities section provides an interior view of three of the station modules: Columbus, Kibo, and Destiny. Once the module is selected, the interior image can be navigated by dragging up and down to see different sides of the module, and left and right to view any racks not shown on the screen. Tapping a rack gives a brief description of the rack and an experiment description if available.

The Benefits section provides information on Human Health, Earth Benefits, and Global Education. Selecting a section allows the benefits to be investigated further. The Media section provides access to three tabs: Podcasts, Games, and Videos. The Games section contains a game that introduces players to the differences in gravity when tossing a ball. Podcasts contains links to NASA ScienceCasts, and Videos contains links to science-related videos. The last section contains links to other Space Station research sites and NASA applications.

The application was built using the Unity Game Engine for cross-platform compatibility and is available for iOS and Android platforms through iTunes and Google Play. Updates are provided on a regular basis.

This work was done by Sharon Goza and David Shores of Johnson Space Center; and William Leu, Raymond Kraesig, Eric Richeson, Clinton Wallace, Moses Hernandez, Cheyenne McKeegan, Logan Kelly, and Michael Kray of Tietronix Software, Inc. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact jsc-techtran@mail.nasa.gov.*** *MSC-25829*

Intro Cov ToC

Integrated Circuit for Radio Astronomy Correlators Supporting Large Arrays of Antennas

NASA's Jet Propulsion Laboratory, Pasadena, California

Radio telescopes that employ arrays of many antennas are in operation, and ever-larger ones are being designed and proposed. Signals from the antennas are combined by cross-correlation. While the cost of most components of the telescope is proportional to the number of antennas, N, the cost and power consumption of cross-correlation are proportional to N^2, and dominate at sufficiently large N. As radio telescopes get larger, there is a need to provide digital-signal-processing electronics that are smaller and less power-hungry than would be implied by the extrapolation of existing designs.

The goal of this work was to develop a custom integrated circuit (IC) that performs one of the most power-consuming processes — correlation — using an efficient architecture. The IC performs digital cross-correlations for arbitrarily many antennas in a power-efficient way. It uses an intrinsically low-power architecture in which the movement of data between devices is minimized. In a large system, each IC performs correlations for all pairs of antennas, but for a portion of the telescope's bandwidth. In this design, the correlations are performed in an array of 4,096 complex multiply-accumulate (CMAC) units. This is sufficient to perform all correlations in parallel for 64 signals. When N is larger, the input data are buffered in an on-chip memory, and the CMACs are re-used as many times as needed to compute all correlations. The design has been synthesized and simulated so as to obtain accurate estimates of the IC's size and power consumption. As of this writing, physical design (layout) and fabrication of prototypes remain to be done.

The IC design provides a power-efficient means of computing all cross-correlations among many signals. The power efficiency is more than two orders of magnitude better than that of existing large correlators, and about a factor of 20 better than planned correlators based on future-generation field-programmable gate arrays (FPGAs). The IC is flexible in that it can be used to construct correlators for almost any number of antennas, although its efficiency is best if N is a multiple of 64.

This work was done by Douglas Wang and Larry R. D'Addario of Caltech for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-50004*

Fabrication of Silicon-Leg Isolated Bi-Cr Thermopiles

Goddard Space Flight Center, Greenbelt, Maryland

The objective of this innovation was to develop a methodology of fabricating thermopile detectors using standard semiconductor fabrication techniques. The goal was to develop a fabrication process that minimized the roughening of the Si legs during patterning of the metallic couples, and to enable delineation of the Si legs without the use of highly toxic or carcinogenic chemicals. Another key requirement was at least 50% optical absorbance across the spectral band.

Prior techniques to pattern metallic thin films on thin Si membranes typically involved etchants that roughen the Si itself. Furthermore, most methods used to delineate Si legs involved the use of potassium hydroxide, which is highly toxic, or trichloroethylene, which is carcinogenic. Typical means to achieve high absorption include the use of Bi thin film, which has poor adhesion to Si, and gold black, which is very difficult to delineate.

This innovation involves a fabrication methodology for realizing a silicon-leg isolated thermopile detector. The detector consists of one or more sets of Bi-Cr couples. The detector is designed to operate between 170 and 300 K in the 14-to-400-micron spectral band, and may be used for thermal mapping of outer planet targets (e.g., Jupiter and its moons). Functional operation of the process involved performing the actual fabrication inside a Class 100 cleanroom.

Alternate embodiments of the innovation would include the use of thermopile materials different from the Bi and Cr used; this is a generic process that can be used for a wide variety of different thermopiles and other thermal detectors. This process resulted in the development of TiN thin film absorbers, which have been demonstrated to have >50% absorption over a 14-to-400-micron spectral range; the development of a TiN etching process that does not etch the Si membrane; and the development of a Si leg delineation process, which does not involve the use of highly toxic or carcinogenic chemicals.

The highly absorbent thin film can be lithographically defined, and is thermally and mechanically robust. Analysis of the innovation's capabilities was evaluated by considering the device yield. A device yield >99% was achieved using this fabrication process.

This work was done by Ari Brown of Goddard Space Flight Center, Elbara Ziade of Boston University, and Vilem Mikula of Catholic University of America. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Scott Leonardi at Robert.S.Leonardi@nasa.gov.*** *GSC-16999-1*

Current Source Logic Gate

John H. Glenn Research Center, Cleveland, Ohio

High-temperature electronic integrated circuits have been demonstrated in silicon carbide (SiC) depletion mode MESFETs. This process is only capable of producing depletion mode n-channel MESFET transistors. With only this type of transistor, designing a logic gate is a challenge. A previous logic gate design that can be constructed in the current process has performed well. This invention improves upon the previous design by increasing output voltage range and decreasing the physical layout size of a logic gate. This logic gate circuit consists of depletion mode MESFET/JFET transistors and resistors that can be constructed with SiC depletion mode n-channel MESFETs.

The circuit is comprised of three circuit constructs: a current source (Q_1 and R_s) consisting of one transistor and one resistor, a current steering switch input stage (Q_2) consisting of at least one transistor, and a resistor divider level shifting output stage (R_1 and R_2). The current source comprised of Q_1 and R_s provides current to bias the output stage, and limits the total device current in the logic gate. The current steering input stage of Q_2 steers current to set the output stage bias point, depending on input logic signal state. Finally, the resistor divider level shifting output stage sets the output stage bias points and further develops valid output logic signal states.

The circuit has two operating points: logic high input and logic low input. As the basis gate for logic functions, the simplest function performed by the gate is the inverting or NOT function, which results in a logic high output for a logic low input, and a logic low output for logic high input. As an inverting logic gate, and treating the current steering input stage transistor as a switch, the circuit will have two ideal operating points. These ideal operating points illustrate optimal circuit operation; realized circuit operating points will differ from the ideal cases, but operation is similar. The logic level high refers to 0V, and the logic level low refers to a negative voltage equal to $1/2V_{ss}$. Replacing Q_2 with series and/or parallel transistor networks results in more complex logic constructs such as NOT AND (NAND), NOT OR (NOR), and in combination, complex sum of product functions.

This work was done by Michael Krasowski and Norman Prokop of Glenn Research Center. ***NASA invites and encourages companies to inquire about partnering opportunities. NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact ttp@grc.nasa.gov.*** *LEW-19356-1*

Design of Double Layer Rectenna Array for Fault Isolation of Schottky Diode in Operation Beyond V-Band Frequencies

Langley Research Center, Hampton, Virginia

Microwave power transmission using rectenna technology has attracted a strong interest in conjunction with wireless electric power delivery to infrastructure and subjects located at a remote place. A typical rectenna, which is a major component of the wireless power transmission technology, consists of an antenna, a

Schottky diode, and low-pass filters for low-frequency electromagnetic wave isolation in the device. To obtain high efficiency, an electromagnetic wave is collected through a high-resonance antenna, and the AC mode of coupled wave energy is delivered to a Schottky diode that rectifies AC power into DC power. By connecting rectennas in series or parallel, or in mixed way — as well as enlarging the receiving area — the rectenna array can capture microwave energy into a desirable mode of high power.

This invention introduces a new design for high-frequency operation beyond V-band. The new design includes parallel plate-type shunt capacitors and via connection on a double-layer layout. It is based on previous work on rectenna development for X-band operation using a dipole antenna structure. In a typical rectenna design, the rectenna consists of a dipole antenna, a low-pass filter, a Schottky diode, and a shunt output capacitor.

Placing two capacitors on both ends of the rectenna structure is important to suppress the re-radiation of high-order harmonic waves. In this invention, the direct connection between the dipole antenna and the shunt capacitor is removed, and two parallel plate capacitors replace the planar capacitors in a typical design. The parallel plate shunt capacitors with high-capacitance values can isolate high-order harmonics within the rectenna structure, and suppress re-radiation of the second and third harmonics through the antenna. Moreover, additional transmitted wave loss at the fundamental frequency can also be eliminated in this design. The capacitance ratio between planar and parallel plate capacitors on the same projected area is more than 20 times, which is directly related to the blocking efficiency comparison of the new and old designs.

Another key feature in this design is the DC routing with via structure connecting the top layer and the bottom layers through the substrate material. DC electrical potential at the top layer is transferred to the bottom layers with negligible loss through vias. An electrical signal with the same polarity from each rectenna is connected in parallel, and the electrical current from individual rectennas can be summed up and increase output power.

The design avoids the direct connection and replaces the function with shunt capacitors and parallel connection of the DC line at the opposite side of a dielectric film using via connection. Using this concept, resonance frequency of the dipole antenna can maintain a low level of return loss even under the variation of impedance values of the adjacent device features. Isolation of faulty diodes can be obtained by removing the lines and blocking the electromagnetic wave propagation at the shunt capacitor. In addition, the benefit of a small cross-section area by a two-layer layout can increase the effective area for power conversion and overall efficiency of a rectenna array.

This invention will provide robust operation during the high power conversion, and upgrade power conversion efficiency of a rectenna wireless power transmission technology. Potential impacts of this application can extend to consumer electronics, industry, military, medical, and transportation.

This work was done by Hargsoon Yoon, Sang H. Choi, Kunik Lee, and Kyo D. Song of Langley Research Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact LaRC-PatentLicensing@mail.nasa.gov.*** *LAR-18135-1*

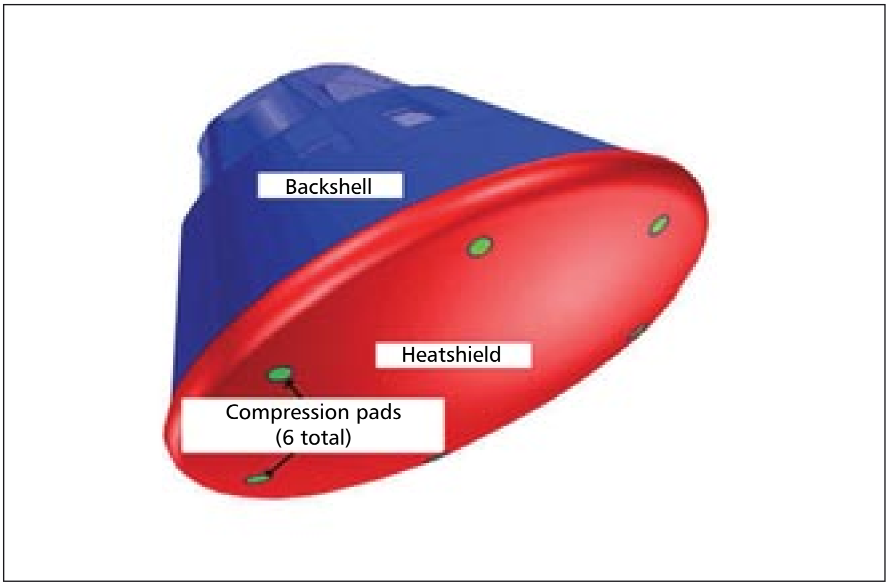
Materials & Coatings

Multifunctional Ablative Thermal Protection System

This material has applications in aerospace systems, manufacturing, and structural components requiring three-dimensional reinforcement.

Ames Research Center, Moffett Field, California

NASA has developed a unique and robust multifunctional material called 3-Dimensional Multifunctional Ablative (3DMAT) Thermal Protection System (TPS) that meets both the structural and thermal performance needs for a lunar return mission and beyond. 3DMAT uses a game-changing woven technology tailored to the needs of the Orion Multi-Purpose Crew Vehicle (MPCV) compression pad. Compression pads serve as the interface between the crew module and service module of the Orion MPCV. The compression pads must carry the structural loads generated during launch, space operations, and pyroshock separation of the two modules. They must also serve as an ablative TPS withstanding the high heating of Earth re-entry. 3DMAT leverages NASA's investment in woven TPS to design, manufacture, test, and demonstrate a prototype material for the Orion compression pads that combines the weaving of quartz yarns with resin transfer molding.



The Orion crew module highlighting the compression pads in the heat shield.

The initial compression pad design for Orion was complex and limited to Earth orbit return missions, such as the 2014 Exploration Flight Test-1 (EFT-1). The 2D carbon phenolic material used for EFT-1 has relatively low interlaminar strength, and requires a metallic sheer insert to handle structural loads. There are few options for materials that can meet the load demands of lunar return missions due to performance or part-size limitations. The 3DMAT material is a woven fiber preform fully densified with cyanate ester resin. It produces a large composite with significant structural capabilities and the ability to withstand high aerothermal heating environments on its outer surface while keeping the inner surface cool and protected from the aerothermal heating. The robustness of the 3DMAT material is derived from high fiber volume (>56%), 3D orthogonal architecture, and low porosity (0.5%). Orion has adopted 3DMAT for all future MPCV missions, including EM-1 scheduled to launch in 2018.

This work was done by Jay Feldman of Engineering Research and Consulting Inc., Curt Wilkinson of Bally Ribbon Mills, and Kenneth Mercer of San Diego Composites Inc. for Ames Research Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact David Morse at david.r.morse@nasa.gov or 650-604-4724.*** *ARC-17602-1*

Hierarchical Support for Nanocatalysts

Lyndon B. Johnson Space Center, Houston, Texas

This work focused on enhancing catalyst activity and durability by developing a method to control size, dispersion, and exposure. Existing nanocatalysts are typically fabricated in bulk or powder form. There are monolithic catalysts, but they rely on meso-porous materials as supports. Bulk nanocatalysts suffer from a lack of complete exposure to reagents, counteracting the benefits of the nanoparticles. Catalysts upon meso-porous support have limited exposure due to diffusion distances through the porous support. This requires higher catalyst loading, and may lead to particle coalescence and deactivation.

This innovation consists of a hierarchical nanocatalyst support structure for incorporation within microchannel reactors. The hierarchical support consists of a 3D network of open pores within the microreactor structure, which is coated with a nanofabricated support (e.g., nanotubes or nanorods). The nanocatalyst particles are deposited upon the nanofabricated support.

There are no separate parts. The hierarchical support is fabricated or assembled within a microchannel reactor system. The hierarchical support is an integral part of a reactor, and the operation is the same as any conventional reactor. Reagents are supplied and temperature is controlled to the desired values.

The preferred system will have the hierarchical support as an integral part of a microchannel reactor layered structure. An alternate embodiment is to use the hierarchical support structure as monoliths inserted into a confined space to avoid flow bypass.

Catalytic efficiency increases with decreasing catalyst particle size (reflecting higher surface area per unit mass), and chemical reactivity frequently is enhanced at the nanoscale. By virtue of their nanoscale dimensions, nanotubes and nanorods geometrically restrict the catalyst particle size that can be supported upon the tube walls. By confining catalyst particles to sizes smaller than the CNT diameter, a more uniform catalyst particle size distribution may be maintained. The high dispersion provided by the vast surface area of the nanoscale material serves to retain the integrity of the catalyst by reducing sintering or coalescence.

This work was done by Susana Carranza of Makel Engineering, and Randall Vander Wal and Jane Fujiyama-Novak of Penn State University for Johnson Space Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact jsc-techtran@mail.nasa.gov.*** *MSC-24632-1*

Control of Carbon Nanotube Density and Tower Height in an Array

Applications include high-density semiconductor chips, and heat dissipation and thermal conduction in personal computers, smartphones, and televisions.

Ames Research Center, Moffett Field, California

Use of arrays of carbon nanotubes (CNTs) as an intermediary for transport of electrical particles (e.g., electrons) and/or transport of thermal energy from one body to another has grown. For example, a CNT array may be used for dissipation of thermal energy or accumulated electrical charge associated with operation of an electronics device or system. However, the device or system may require use of different CNT array densities in various regions because of differing transport requirements.

The technology described here allows control of CNT growth density on a coarse scale and on a fine scale simultaneously, preferably with two or more substantially different and adjustable scales (coarse and fine) for the CNT density. The CNT density is allowed to vary from one location to another. The technology allows variation and control, over a factor of about 1 to 1,000, in the coarse-scale local CNT density, and of about 1 to 10 in the fine-scale local CNT density.

This method provides control over the growth density or tower height of CNTs on a relatively coarse scale, with density adjustment over several orders of magnitude, using an applied electrical field or voltage difference that is aligned substantially perpendicular to the substrate surface, which is adjacent to the surface during growth. Control or influence of CNT growth density on a finer scale, estimated at a factor of 2 to 10, is provided using temperature control for the CNT growth process. For example, an application of a modest electrical field of between 5 and 20 Volts over a transverse electrode-to-electrode gap of about 25 mm (electrical field value $|E|=(28) \times 10^3$ volts/cm) is estimated to change CNT growth density by 1 to 3 orders of magnitude (coarse scale). Variation of CNT source average temperature between 700 °C and 850 °C is estimated to change CNT growth density by a multiplicative factor of 2 to 10 (fine scale).

A first region may have a first range of CNT densities, and an adjacent region, spaced apart from the first region, may have a second range of CNT densities that partly overlaps, or has no overlap at all, with the density range of the first region. The second region has a higher CNT density, and uses variable heating and/or a reduced electrical field to provide the higher CNT density based on an experimentally determined growth curve and experimental configuration of a device. This approach should be distinguished from masking of regions on a substrate, where the result is binary where either a CNT array with a fixed density appears, or no CNTs appear in that region at all. The all-or-nothing approach is fine if the goal is thermal transport because maximum thermal transport benefits if the CNT concentrations are as high as possible. However, if the need is for electron transport (e.g., between adjacent signal processing components on a semiconductor chip), the desired CNT density may lie in an intermediate range, with both a lower bound and an upper bound.

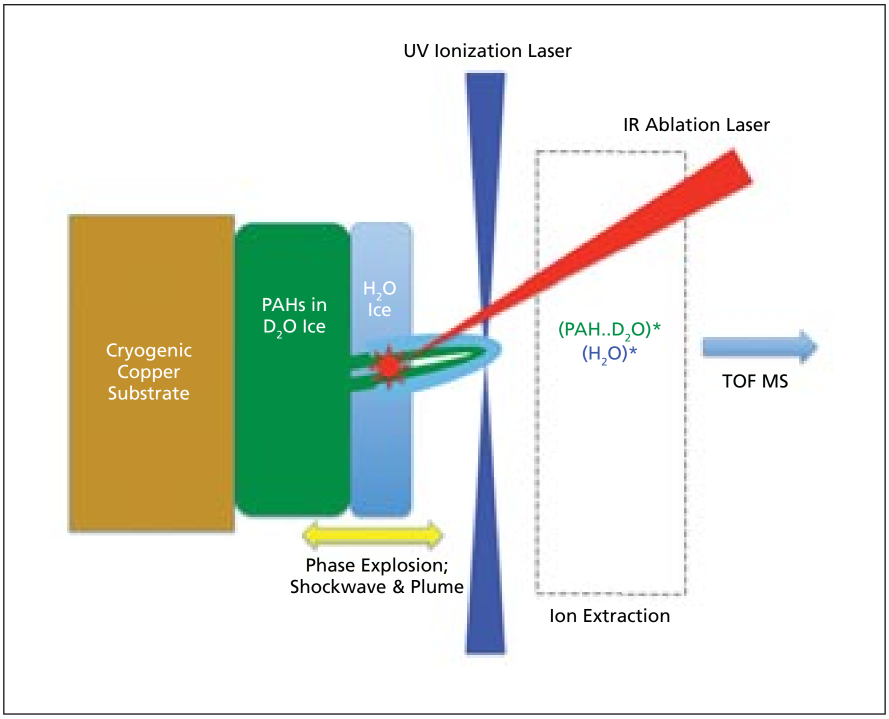
This work was done by Lance D. Delzeit and John F. Schipper of Ames Research Center. ***NASA is actively seeking licensees to commercialize this technology. Please contact Trupti Sanghani at trupti.d.sanghani@nasa.gov or 650-604-6889 to initiate licensing discussions. Follow this link for more information: http://technology.nasa.gov/patent/TOP2-139.*** *ARC-15314-1*

In-Situ Chemical Analysis of Material Surfaces

Composition by freezing uses laser ablation and laser ionization mass spectrometry for detection of chemical, pharmaceutical, biotech, and hazardous materials.

NASA's Jet Propulsion Laboratory, Pasadena, California

In order to understand whether the ablation laser would cause chemical reactions within the trapped organic molecules during resonant laser ablation of water ice containing organic molecules, a two-layer approach was devised. The first layer consisted of D_2O ice containing organics that are inactive for the laser



D_2O ice is doped with PAHs being interrogated using an H_2O ice-ablating infrared laser.

wavelength used (2.94 microns), and shown not to ablate under these conditions. When an additional layer of H_2O ice was deposited on top of the D_2O layer, both H_2O and D_2O layers, and the organics embedded in the D_2O layer, became ablated due to resonant excitation of the H_2O ice layer that transferred energy to the D_2O layer. This showed that the organic matter is not damaged.

H_2O ice absorbs the infrared laser pulse photons at 2.94 microns during a few nanoseconds pulse duration. Subsequently, within the H_2O ice layer, which is typically about 1 to 3 micrometers thick, phase-explosion occurs, sending pressure waves in every direction. These pressure waves (or shockwave, based on its velocity in the medium) travel to the material that is below the H_2O ice layer (in this case, D_2O ice) and transfer the pressure waves into the D_2O ice layer. Subsequently, both the H_2O ice and the D_2O ice containing the trapped material are ejected into vacuum, where they are ionized through resonance enhanced multiphoton ionization (REMPI), followed by time of flight mass spectrometry.

Chemical composition of materials — in particular, biological — is done using a well-known technique called matrix-assisted laser desorption and ionization (MALDI). Using this technique, the analyte (molecules of interest) is dispersed in matrix medium that can be resonantly excited and ionized by the same laser. Such a method needs extensive sample preparation. The new method would avoid such a sample preparation into a laser-active matrix medium because the laser-active ablation initiation material (H_2O ice) is deposited on top of a sample.

This new method increases the flexibility and removes much of the sample preparation efforts. This two-step laser ablation and ionization mass spectrometry (2S-LAIMS) technique allows any surface to be tested for surface contaminant/composition without extracting material from the surface and preparing samples that need to meet the stringent conditions of MALDI mass spectrometry. Using 2S-LALIMS, it should now be possible to analyze the surface composition by bringing the instrument to the sample in its native form.

This work can mature into a handheld 2S-LAIMS instrument that can be used to routinely detect surface composition of many materials; in particular, organics, trace metals, or biomolecules.

This work was done by Murthy S. Gudipati of Caltech and Rui Yang (postdoctoral fellow, presently at the Fudan University) for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-49484*

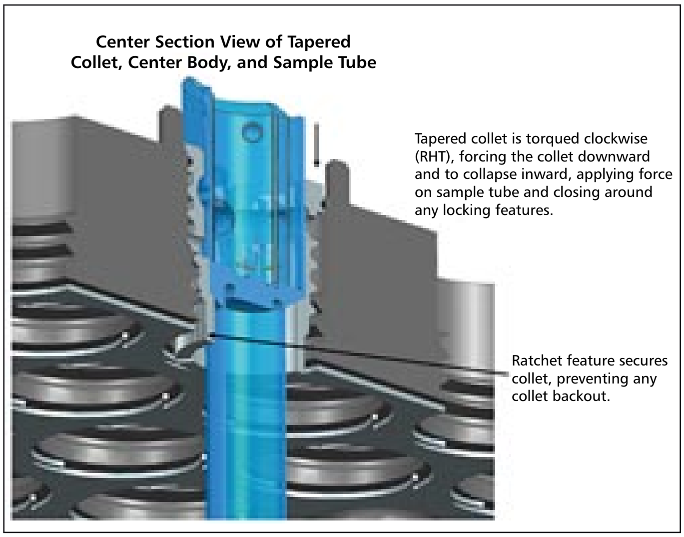
Mechanical & Fluid Systems

Ratcheting Threaded Tapered Collet for use in Planetary Sample Caching Systems

The desired sample tube preload can be tailored to specific applications, and allows each sample to be individually secured.

NASA's Jet Propulsion Laboratory, Pasadena, California

A ridged retention interface is necessary to secure planetary sample tubes within a caching system for use in future sample return missions. The assumed retention interface requirements are as follows: the interface shall maintain sample integrity at large deceleration landing loads; the interface shall minimize weight and complexity; and any required actuation for sample tube retention shall be performed by an external source (such as a robotic end-effector).



The tapered collet, center body, and sample tube.

A tapered collet similar to a milling machine's tool holder was designed with a threaded profile on its outer tapered diameter. When the collet is threaded into a corresponding non-tapered threaded hole, the collet collapses inward, applying a radial force on the sample tube within. The sample is retained within the collet by both friction force and any captured features designed into the sample tube's OML (outer mold line). Ratcheting teeth on the collet ensure that it remains locked in place once a preloading torque is applied.

The collets are pre-threaded into the sample cache at a zero preload state during assembly, test, and launch operations (ALTO). After sample acquisition, the sample tubes are inserted in the collet cache via a robotic end-effector. The end effector then torques the collet to the desired preload, reacting the resulting force via standoffs located on the cache to act as moment reaction features.

The threaded tapered collet combines the mechanical advantages of a traditional collet and a tapered pipe thread to produce a lightweight, simple, and robust latching system. The desired sample tube preload can be tailored to specific applications, and allows each sample to be individually secured.

This work was done by Zachary R. Ousnamer and Louis R. Giersch of Caltech for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-49924*

Planetary Ice Mining by Down-Hole Energy Injection

This lightweight technology operates in low gravity with energy efficiency.

John F. Kennedy Space Center, Florida

Ice has been discovered on Mars and is present in the permanently shadowed craters on the Moon and on many asteroids. The ice is usually buried beneath an overburden of regolith. Evidence indicates this overburden may be a meter deep in some locations for the Moon; for Mars, it varies with latitude and may be as deep as or deeper than two meters in many locations. To obtain this ice as a resource in usable quantities, existing technology will require that it be strip-mined.

The overburden of regolith must be mechanically removed so that a rover can drive down to the ice and chip off quantities from its upper surface. Chipping frozen regolith is extremely difficult because it has the mechanical hardness of granite. Using lightweight rovers appropriate to spaceflight, the removal of so much overburden will be a long and cumbersome process, making the use of this resource much less feasible. Chipping ice in low gravity will be energetically expensive and mechanically difficult. Excavation of regolith in low gravity with vanishingly small traction forces is very difficult. Operating in cryogenically cold conditions where the ice exists is difficult because metals become brittle and machinery wears out or fails. A better, more efficient method to extract ice from the regolith of bodies in space is needed.

The purpose of this innovation is to drill into the regolith to a depth that is both rich with ice and beneath the surface, sublimate ice around the bottom of the bore shaft, and capture it in vapor form at the cap at the top of the bore shaft, where it is liquefied or re-frozen for transportation and storage. The icy regolith therefore need not be excavated via strip-mining, but instead acts as a relatively impermeable bottle to channel the vapors back to the equipment at the surface. The technology performs this sublimation in an energetically efficient way so that a sufficiently large quantity of ice is extracted from each borehole without wasting energy.

The innovation consists of a drill that is extracted from the regolith after each borehole is drilled. One of several different devices is then lowered into the borehole to heat the regolith around the shaft of the drill, especially toward the bottom of the shaft. A cap on the top of the bore shaft keeps sublimating ice from escaping. The relatively impermeable regolith ensures the vapors will travel up the bore shaft where it will be captured, rather than sublimating away to the vacuum of space.

For regolith conditions where the borehole might collapse as ice is removed from the surrounding soil, the technology includes three different methods to keep the borehole from collapsing. One method is to insert a sleeve or pipe into the shaft before ice extraction begins. The second method is to sinter the soil around the bore shaft so that it melts locally and becomes a mechanically competent pipe. The third method is to pour cement (made from local regolith at the surface with an added binder) into the bore shaft similar to the method used for oil drilling on Earth. However, in many, if not most cases, there will be no need to stabilize the shaft because the regolith is already sufficiently competent to maintain a small-diameter shaft without collapse.

The technology also includes a system to cap the top of the bore shaft to capture and cool the vapors after they reach the cap, and to pressurize them in pipes or tanks to bring them to the liquid state for transportation and storage or to freeze them back to the solid state for transportation and storage.

Heating can be supplied in the bore shaft by several methods. It can be by simple electrical heating coils, which then radiate and/or directly conduct thermal energy into the ice. It can also be by microwave or lasers that can be tuned to the maximum absorption frequency of the icy regolith. The microwave or laser hardware could be inserted into the shaft or it could remain at the surface, pointing down the shaft. Passive reflectors or re-radiators could exist at the bottom of the shaft to help couple the radiated microwave or laser energy into the surrounding regolith. For example, a material that absorbs microwave energy to become hot could be inserted into the bottom of the shaft to couple the microwave energy into the regolith far more efficiently.

For sintering the surrounding soil, microwave, laser, or electrical heating coils could be used. The device can be lowered slowly into the shaft, sintering the walls as it goes. The sintering hardware could be attached directly to the drill bit so that the shaft is drilled and sintered in one operation, or it could be lowered into the shaft after the drill is extracted. It is optimal to perform the sintering as closely behind the drilling operation as possible, because the drilling will have already heated the walls of the bore shaft so sintering will be more energetically efficient. The sintering can be accomplished with the same device or a different device than the one that performs heating for ice extraction. However, for sintering, the energy levels need to be much higher so that not just ice melts/vaporizes, but the mineral grains of the soil also melt. Partial melting creates a sinter instead of a glass, and is desirable so that molten material does not fall into the bore shaft.

Peripheral equipment includes one or more transportation devices such as a rover, a flying platform, or any other method of moving equipment around on the body in space; hardware to liquefy or freeze the vapors after they reach the well's cap; and pipelines, tanks, or vehicles to move the liquid or frozen volatiles around after they have been either liquefied or re-frozen at the surface.

This work was done by Philip Metzger of Kennedy Space Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact KSC-DL-TechnologyTransfer@mail.nasa.gov.*** *KSC-13723*

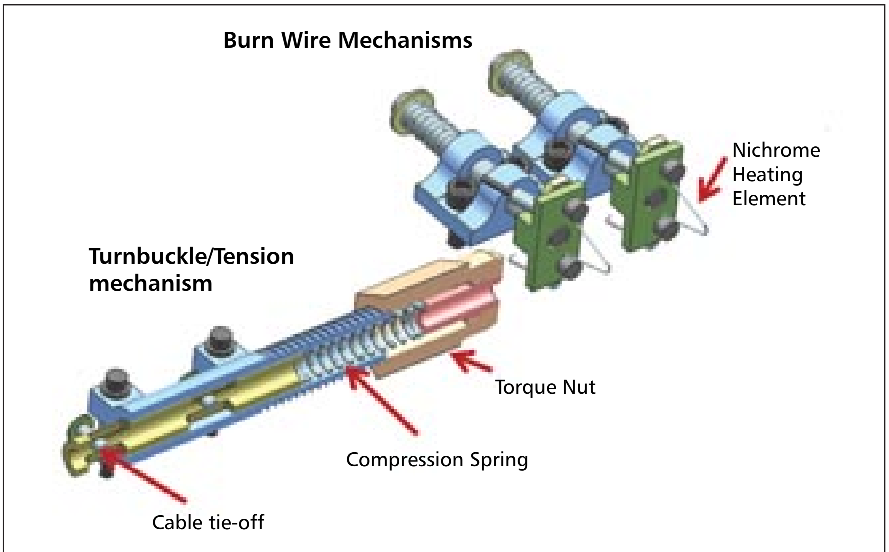
Launch Tie-Down and Release Mechanism for CubeSat Spacecraft

This hardware configuration takes up an extremely small volume inside the CubeSat bus.

NASA's Jet Propulsion Laboratory, Pasadena, California

As CubeSats take on increased functionality, including larger solar arrays for increased power demands and large antennas for science and communications needs, the requirements for launch tie-down and release mechanisms are evolving. In the past, some large CubeSat-deployable structures (solar arrays) relied on the confining walls of the CubeSat canister to act as the restraint mechanism. However, this practice is largely eliminated now, with most CubeSat specifications requiring a minimum amount of dwell time (after the CubeSat has been ejected from its parent canister) before the deployable structure can be released and deployed on orbit. Thus, a reliable restraint and release mechanism that does not depend on the geometry of the canister walls must be implemented.

The proposed restraint/release mechanism has three main components: 1) tie-down cable, 2) tension mechanism, and 3) burn wire actuation mechanism. The tension mechanism allows the Vectran tie-down cable to be easily tensioned without having to tie off a knot under tension (which can be difficult, especially in tight spaces). The integrated spring in the mechanism ensures that the assembly stays stowed and under tension, even if the Vectran tie-off cable changes length slightly due to thermal loads or launch vibrations. Lastly, the tie-off cable is released



The burn wire and tension mechanisms shown in cross-section.

using two redundant burn wire mechanisms. These mechanisms are based on an earlier design conceived at the Naval Research Laboratory (NRL) using a moving Nichrome hot-wire that thermally cuts through the Vectran tie-off cable.

The tie-down cable is a special space-rated Vectran material. The Vectran cable is a braided construction with eight carriers, each having a denier weight of 400. The cable has a breaking strength of 140 lbf and an approximate outer diameter of 0.036". The tension mechanism uses a 5/16-24 thread that has a linear travel of about 0.24". Thus, the tie-off cable can have a little bit of slack when it is tied off in the stowed position. The tension mechanism then uses some of the 0.24" of travel in order to fully tighten the tie-off line. The compression spring inside the tension mechanism has a force of 10 lbf in the fully stowed position. Under operation, when tightened, the nut of the tension mechanism compresses the spring to the fully closed position. The nut is fully tightened, but then backed off slightly to ensure the spring is not jammed. Thus, under launch vibration, if the acceleration force exceeds the 10 lbf force of the spring, the tie-off cable does not travel forward because it hits the hardstop of the nut. However, if the tie-off cable length increases slightly due to thermal displacements, the tension on the tie-off cable remains (at 10 lbf).

The Vectran tie-down cable is thermally cut using two redundant burn wire mechanisms. These burn wires are based on the original design developed by the NRL. However, in the updated design, the mechanism underwent several significant modifications to optimize and enhance its capabilities. In order to leverage the heritage of the NRL design, the burn wire mechanism uses the same 30 awg (.010" diameter) Nichrome wire. Using the same Nichrome wire geometry allowed a decrease in the number of verification tests.

In operation, a 1.6-amp current is applied to the Nichrome wire for approximately 5-10 seconds as the Nichrome wire heats up and thermally cuts the Vectran tie-off cable. The burn wire mechanism was demonstrated to work in ambient lab conditions, as well as at vacuum conditions at -60 °C and +125 °C. Most of the other elements of the burn wire design were modified and enhanced for this application. The electrical leads are constrained by a highly insulated ULTEM tip.

The Nichrome wire is preloaded using a single spring and 1/8" diameter shaft. The single shaft simplifies the design and allows for the ULTEM tip to freely rotate in order to minimize built-up mechanical stresses at its interface with the Vectran cable. It also allows for multiple configurations of the burn wire mechanism, depending on the orientation of the Vectran tie-down cable. For example, the Nichrome wire can be mounted in the horizontal or vertical configuration without changing the design. The Nichrome wire is preloaded using a stock compression spring with a spring constant of 2.5 lb/in, and a maximum suggested load capacity off 0.74 lbf.

This work was done by Vinh M. Bach, Samuel C. Bradford, Kim M. Aaron, Mark W. Thomson, Phillip E. Walkemeyer, and Brittany S. Velasco of Caltech for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-49969*

Limboid Reconfigurable Robots for In-Space Assembly

A Limboid workforce with access to a tool crib could staff robotic space factories.

NASA's Jet Propulsion Laboratory, Pasadena, California

Many future space vehicles, planetary bases, and mining operations will be too large and heavy to launch on a single rocket. Instead, component parts would need to be launched on multiple rockets and assembled in space. To enable versatile in-space assembly, a novel class of reconfigurable robots called Limboids has been conceptualized. Limboids are robotic limbs that attach and detach from each other to form a variety of useful configurations. These configurations might be as small as a single limb, which is best for dexterous manipulation of small parts, or as large as necessary for gross manipulation. As a modular system, Limboids could be supplemented with additional tools and limbs.

A core concept of Limboids is "modularity at the limb scale." Each robot, called Limbi, is a self-mobile limb and can function as a standalone robot for single-handed tasks. For example, one Limbi could grab a battery pack from a storage container and insert it into a satellite. Both ends of Limbi are electromechanical docks that can attach to a structure, other robots, or tools like grippers and drills. The base structure powers and controls the robots through these docks, so Limbi can walk end-over-end across the structure without a battery or tether. Researchers recently used a prototype Limbi to demonstrate end-over-end mobility and assembly of a modular structure (Figure 1).

Because the electromechanical docks provide power to the robots, Limboids could move around and reconfigure themselves without the complexity of power cords. Examples of configurations and use cases for Limboids are shown in Figure 2. These configurations consist of a) Limbi robots working in parallel to perform independent or cooperative work, b) a long arm for grabbing incoming spacecraft, c) a walker-manipulator to carry objects while moving, and d) a torso with multiple arms for manipulating large objects. The use cases include e) three limbs working together to build a chain of parts, and f) a two-armed Limboid holding a large object.

In the future, Limboids might help build a large orbiting structure, such as a solar farm or an asteroid-processing facility. They could unpack structural components and climb out along the structure as they build it, using built-in power lines instead of carrying tethers or batteries. Alternatively, they might staff an orbiting spacecraft factory, where they would crawl around on

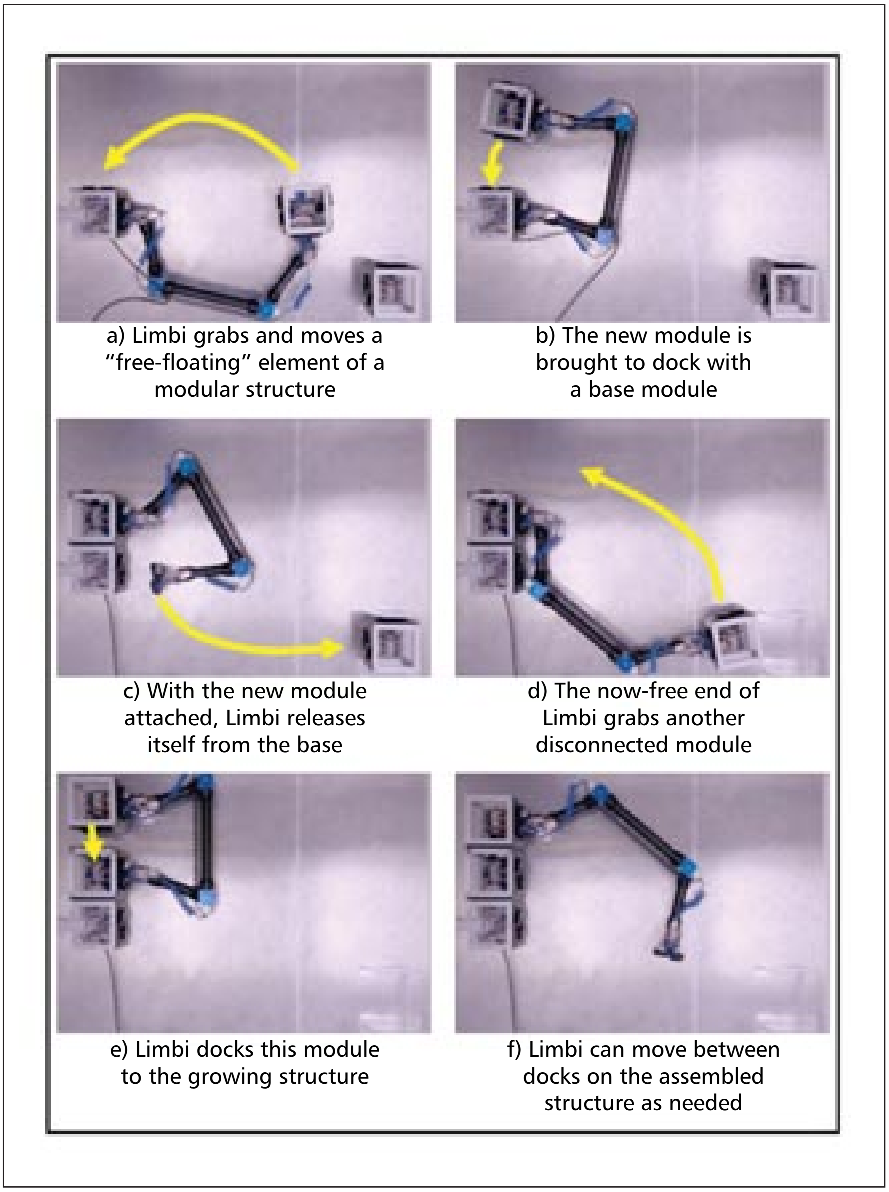


Figure 1. A laboratory prototype of a Limbi robot autonomously builds a modular structure. This process could repeat to build a large truss or spacecraft. As shown here, the modules are small, but a similar approach would work for large modules.

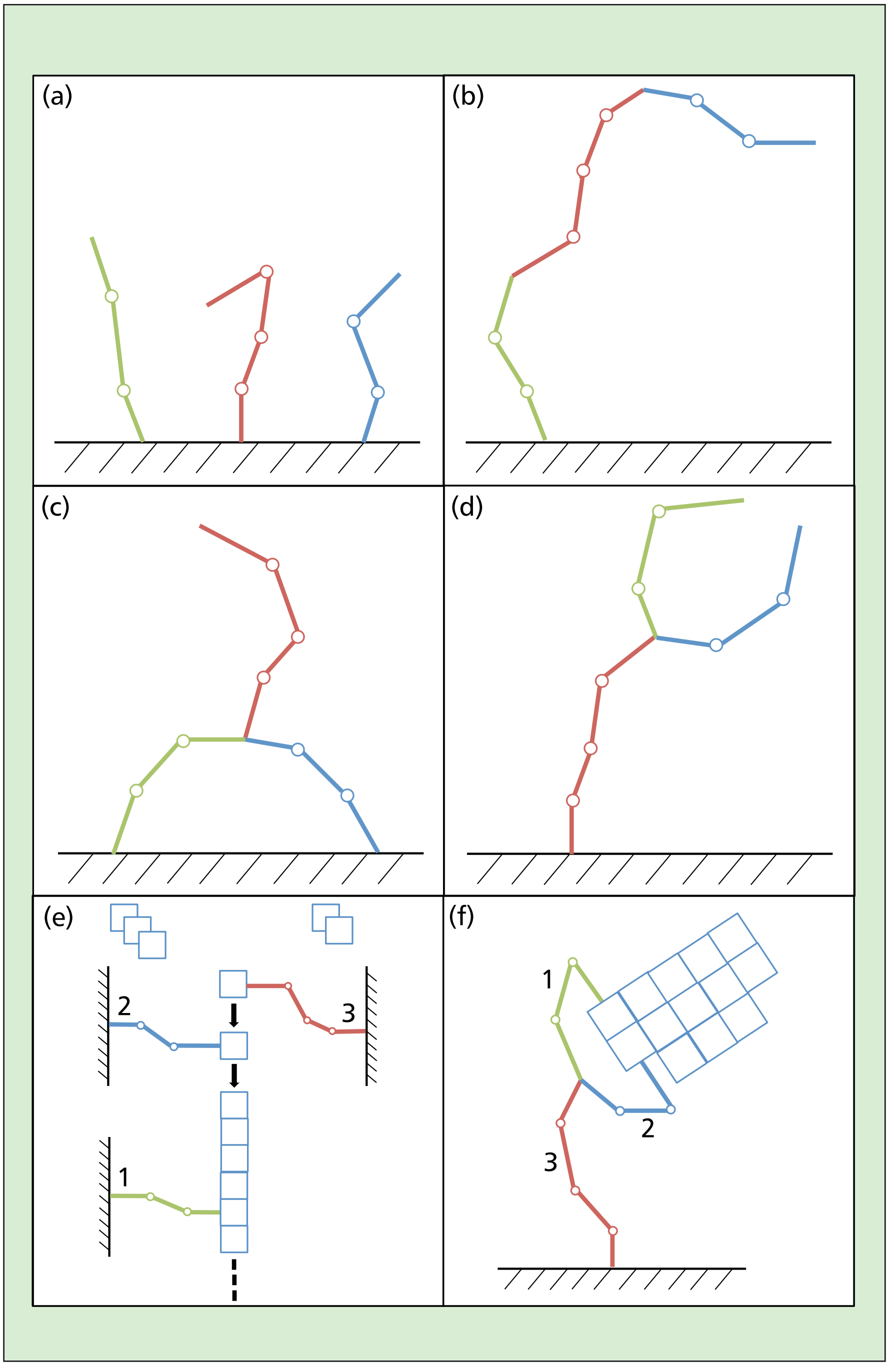


Figure 2. Limbi robots can form a wide variety of Limboid configurations, enabling small-scale dexterous manipulation, gross manipulation of large objects, docking with incoming spacecraft, and two-handed manipulation.

trusses or walk on a floor. There, they would grab incoming shipments, unpack spacecraft components, assemble a solar panel array, and attach tanks, batteries, and instruments to the spacecraft hull. They could be embedded in either of these settings and meet manipulation demands over many years of factory use and multiple spacecraft design cycles.

This work was done by Sawyer Brooks, Peter T. Godart, Brendan Chamberlain-Simon, Russell G. Smith, and Paul G. Backes of Caltech for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-50052*

Cam Hand

This robust gripper design has applicability to both robots and as a prosthetic for the physically challenged.

NASA's Jet Propulsion Laboratory, Pasadena, California

A durable gripper tool was designed for use by RoboSimian robots intended for use in disaster scenarios that demand high-force, robust manipulation. The resulting Cam Hand fills a previously unaddressed niche that emphasizes grip strength and robustness over dexterity. The design uses a number of unique features to ensure high operational flexibility. While this gripper was created for use on a robot, its basic design could be refined for other applications; in particular, as a new class of prosthetic that would exist between the traditional hook and pinch models and the dexterous models currently under development.

The Cam Hand, shown in Figure 1, is characterized by a number of design features. The most significant is the continuous rotation of the fingers about the "palm" surface of the gripper. This unique range of motion offsets the lack of finger dexterity by enabling an unprecedented number of grasping angles and operational modes through repositioning the fingers. Of great importance to its use on RoboSimians are the "foot" modes that allow the robot to use all of its limbs for mobility or manipulation. The gripper is also capable of a new type of grasp: a "cam" mode for internal grasps of objects or features as shown in the lower left of Figure 1. This mode is similar to the cam protective equipment used by human climbers. Even though these cam grasps rely on friction, they are secure due to the self-locking action of the cam mechanism. Also unique to this gripper is the ability to independently grasp two items. This capability can be realized by the double-hook or by using one set of fingers to create a grasp against one side of the gripper body while the other set uses the other side. Additional functionality can be realized from the continuous finger motion that, when coupled with specifically designed fingers, enables the functions of scissor-mechanism tools such as wire cutters. Another unique attribute enabled by the finger rotation is that when all of the fingers are rotated simultaneously in the same direction, a "wrist" degree of freedom is created. In addition to giving the gripper more utility for the same design complexity, the wrist motion is very close to the grasp location, an advantage for the kinematics of a robotic manipulator and an enormous design hurdle for more traditional gripper and arm combinations.

While the basic ideas of the Cam Hand are achievable at different scales and various detailed design instantiations, the version created for the RoboSimian robots emphasizes strength, as shown in Figure 2. In particular, the gripper was designed to allow the full weight of the 125-kg RoboSimian to hang from one finger without damage. This design point was chosen both to allow a RoboSimian to climb, but also as an estimate of the maximum loads that the robot could impart on the gripper during mobility or manipulation operations. This desire for strength drove the rest of the design. While there are four fingers, to save volume, the outer two fingers are slaved together as the output of one drivetrain resulting in only three independent degrees of freedom (DoF) with four fingers. However, these three DoF are sufficient for relatively complex operations such as grasping and triggering human tools like electric drills. It has a maximum grip strength of 304.5N at the tip of each outer finger (assuming each is simultaneously engaged and evenly loaded) and 609N at the tip of each inner finger (or an overall hand grip strength of 609N at the tips, increasing the deeper into the fingers the grasped object is located). Well over the grip strength of the human hand, this actuated strength is sufficient to grip a concrete block on two faces and lift it, or pierce through half-inch drywall. However, the hand is actually more resistant to forces put into it than what it can actively exert on an object. Passively, each reacted tip force for each outer finger is 1.5kN finger (assuming each is simultane-

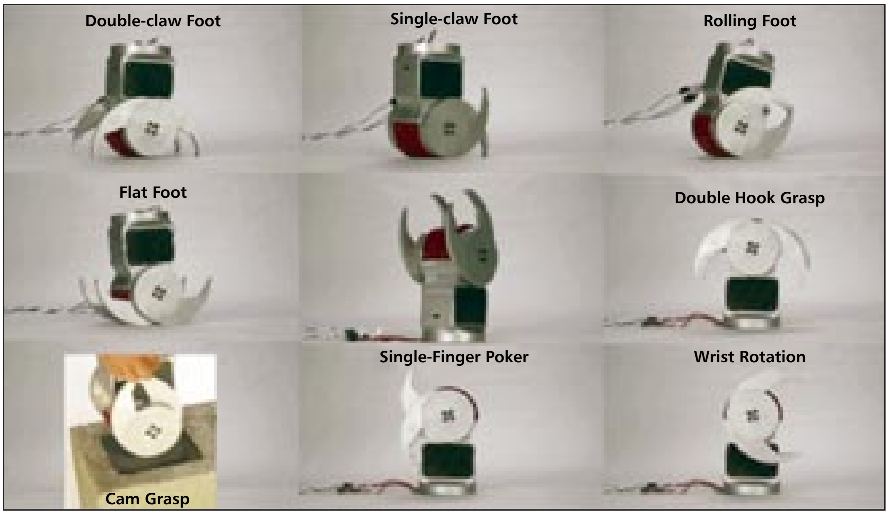


Figure 1. The Cam Hand can operate in a large number of modes, including both mobility and manipulation, giving robots more functions than otherwise possible.

Figure 2. In its current design form, the Cam Hand is extremely strong and robust. It easily supports the 125kg mass of an entire RoboSimian. Its self-contained mechanism and electronics could be adapted to human anchoring devices or prosthetics.

ously engaged and evenly loaded) and the inner fingers handle 3.0kN.

In order to minimize impact on the RoboSimian system design, the Cam Hand was designed to only require power and communication inputs. Integrated electronics handle all motor control and sensor interfaces, creating a convenient package that can be added not only to RoboSimian, but any other robot manipulator of the same scale.

As mentioned, while this version of the Cam Hand is intended as a robotic gripper, the principles could be adapted to use as a practical prosthetic. In particular, it can emulate many more of the simple grasps humans use on a daily basis than is possible with the traditional hook prostheses. The advent of highly articulated prostheses promises dexterous functionality, but these designs will remain either expensive, weak, or both. A Cam Hand prosthesis can be designed that is relatively inexpensive, strong, and physically robust, giving prosthesis users great capability at a lower price point than currently possible.

This work was done by Brett A. Kennedy and Kalind C. Carpenter of Caltech for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-49607*

Laser Architecture and Atomic Filter for Daytime Measurements Using Spaceborne Sodium Lidar

Goddard Space Flight Center, Greenbelt, Maryland

A satellite-borne sodium lidar will provide key measurements that elucidate the complex relation between the chemistry and dynamics of the Earth's mesosphere, and thus provide a thorough understanding of the composition and dynamics of this region. The inclusion of a well-characterized mesosphere in global models is essential for weather and climate prediction in the lower atmosphere. It also will help to elucidate the complex vertical coupling processes through which atmospheric weather affects space weather. Furthermore, once the technique is developed, it can be used to study the composition of other planetary atmospheres, which is identified as a key point in the recent Planetary Decadal Survey.

A middle atmospheric lidar is a soft-target lidar. The signal return is defined by the density and backscattering cross-sections of particles and molecules that the transmitted photons encounter in their propagation path. Above 80 km, the atmosphere contains a number of metals of meteoric origin and other atomic species that can resonate with photons that are tuned to the correct wavelength (for sodium it is 589 nm). Although other mesospheric metal of meteoric origin such as K, Fe, Ca, and Ca^+ can be observed by lidar, the Na lidar is the most widely utilized, making possible long-term observations by a number of lidar systems that have provided details about seasonal, latitudinal, and diurnal variations.

Two technologies will be key for a future spaceborne sodium (Na) lidar instrument because they will enable daytime Na measurements: (1) burst-mode pulsed laser architectures, and (2) a receiver atomic filter utilizing a Faraday rotation technique. Means to increase the overall laser signal energy are being investigated, including delaying and interleaving multiple laser pulses. For the receiver, the atomic filter has been used in ground-based Na lidar systems to filter the weak sodium signal from the much stronger solar background. The developed instrumentation will serve as the core for planning a spaceborne lidar to measure the mesospheric Na layer.

It is not only atmospheric science that can be addressed with such instruments. Global Na layer models show that the characteristics of the Interplanetary Dust Particle (IDP) input required to model the observed atomic Na layer correlate roughly linearly with the poorly understood parameterization of vertical transport. Since advanced lidars are also able to measure parameters of the background atmosphere in the MLT (i.e., wind and temperature), they provide a crucial set of measurements that will constrain the IDP's input and consequently Zodiacal Cloud Models (ZCM).

Modeling the climatology and global distribution of the Na mesospheric layer requires the utilization of a complex combination of ZCM, chemistry of the meteoroid ablation, and Global Circulation Models (GCM). The measurements provided by spaceborne lidar would enable not only the constraint of ZCM, but also the utilization of the layer as a tracer for global circulation, thus validating and improving GCMs as needed.

This work was done by Diego Janches, Sarah L. Jones, Michael A. Krainak, Branimir Blagojevic, and Anthony W. Yu of Goddard Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Scott Leonardi at Robert.S.Leonardi@nasa.gov.*** *GSC-17231-1*

Rangefinder for Measuring Volume of Cryogenic or Caustic Turbulent Fluids

A non-intrusive laser rangefinder yields extremely accurate fluid height measurements.

Stennis Space Center, Mississippi

Specific impulse (ISP), or simply impulse (change in momentum) per unit amount of propellant consumed, is a measure of rocket and jet engine efficiency. The amount of propellant, or in the case of engine testing at the Stennis Space Center (SSC), cryogen consumed during rocket engine testing must be measured to accurately quantify ISP. One way to determine the amount of cryogen used is to measure the change in cryogen fluid height within a storage/feed tank during testing and then relate the change in height to volume of cryogen consumed. A float system coupled with discrete vertically positioned Reed switches is currently used at the SSC to determine cryogen fluid height and then determine cryogen consumed during a rocket motor test firing. However, the cryogen fluid level within a run tank varies continuously and the switches are placed at discrete locations, limiting the accuracy of this method. If individual switch failures occur, the error increases due to the increased distance between switches/measurement locations. In addition, since pressurized gas is used to force the significantly cooler liquid cryogen out of the tank during a test, the liquid cryogen surface is turbulent and not flat or smooth, which can also affect accuracy.

An optical sensor was demonstrated that can accurately measure the amount of fluid in a closed vessel at heights that are in-between Reed switches. This technology incorporates the existing Reed switch ball-shaped target that floats on the fluid surface with optical fibers, a laser rangefinder, a small athermal telescope, and detailed knowledge of the vessel shape. The laser rangefinder can be located outside the tank to operate in a non-cryogenic environment. Modulated diode laser light, generated with the laser rangefinder, is brought into and out of the tank using optical fibers. Light from the fibers illuminates the current Reed switch float within the tank. The ball-shaped floats have sufficient optical cross section to serve as rangefinder targets so that the light scattered off the float can be collected with an athermal telescope. The telescope, in turn, focuses light back into optical fibers to bring the light onto the laser rangefinder detector outside the tank. This optically derived position measurement is then processed with the current discrete position measurement using a Kalman filter to improve accuracy and reduce noise and other artifacts, like fluid height fluctuations. Measurements and analysis performed indicate that a non-intrusive, commercially available laser rangefinder with fiber-optic feedthrough into a cryogen tank coupled with a Reed switch (or other) float system could yield extremely accurate, near-continuous fluid level measurements under many conditions. These measurements could also be combined with flowmeters and other sensors.

This work was done by Robert E. Ryan and Mary A. Pagnutti of Innovative Imaging and Research Corporation for Stennis Space Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact SSC-Technology@nasa.gov.*** *SSC-00401*

Micro-Force Sensing Nanoprobe

Goddard Space Flight Center, Greenbelt, Maryland

The NGXO (Next Generation X-Ray Optics) project has several problems relating to how to bond a very thin glass mirror to a metallic structure without distortion. One problem is that all epoxies shrink (at the micron level) when they cure. This shrinkage distorts the optical quality of the mirror unacceptably. Another problem is how to correlate finite element models of thin glass mirrors to verify that they are accurately predicting the distortions that a real glass will see due to enforced displacements, such as those applied by epoxy shrinkage. The forces required to simulate epoxy shrinkage and to balance a mirror on a bed of actuators are in the 100-1000 micro-newton range. The displacements are on the order of a few microns. These tiny forces and displacements cannot be easily measured or actuated with typical lab equipment.

A nanoprobe capable of movement in the nanometer range and simultaneous force measurement in the milli-Newton range has been created. This device has applications in optical systems where very small distortions are desired along with a measurement of the forces necessary to create such distortions. A collection of such devices allows a new way for mirrors — especially thin mirrors — to be held without distortion by controlling the force supporting the mirror via adjustments to the nano-actuators. Another application is an apparatus for correlating finite element and optical ray-trace models.

A known force in the milli-newton range is applied to a thin mirror, and the distortion is measured with an interferometer and compared to predicted finite element distortions. The force sensor has a range of ~30 mN and resolution of ~.01 mN. The nano-actuator has 30-nm resolution, 12.5-mm travel, 0.2-mm/s top speed, and 50N max force. The force sensor is attached to the nano-actuator shaft so that the sensor tip becomes the tip of the nano-actuator. Both devices are linked together and controlled in LabVIEW software. The unique feature of this device is that for the first time, it is possible to push on something with known micro-newton or milli-newton forces, and/or displace something and measure the resulting force.

This work was done by David Robinson, Ryan McClelland, and William Zhang of Goddard Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Scott Leonardi at Robert.S.Leonardi@nasa.gov.*** *GSC-16061-1*

High-Channel-Count, High-Scan-Rate Data Acquisition System for the NASA Langley Transonic Dynamics Tunnel

Langley Research Center, Hampton, Virginia

The NASA Langley Research Center (LaRC) Transonic Dynamics Tunnel (TDT) has been operational since 1960, investigating a wide range of aeroelastic and non-aeroelastic phenomena. A dedicated aeroelastic test facility, the TDT is a large, variable-pressure, transonic wind tunnel. To support unique types of aeroelastic and dynamic tests, the TDT possesses a dynamic data acquisition system (DAS) with synchronous scanning of all analog channels. Steady (static) values are simply computed as the mean of any signal. The existing TDT DAS is referred to as the Open Architecture Data Acquisition System (OA-DAS). An effort was initiated to replace OA-DAS in order to increase the scan rate, increase the channel count, increase the reliability, increase user friendliness, and improve upon some features while maintaining synchronous scanning and other unique abilities. This effort has been spearheaded by researchers within the Aeroelasticity Branch (AB) co-located with the TDT; hence, the new data system has been named AB-DAS. The new data system will serve as the primary data system and will substantially increase the scan rate capabilities and analog channel count. This synchronous and dynamic system enables high-channel-count buffet and aeroacoustic tests in addition to the range of other testing done at TDT.

The incremental development of AB-DAS is divided into three phases. Phase I efforts have enabled AB-DAS to serve as a standalone data system for TDT for a specific genre of tests. Phase II efforts will be those that increase capability such that AB-DAS can assume all functionality and replace OA-DAS as the primary tunnel DAS. Phase III efforts will be continued performance enhancements beyond those required to replace OA-DAS.

The hardware components of AB-DAS include the existing tunnel systems; steady pressure systems; signal conditioners; analog-to-digital converters; processing, display, and storage computer systems; Phase II hardware for further capability development; and instrumentation sources. A new storage area network was created for data handling of AB-DAS systems. The current capability of the storage area network is 1 Gbit with CAT V cables, and the future capability will include 10 Gbit with CAT VI cables. The current 1-Gbit network enables rapid transfer of large files since there is no throttling of the network, and it is independent of other DAS communication functions operating on DASnet. The 10 Gbit will enable substantially faster communication for data file expansion capability. Specialized backplane communication protocols include PXIe-MC/PCIe/MXI communication.

An acceptance test has already been completed that enables standalone operation of AB-DAS to acquire high-channel-count, high-scan-rate buffet and/or aeroacoustic data that is dynamic and synchronously acquired. In its current state, AB-DAS can be used for TDT tests that do not require a balance or digital channels. The current version of AB-DAS has been successful in several wind tunnel tests and incorporates many user-friendly features. Some of these features include unique wind-off tare capabilities; a built-in in-situ calibration routine; compatibility with displays, existing facility systems, and post-point analysis routines; and the ability to broadcast all data quantities to customer systems. The data quality of AB-DAS has been validated through a formal operational readiness review, through the use of calibrated standards, and through parallel testing with the existing tunnel data system.

This work was done by Thomas G. Ivanco, David J. Piatak, and Martin K. Sekula of Langley Research Center; Scott A. Simmons, Walter C. Babel, Jesse G. Collins, and James M. Ramey of Jacobs Technology, Inc.; and Dean M. Heald of Analytical Services & Materials, Inc. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact LaRC-PatentLicensing@mail.nasa.gov.*** *LAR-18788-1*

Fusible Alloy Thermometer

Goddard Space Flight Center, Greenbelt, Maryland

This work was based on the need for a relatively small passive detector of maximum temperature reached by an object that can be visually inspected. The device requirements are to be hermetically sealed for contamination control, give a clear indication of maximum temperature achieved (non-reversible) with a ~10 °C resolution, have an essentially unlimited shelf-life and insensitivity to radiation, be passive without any electronics or mechanisms, provide good thermal conductivity, and be low-cost. Prior detectors have an unclear lifetime, contamination outgassing properties, and radiation tolerance. These could be used at much higher temperatures than plastic methods (>>100 °C), though out of scope for the tests performed to date.

A device that permanently records the maximum temperature reached (47-70 °C) was tested, though other temperatures are possible. The low-cost device is hermetically sealed with no possibility of organic contamination, has an essentially unlimited shelf-life, is impervious to radiation damage, can function in any orientation or gravity, is unpowered, and passive. The device is read by visual inspection after opening the seal.

This work provides a metallic, robust, simple, non-reversible thermometer. The device features a commercial off-the-shelf (COTS) ultra-high vacuum flange with COTS eutectic metals and COTS Kapton tape. The design is flexible for space or non-space extreme environments where the temperature can be read optically, and can be used at much higher temperatures.

This work was done by Jason Dworkin of Goddard Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Scott Leonardi at Robert.S.Leonardi@nasa.gov.*** *GSC-17336-1*

Small-Volume Pressurized Sample Handling System

NASA's Jet Propulsion Laboratory, Pasadena, California

A method was developed for effective, efficient, non-destructive, in-situ sample processing. Pressure vessels are used for sample delivery and collection, a shaker is used to keep the particles suspended, a back pressure of argon gas is used to keep the system under pressure to regulate the flow, and flow restrictors and frits are used that never come into contact with the sample slurry to avoid clogs.

Two pressure vessels are connected by a piece of tubing with the sample delivery vessel fitted such that the tubing reaches close to the bottom of the vessel. The sample delivery vessel is also attached to a water pump via a valve. The collection vessel is connected to a T-junction, with the two remaining sides connected to an argon tank and a flow restrictor, each with its own valve.

After the soil sample is loaded in the sample delivery vessel and the system is closed, the entire system is pressurized with argon up to the water pump valve. The water pump is set to just above the gas pressure, and this valve and the flow restrictor valve are opened. This induces a flow of water into the sample delivery vessel at a rate determined by the differences in applied head pressures. The flow restrictor faces no risk of clogging because only gas flows through it. The sample delivery vessel is attached to a shaker to keep the slurry suspended for the length of the experiment.

This instrument addresses several difficulties in dealing with slurries and small volumes by eliminating any frits or flow restrictors, and shaking to keep the slurry suspended. It also adds the capability to pressurize the system. Each part of the instrument design can be miniaturized further from the prototype to make it flight compatible.

This work was done by Valerie Scott Kristof and Xenia Amashukeli of Caltech for NASA's Jet Propulsion Laboratory. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov.*** *NPO-49601*

Propulsion

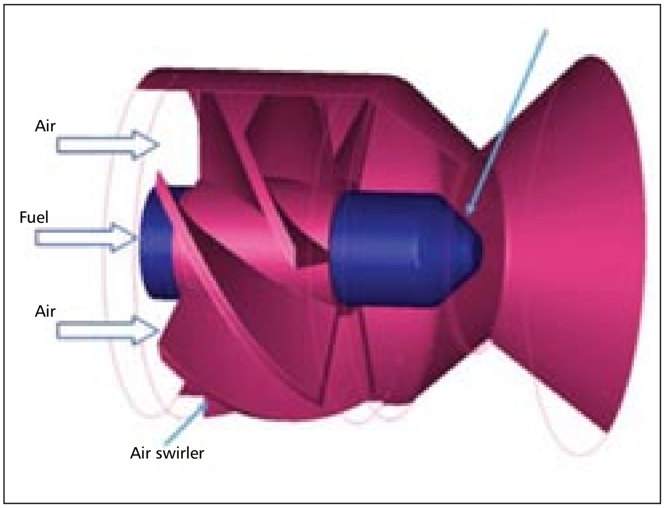
Generation-2 Lean Direction Injection System

This technology eliminates the risk of flashback and auto-ignition, and achieves emission and operability goals.

John H. Glenn Research Center, Cleveland, Ohio

An advanced Lean-Direct-Injection (LDI) turbine engine combustor was developed. Named LDI-II, which stands for second-generation LDI, this technology has vastly improved and expanded the performance characteristics of the initial LDI design by not only exceeding NASA's N+2 emissions goal, but also meeting the operability requirements of full engine power range. The key enabling feature of the technology is the coherence combination of fuel staging and positioning/sizing of swirler-venturi fuel/air mixer elements.

Earlier versions of LDI configurations have been primarily designed for single-flow-point evaluation for emission performance. They have relative low Technology Readiness Level (TRL 1-2) due to the exploring stage of the technology. The LDI-2 has significantly raised the TRL to 3-5 by incorporating the engine product design philosophy into the development process, and vastly expanded the performance envelope as would be seen in production hardware. The result is a steep jump in performance over the first-generation LDI in emissions, operability, and engine realistics.



The venturi-swirler element employed for the LDI-2 is the same as those in the earlier LDI-I.

The fundamental building block of the LD1-2 is the multi-swirler-venturi fuel/air (F/A) mixer elements for low-emission performance. They are laid out in the combustor dome in clustered fashion to form the dome front, and facilitate fuel and air flows and their intimate mixing. Multiple fuel staging (2-4 stages) by shifting and turning on and off the fuel among certain F/A mixer clusters enables the expanded operation envelope. The LDI differentiates itself from the LPP (lean-prevaporization-premix) by eliminating the risk of flashback and auto-ignition. By optimally combining the fuel staging with the swirler-venturi F/A mixer element clusters, the design is able to achieve both emissions and operability goals.

The success of the LDI-2 has led to the further development into LDI-3, with the goal of reaching a TRL of 6 and higher. In the advent of lean combustion technologies for turbine engines in the midst of ever stringent environmental regulations, the achievement so far has demonstrated a near-term potential of the technology adaptation to new engine development. The LDI may well become the interruptive technology replacing the ongoing LPP, due to its low risk, cost, and high-performance potential.

This work was done by Phil Lee of Woodward FST, Inc. for Glenn Research Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact http://technology.grc.nasa.gov.*** *LEW-19376-1*

Testing Aircraft Electric Propulsion Systems on NASA's Modular Stand

This test stand allows the aviation industry to test a wide range of electric propulsion systems to understand efficiencies and identify needed design improvements.

Armstrong Flight Research Center, Edwards, California

As powered flight expands to include electric propulsion technologies, aeronautics designers need to understand the electrical, aerodynamic, and structural characteristics of these systems. Therefore, researchers at NASA's Armstrong Flight Research Center have developed a modular test stand to conduct extensive measurements for efficiency and performance of electric propulsion systems up to 100 kW in scale.

The test stand helps engineers understand subsystem interactions as well as efficiencies of different batteries, motors, controllers, and propellers. It offers opportunities to determine effective test techniques for this emerging technology. The test stand's large suite of sensors gathers extensive data on:

- Torque (±1,800 lbf-in)
- Thrust (±500 lbf)

NASA Armstrong's modular stand for testing aircraft electric propulsion systems with propeller installed.

- Motor speed (0 to 20,000 rpm)
- Vibration/acceleration (±50 g, 0.5 Hz to 2 kHz)
- Motor, inverter, and battery voltages and currents (±500V AC/DC, ±500A)
- Temperatures of motor, inverter, and batteries (–40 °C to +125 °C)
- Ground plane acoustics (20 Hz to 16 kHz)
- Atmospheric conditions (e.g., ambient temperature, static/dynamic pressures, wind speed, humidity)

The data acquisition system offers high-speed sampling rates — up to 2.5 million samples per second per channel — enabling the test stand to provide accurate efficiency measurements. Developers can use these measurements to characterize new electric propulsion technologies, refine simulation models, and develop best practices through lessons learned.

A key feature of this innovation is its modularity, allowing researchers to test a variety of motors, controllers, batteries, and a wide range of parameters. For example:

- The test stand can accommodate different motors, up to 100kw, through the use of motor adapter plates.
- The software reduces reconfiguration time as sensor suites are easily added or removed.
- The top section of the test stand can be quickly removed, enabling easy transport indoors to protect test articles from adverse weather without dismantling the setup.
- The test stand can be mounted onto a truck to perform dynamic testing.
- Modular wiring and test structure allows components to be switched out with minimal changes to the instrumentation and data acquisition system. It also allows certain configurations of the test stand to be easily changed without having to create completely new cabling.

Safety considerations were of paramount importance for NASA Armstrong during the design of this test stand. Remote command and monitoring allows test operations to be conducted from a safe location. Furthermore, software and hardware implementations of emergency shutdowns and lockouts reduce the risk of injury and asset.

NASA Armstrong's electric propulsion test stand represents a step toward establishing best practices for measuring the performance and efficiencies of these cutting-edge systems.

This work was done by Yohan Lin and Aamod Samuel of Armstrong Flight Research Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact NASA Armstrong Technology Transfer Office at 661-276-3368 or by e-mail at AFRC-TTO@mail.nasa.gov.*** *DRC-015-006*

Iodine-Compatible Hall Effect Thruster

The use of iodine reduces the technical demands on thruster design.

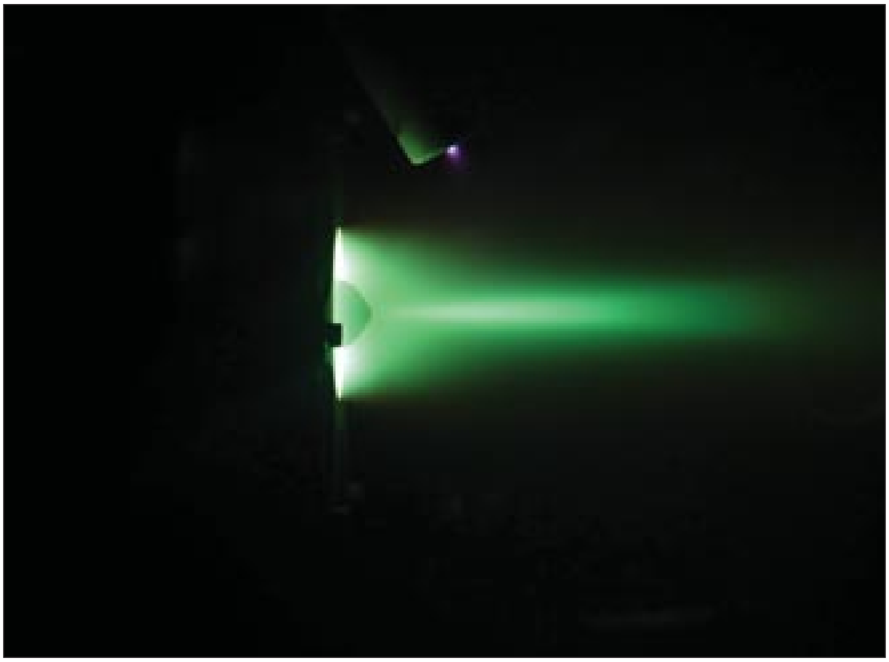
Marshall Space Flight Center, Alabama

The Hall effect thruster (HET) was designed for long-duration operation with gaseous iodine as the propellant. Iodine is an alternative to the state-of-the-art propellant xenon. Compared to xenon, iodine stores as a solid at much higher density and at a much lower pressure. Because iodine is a halogen, it is reactive with some of the materials with which a Hall thruster is typically constructed. Through research and testing, the new method allows for the HET to be used with iodine propellant for long periods of time.

The thruster is distinguished from the nominal commercial thruster by the materials of construction, the geometry of the anode, and the presence of iodine-resistant coatings. The anode and gas flow lines are made from a non-magnetic, iodine-resistant alloy. The propellant voltage isolator is made from iodine-resistant metals and brazes. The gas distributor was also completely redesigned to allow the use of multiple materials, and for it to be disassembled.

A HET uses crossed electric and magnetic fields to generate and accelerate ions. The overall structure is defined by a magnetic circuit that produces a steady magnetic field across a typically annular channel. The upstream portion of the channel includes a gas distributor that also typically functions as an anode. In the HET described in this work, the downstream portion of the channel is dielectric. A potential difference or discharge voltage is applied between the anode and an external cathode. The resulting electric field is predominantly axial, and is concentrated near the channel exit by interactions between the magnetic field and the plasma. In the channel, electrons are strongly magnetized and their transport is predominantly azimuthal due to the Hall effect. The extended electron path enables an efficient, impact-driven ionization cascade. Ions are weakly magnetized, and most are accelerated directly out of the channel, forming the ion beam.

Iodine-compatible Hall effect thruster.



Accelerated iodine plasma beam.

The physical shape and dimensions of the thruster are very similar to a xenon thruster. However, because iodine stores as a low-pressure solid, the reservoir may be irregular in shape, conforming to available space. The gas pressure only needs to be several psi — a factor of 1,000 lower than that of xenon. The feed system also needs to be heated to prevent condensation.

This work was done by James Szabo, Bruce Pote, and Vlad Hruby of Busek Co. Inc. for Marshall Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Ronald C. Darty at Ronald.C.Darty@nasa.gov.*** *MFS-33240-1*

Burnable-Poison-Operated Reactor Using Gadolinium Loaded Alloy

Marshall Space Flight Center, Alabama

The problem to be resolved in this work was the use of radial control drums as the sole active reactivity control system for nuclear thermal propulsion, which results in significant rocket performance changes during full-power operation. This can result in large inefficiencies in propellant usage, inaccurate estimations in Isp and thrust, and can be a dangerous operation requiring continuous active control of the reactor given the unstable nature of current nuclear thermal rocket reactor designs.

The innovation described here eliminates the active movement of the radial control drums during full-power operation. The innovation mixes ppm quantities of burnable neutron poison into the existing structural material of the nuclear reactor for nuclear thermal propulsion to passively control the reactivity of the core.

The innovation consists of adding ppm quantities of Gd (enriched or natural isotopic composition) to existing components in the nuclear thermal rocket. By controlling the spatial self-shielding, it was possible to attain a linear depletion rate of the neutron poison that matches the reactivity changes due to the production of xenon-135 (stable and meta-stable states) and other fission products, and the depletion of the fissile material. The result is that a flat reactivity profile is attained without any operator input, removing the need for radial control drum movement during operation.

In order to counter the drop in reactivity found during full-power operation due to fuel depletion and fission product accumulation, BORGalloy (Burnable-poison Operating a Reactor with Gadolinium alloy), a burnable neutron poison doped alloy, was introduced into the reactor. A burnable neutron poison is an isotope that has a large neutron absorption cross-section that is converted into a non-neutron-absorbing isotope with the absorption of a neutron. The premise of the concept is that as the neutron poison is depleted, there will be a resulting increase in the core reactivity, which, if done correctly, can be tailored to match the reactivity reduction from the fissile depletion and fission product buildup.

The poison is Gd dispersed in minute quantities in the outer tie tube. The poison was selected because of its extremely high absorption cross-section and its conversion to an isotope that has a comparatively much lower absorption cross-section. When the poison is introduced into the core such that it has minimal self-shielding (maximum exposure to the core's neutron flux), it can be rapidly depleted and result in an appreciable change in reactivity. Additionally, the low self-shielding ensures that the depletion rate remains relatively constant for all burns, eliminating the need to replace the poison at the beginning of each burn.

Various locations were explored, including the moderator sleeve, the inner and outer tietubes, and the fuel matrix. Of these, the outer tie-tube was selected as the location of choice. This is due to its thinness and its reduced role as a structural element when compared with the inner tie-tube. The thinness of the component reduces the spatial self-shielding of the poison, and the reduced need to provide structural support minimizes the chance that additions of Gd to the material will reduce its strength below acceptable levels. While the fuel matrix was seen to be promising in terms of self-shielding, particularly for the graphite composite matrix, it was decided that the outer tie-tube was preferred due to the exponential increase in development costs associated with fuel development.

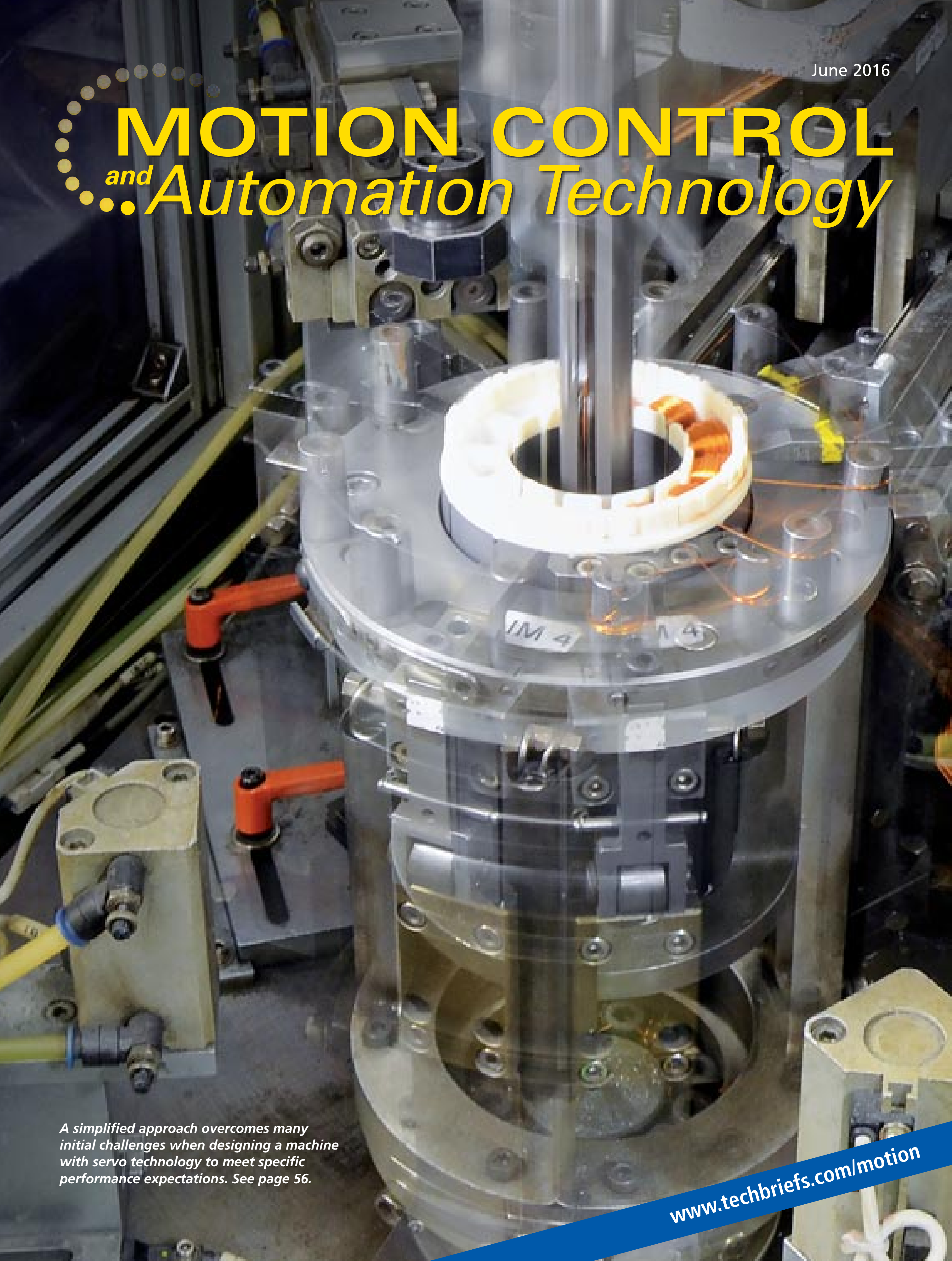
With the identification of the burnable poison, it was implemented into two LEU fueled NTP cores to flatten the reactivity profile during full-power operation: LEU tungsten fueled (SCCTE) and LEU graphite composite fueled (SULEU). Through the variation of the Gd content, it is possible to achieve a near-flat reactivity change during full-power operation for the TMI-1, MOI, and EOI for both cores. It was found that 20 ppm to 200 ppm Gd is required to achieve near-flat reactivity profiles for TMI-1, MOI, and TEI, depending on the isotopic enrichment of the Gd.

It is important to note that while the use of burnable poisons in terrestrial reactors is a well-known technology, their implementation typically involves the burning of the poison over the course of months, rather than minutes. Consequently, the rapid burn-up behavior of BORGalloy, while computationally demonstrated, needs experimental validation to demonstrate that a noticeable and rapid depletion of the poison is achievable, and that the poison can in fact be distributed in the material in a uniform and predictable manner within calculated tolerance levels.

This work was done by Paolo Venneri and Michael Eades of Ultra Safe Nuclear Corporation for Marshall Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Ronald C. Darty at Ronald.C.Darty@nasa.gov.*** *MFS-33349-1*

June 2016

MOTION CONTROL and Automation Technology



A simplified approach overcomes many initial challenges when designing a machine with servo technology to meet specific performance expectations. *See page 56.*

www.techbriefs.com/motion

Intro Cov ToC

SIMPLIFIED MACHINE DESIGN APPROACH

for Optimal Servomotor Control

An often asked question from industrial machine builders or integrators is how they can effectively design or implement the conversion of a machine with servo technology to meet performance expectations. This is a specialized task filled with layers of complexity that can prove difficult to execute, even when the scope of work is fully understood.

Available and different technologies present various possible engineering variations and unique operating processes. If there is a misunderstanding or knowledge gap for any given process in the work to be performed, the possibilities expand exponentially and create further complexity with added risk. This article presents a simplified design approach for servomotor utilization to overcome many of the initial challenges. The approach is based on several different but typical mechanical axis configurations and requirements that highlight risk management, optimal performance, and reduced development time.

When considering a machine design, there are clearly many factors to address in the planning phase. Reviewing all possible situations to reduce risk of failure as well as working through the different combination scenarios — all the ifs, ands, and buts — is a demanding set of tasks. For this reason, it's essential to build baseline knowledge of machine functions and each of its axes, relative to the overall chosen operating process and work to be performed. Start by developing a thorough understanding of the chosen process to complete the machine's function, the full picture encompassing the ins and outs, identify any variables and tradeoffs, and recognize there likely will be some unknowns. This extends to the advantages and disadvantages of available motion technologies considered and applied to each axis of the machine.

Acquiring as much in-depth comprehension up front will undoubtedly alleviate potential issues downstream and greatly enhance the opportunity for successful execution. Also, at the center of the design is risk management of specific technologies available and their interface with each other related to the tradeoffs and decision priorities to be given to the machine's function for the desired process.

Technologies and Degrees of Performance

What is considered high-technology performance for one manufacturing process is not necessarily high-performance for another. It is natural for the machine builder to deploy technologies they have experience with. However, new challenges often entail the utilization of newer technologies. When a retrofit or a new machine design requires the utilization of closed-loop (servo) motion control technologies, there are often misconceptions involved. For example, misconceptions often occur between what was required for a machine's optimization utilizing previous technologies and what is now required for a machine's optimized performance. Proper deployment of closed-loop motion control technologies requires balancing its capabilities, tradeoffs, and other factors that will enhance the new machine's performance.

Previous technologies may include, but are not limited to, hydraulic actuators, variable-speed motors, pneumatics, or any number of the typical open-loop, ON-OFF control, and in some

cases, semi- or pseudo-closed-loop technologies. Even newer closed-loop control concepts must be considered or balanced with older concepts to reduce risk. For example, it may be a great enhancement to run a machine and control all its axes by a virtual master axis. However, if one axis is essentially driven by two or more motors (hard-coupled or pseudo-coupled mechanically by the mechanism/load), the additional latency of one motor's drive talking to another through the virtual master's control, rather than directly to each other, will increase risk as a function of speed at which the machine is to operate.

In general, any process that is to run at a faster rate requires a machine with the capability of faster response times than its previous design to maintain quality. In other words, the machine must have the capability to move and act on the product at a faster rate, and to respond to all commands and disturbances within the limit of the product and process itself.

Often an actual process time is fixed and cannot be increased under an existing technology, leaving only product transfer times as the available time to be sped-up. In turn, this increases specific axis' peak horsepower (hp) requirements during acceleration/deceleration times from its baseline by the product of the increased ratio: speed and torque (a 15% increase of each, speed and torque, during peak requirements is a 32.25% hp increase). Many of the issues involved, when converting a process machine from some form of open-loop, ON-OFF (bang-bang) control or pseudo-closed-loop control method to a closed-loop servomotor controlled machine, may not be particularly intuitive to a first-time servo machine designer.

Identifiable Issues

Inertia. Inertia was not a concern or even a consideration in the past for some specific axes of a machine design. For some other axes, an optimal machine required a high system inertia (load and actuator) to dampen any disturbance from being seen by the product. We want to utilize a high-performance servo to increase speed and thus productivity, with the same or improved quality. This requires axes with higher-bandwidth (BW) capability than most

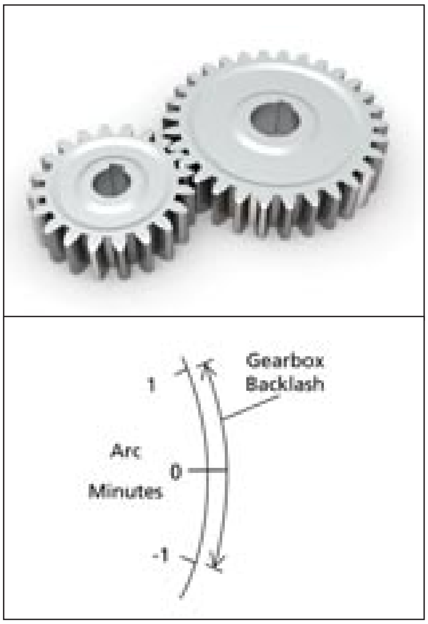


Illustration of gears and backlash.

previous designs in order to sense commands, product changes, and disturbances, such that we can respond to errors (delta (Δ) between command and actual) and make the appropriate corrections both quickly and easily. In order to accomplish these tasks, a lower system inertia is generally desirable and most frequently required. This is especially true of processes requiring point-to-point moves or on-the-fly corrections for continuous or pseudo-continuous processes. Production energy costs are often reduced by the higher levels of production efficiency.

Mechanical Advantage by Gears. Another issue that occurs, especially with previously designed machines, is backlash within an axis' mechanism. Often this type of axis movement was only mildly considered a potential process issue. The reason is because the unidirectional driven advantaged mechanism driving against the load usually stays on one side of the mechanism's backlash. However, with the constant velocity correction of a servomotor, the full ± displacement is repeatedly seen.

Mechanical Advantage by Timing Belt. For many previously designed machines (especially uni-directionally driven), the amount of compliance produced by a belt is typically not a major concern in regards to the process, as long as it is sized large enough so that it does not break. However, with the constant velocity correction of a servomotor, the full ± displacement of the belt's compliance can be repeatedly seen. The typical doubling of the belt's width (as calculated for a unidirectional mechanism) to reduce compliance may make the belt too wide. In this case, the designer may need to utilize as much width as the available space will allow and if possible, further reduce belt compliance (increase rigidity) by selecting a stronger or thicker belt. [Note: Be careful. A thicker belt reduces compliance (desirable), but powers natural resonance frequency (undesirable), depending on where the frequency is within the control system's spectrum. Then there is another issue: a larger belt will have a greater side load that must be considered in the design (bearings, tensioners, pulleys, and/or motors could be affected).]

For many designers, these new issues can present hard concepts to get through at first. What worked for a host of different open-loop, ON-OFF control and pseudo-closed-loop control technologies is now in part or as a whole a potential hindrance against the new machine design, impacting the desired goal of increased production and quality. Thus this new design may need additional effort from the mechatronic designers with typical disciplines in mechanical, electrical, electronic, control, process, and programming fields in order to simplify and achieve the goals of risk management, optimal performance, and reduced development time.

Minimizing Potential Process Issues with the New Design

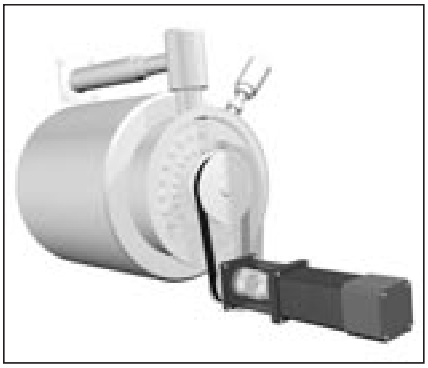
Typically, when utilizing a servo system technology to meet this overall goal, the designer will need to enhance the BW response capability for each axis of the new machine. To accomplish the task, we must consider a number of variables. They include frictional loads and any external loading (gravity or otherwise), the inertia between the load reflected back to the motor for a practical controllable solution within the process required tolerances, and also the backlash and compliance of each axis. For a typical servo mechanism, it is desirable to have a rigid style (compression, etc.) coupling to minimize compliance.

For many direct-drive axes, the steel's compliance between the motor and load can be a limiting factor. The steel's compliance can affect the ultimate BW of the servo control loops. Even a machine's frame compliance can become a major player against axis BW capability, motion stability, and controllability, where with previous technologies it may not have been of any concern. For example, to achieve the best possible axis BW capability, controllability, and minimal risk of any issues for direct-drive cartridge motors, it is very important to design the driven shaft (if applicable) with an outside dimension (OD) as large as possible for as long as possible, with an overall shaft length as short as possible. (Use as large an ID bearing here as possible to help system BW.)

Direct-drive cartridge motor technology utilizes a machine's bearings to support the rotor of a full-frame motor for the ease of installation, and can often eliminate the need for a mechanical advantaged mechanism (gearheads, pulleys, and belts, etc.) like other direct-drive motor designs.

Prioritizing for Risk Management and Tradeoffs

It cannot be stressed enough that controlling factors for risk management are the machine's functions with the chosen process to accomplish the work of each axis, as they apply to the new product production requirements and not the new or original machine's design. Remember, for all new designs and especially for proof-of-concept designs, cost reductions cannot be reasonably applied



Mechanically advantaged mechanism by a belt and planetary gearhead.

to a machine whose manufacturing process doesn't yet work. Changing the machine's motion technology and control by specifically keeping the machine functions and chosen process in the forefront for making decisions and tradeoffs for each axis, with available servo system technologies, will greatly reduce risk and enhance the success of any machine design.

After chosen process and machine functions are understood (ins and outs, and basic safety requirements), we can now begin asking questions to determine direction and possible solutions for the work to be performed by each axis. The following set of questions is not meant to be all-inclusive, but rather a strong start to simplifying the design approach of each axis for servomotor system utilization.

1. Does the axis in question require point-to-point moves (typical Position Mode operation)?

Reduce load inertia and mechanism inertia as much as possible. For example, utilize aluminum over steel if possible, and/or remove unnecessary metal from components, especially at the larger diameters where not otherwise needed. Remember, the moment of inertia of a rotating component about its center axis goes up by its diameter to the 4th power.

Reduce friction as much as possible: bearings versus bushings, ball screw versus acme style screw, etc.

Reduce mechanism compliance as much as possible. Use the knee of the cost curve versus capability, when applicable.

Reduce, minimize, or eliminate mechanism backlash as much as possible: belt versus gearhead, versus direct-drive, etc.

Minimize the number of moving bodies between the load and motor, and make the mechanism's drive train as rigid as possible. For example, a rack-and-pinion mechanism must be locked together such that the rack/pinion does not rise up on its teeth during a high-speed acceleration or deceleration.

Use a rigid (compression style, etc.) or equivalent coupling when applicable for the mechanism, reducing potential for mechanical wind-up and otherwise relatively large coupling inertia.

For indexing applications (especially high-speed), increase feedback resolution to maximum (knee of the cost versus capability curve), if one has not done so already.

Ensure proposed control method(s) can achieve safety protocols and any other specific requirements.

Consider basic maintenance procedure requirements in harmony with the process and safety protocols up front.

2. Does the axis in question require a continuous operating velocity (typical Velocity Mode operation)?

One must consider velocity tolerances long term versus short term, if applicable. If very short-term tolerance is more critical/dominant (smaller short-term Δ tolerance required per some time unit), then a higher than normally desirable load inertia may still be more suitable. Process needs to be understood and for a specific process, it could go either way: minimized load inertia (with maximum feedback resolution) versus a purposely designed larger load inertia (to dampen short term response) — it is very hard to make a judgment call without specific process information.

If long-term tolerance is dominant (tight long-term Δ tolerance required per some time unit), then typically it is best to maximize feedback resolution, and reduce load and mechanism inertia, allowing the servo to maintain the best control with the highest BW.

If the process requires the best of both worlds, reduce load inertia and mechanism inertia, and increase feedback resolution to the maximum available (utilize knee of the cost curve vs. capability).

When applicable, reduce load inertia and mechanism inertia as much as possible to increase BW capability. Reduce friction as much as possible, and reduce stiction as much as possible, especially for low-speed process applications. Eliminate mechanism backlash, and reduce mechanism compliance as much as possible. Use a rigid (compression style, etc.) or equivalent coupling when applicable for the mechanism, and minimize the number of moving bodies between the load and motor.

Increase feedback resolution to maximum (knee of the cost curve vs. capability). Controls: if possible, run the drive in a position mode for the appropriate time and displacement range. Typically, a better constant velocity tolerance can be achieved at the servomotor when run inside a position loop. Ensure the proposed control method(s) can achieve safety protocols and any other specific requirements. Consider basic maintenance procedure requirements in harmony with the process and safety protocols up front.

3. Does the axis in question require a continuous force be applied against some load (typically Torque Mode)?

Reduce friction as much as possible because stiction can easily become an issue. If an external force is applied for some time in a locked-rotor state, the motor must be sized accordingly. This is not a typical servo application. Many, if not most servomotors are rated at a low RPM (stalled rotor state), with just enough speed to ensure even heat distribution. Contact the motor manufacturer when applicable. Ensure proposed control method(s) can achieve safety protocols and any other specific requirements. Consider basic maintenance procedure requirements in harmony with the process and safety protocols up front.

4. Does the axis in question require extremely low speed (≤1 rpm)?

Reduce friction and stiction as much as possible; stiction can easily become an issue. Eliminate mechanism backlash. Reduce mechanism compliance as much as possible; use a rigid (compression style, etc.) or equivalent coupling when applicable for the mechanism, and minimize the number of moving bodies between the load and motor. Increase feedback resolution to maximum or at minimum, use knee of the cost curve for higher resolution. Control: if it is a velocity application versus positioning, then if possible, run drive in a position mode for the appropriate time and displacement range. Typically, a better constant velocity tolerance can be achieved at the servomotor when run inside a position loop. Ensure proposed control method(s) can achieve safety protocols and any other specific requirements. Consider basic maintenance procedure requirements in harmony with the process and safety protocols up front.

5. Is the specific axis in question vertical?

Utilize a failsafe-brake (internal to the motor or external axis brake) and/or counterbalance load. If a failsafe-brake is utilized, ensure its physical engagement and disengagement is timed with the drive commands, with proper delays for the subject brake's engagement and disengagement. If counterbalancing load, take into consideration the additional load inertia and its effect on accel-

Direct-drive mechanism.

eration and deceleration torque requirements. If counterbalancing load, there are typically tradeoffs due to actual process cycle times, resulting in only a percentage of the load being counterbalanced. For partially unbalanced loads, use a current offset when applicable to offset the imbalanced load and to minimize control-loop integration requirements (typically reduces phase shift and lowers risk). Ensure proposed control method(s) can achieve safety protocols and any other specific requirements. Consider basic maintenance procedure requirements in harmony with the process and safety protocols up front. Refer to suggestions above for typical mode of axis operation: position, velocity, etc.

Summary of the Design Approach for Each Axis

In order to enhance the bandwidth response capability and controllability of any servomotor-controlled axis, a combination of factors must be considered in relation to the machine function, chosen process, and work to be performed by each subject axis. They are friction and stiction, external loading, backlash and compliance, load and mechanism inertia at the motor, feedback resolution, and finally, when applicable, the motor's drive, PWM/SVM, and update rates (separate controller update rates, if applicable). Furthermore, the total (but desirably minimized) number of moving bodies between the load and motor along with the natural frequencies of the design may also need to be considered as the mechatronic design comes to completion.

One cannot reasonably apply cost reductions to a machine whose manufacturing process doesn't yet work. This is why the needs of the chosen operating process should take decision priority over the machine's initial performance tradeoffs and cost reductions. It is often best, for the initial machine build, to design for the highest capability at the lowest cost. If the new machine meets the production requirements utilizing the knee of the cost curve for its components, there may still be room for some cost reductions. On the other hand, if any specific component of the machine requires additional capability, the additional cost can be more easily justified.

Conclusion

Machine builders are continually faced with challenges in areas of technology complexity and knowledge barriers related to the scope of work to be performed, whether it involves a new design, re-design, or conversion implementation. By utilizing the latest servo system technology with a simplified axis design approach, and identifying the action items for a number of typical mechanical configurations, they can effectively manage design risk and achieve optimal machine performance while reducing development time.

This article was contributed by Kollmorgen Corporation, Radford, VA. For more information, visit ***http://info.hotims.com/61062-321***.

Anti-Creep Mechanism Enables Ultra-Precise Motor Table Positioning

Motion control is essential for the digitization and automation of high-tech equipment, but bearings remain basic to frictionless movement. Bearing Engineers, a bearing distributor, recently changed its name to Motion Solutions (Aliso Viejo, CA) to better reflect their evolution into a custom designer of motion solutions for high-tech electromechanical systems. Developing custom solutions has lead to developing lines of proprietary products that the company manufactures in-house.

A company came to Motion Solutions seeking a better linear motor table for positioning laser surgery equipment. The customer's Lasik eye surgery equipment was not performing smoothly enough, and its running parallelism was not up to their standards. The problem was being caused by linear bearing cage slippage. Though positioned horizontally, at full operating speed, the bearing retainer would creep as the momentum of the bearing movement was transferred to the cage (also called the retainer). An anti-cage creep mechanism was the logical solution.

The term "anti-creep" is used to describe the method of eliminating any slippage of the retainer holding the crossed rollers between the two V-grooved rails of the slideway. In addition to maintaining precise movement, without creepage, downtime is reduced, lowering the cost of maintenance.

An anti-creep device eliminates this creeping of the retainer so the slideway can be used in any mounting direction and with lower-momentum motors such as linear motors. Several complex anti-creep devices have been developed. To prevent cage creep/slippage, manufacturers have used a few different approaches such as a rack and pinion mechanism, an external attachment made of plastic gears outside of the rail, and a metal gear inside of the rail. Some of these devices are quite expensive.

The STUDROLLER crossed roller anti-creep slideways.

Cage creep is prevented by the studs that roll into the raceways' depressions.

After comparison tests, one mechanism was chosen that does not use a gear. The STUDROLLER™ anti-cage creep mechanism from NB Corporation of America (Hanover Park, IL) uses a roller with round balls studded around its surface. It has the smoothest tracking motion and therefore is quieter than an externally attached toothed-gear anti-creep device. In this mechanism, creep is prevented because the raceway has depressions that track the studs or nodules, preventing slippage in any position.

Motion Solutions' assembly area.

By placing studs in the center roller and machining a path along the rail, the retainer will never slip. It is suitable for high acceleration, vertical or horizontal mounting, and uneven load distribution.

Motion Solutions saw that the improved linear motor table held promise as a proprietary product. However, they had commercial concerns, including cost, which varied for crossed roller bearings with anti-creep mechanisms depending on the complexity of the design and whether the application has to be custom-designed to accommodate them. Since the NB device uses a studded roller, as opposed to a gear or exterior control, the cost is almost the same as a standard slideway — almost half the cost of other anti-creep devices, and there are no redesign costs to replace a standard slideway.

The product lowered the customer's cost by 17 percent, and Motion Solutions was able to establish processes that would shorten the lead time to between two and three weeks. The linear motor table — which initially was incorporated into Lasik eye surgery systems focusing optics and lasers on the eye — has a demonstrated level of precision that can be used for other applications. It's suitable for any positioning equipment that demands high tolerance and repeatability in the medical, life sciences, and semiconductor manufacturing industries. Successfully meeting the challenge has led to the development of a proprietary line of precision positioning tables that also meets the demanding requirements of liquid crystal-related equipment, measuring instruments, assembling systems, and material transfer equipment.

The Motion Solutions Linear Motor Table is powered by an ironless core linear motor. The smooth, noncontact drive system prevents force ripple (attraction force or cogging). Designed for high-speed positioning, the linear motor tables allow speeds up to 2,550 mm/second. A compact, lightweight aluminum alloy enclosure houses a linear encoder that positions down to 10-nanometer resolution. Each encoder is customized per a client's needs. They can choose from four motor sizes, three base length options (84, 168, or 210 mm), and encoder resolutions from 5 microns to 10 nanometers.

This article was contributed by NB Corporation of America. For more information, visit ***http://info.hotims.com/61062-322****.*

Motor Drive

The RoadRunner SoftStep R213S microstepping motor drive from Testra Corp. (Tempe, AZ) features an onboard processor that treats the input steps as small vector moves, and chains them together with 250 or 256 microsteps per regular motor step with controlled accelerations. Dual chopper stabilized current comparators and auto-calibration eliminate communication discontinuities and maintain sine wave drive, reducing motor noise. The drives are equipped with jumpers installed with a divisor setting of 10 to make them Gecko-drive compatible; jumpers can be reconfigured by the user. The drive microsteps in either 250 or 256 increments per step for DS (double-step) settings, 1 (full-step), 2 (half-step), 4, 8, 16, 32, 64, 128, and 256. The drive measures 2.5 × 2.5 × 0.825", input power is 20VDC – 80VDC, and current drive is 1 to 7 amps. Other features include resistor programmable current, opto-isolated inputs, and step frequency to 5 Mhz. Available options include custom waveforms to match individual motor characteristics, and user-programmable waveform.

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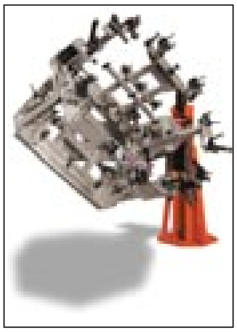
Positioners



ALM Positioners (Rock Island, IL) released the Model MHL1P 10,000-pound-capacity single-column positioner that features 68.5" vertical travel in 35 seconds; a pendant-controlled, 4-HP, column-mounted hydraulic unit for lifting and lowering; solenoid-controlled safety pawls; 360-degree CW or CCW rotation; a rotator with 267,200 inch-pounds of torque; and a 48" base. It is offered as a dual-motor rotator and variable frequency drive (variable speed rotation of .75 to 2.3 RPM), as well as a single rotator.

Also available is the MHL1P 3-axis, single-column, 6,000-pound-capacity positioner that requires no special foundation and is suited for situations in which total product access is needed. It features 68.5" vertical travel in 40 seconds; 4-HP column-mount hydraulic unit with pendant-controlled x,y,z axes; solenoid-operated safety pawl in the column; 15-HP secondary for variable speed rotation; 180-degree rotation on axis 1 (360-degree optional); 360-degree rotation on axis 2; optional wireless foot control; and optional programmable operation. The positioners eliminate slings, chain transfer, and screw systems, and allow the operator to raise and position weldments or assemblies to a convenient height and working position.

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Linear Slide

Haydon Kerk Motion Solutions (Waterbury, CT) introduced the WGS Wide Guide Screw linear slide that utilizes a screw-driven carriage. Length and speed are not limited by critical screw speed, allowing high RPM, linear speed, and long stroke lengths. The slide offers stroke options of 6, 12, and 18" in three leads (0.1, 0.5, and 1.0"). Each slide comes with a size 17 and a size 23 motor mount. The slide utilizes sliding plane bearings on a low-profile aluminum guide rail. The lead-screw is made of stainless steel, and all moving surfaces include Kerkite® polymers running on a Kerkote® TFE coating. The slides come with wear-compensating, anti-backlash-driven carriages. Additional driven or passive carriages can be added, along with application-specific customization. Linear guides without the drive screw also are available.

For Free Info Visit http://info.hotims.com/61062-302

Angle Sensors

Novotechnik U.S. (Southborough, MA) introduced the RSX-7900 Series angle sensors that provide up to IP69K ingress protection and ISO13849 PL-d safety compliance in a non-contacting design. The sensors are available in six standard measuring ranges with angles from 0 to 60, to 0 to 360 degrees with unrestricted rotation. Resolution is 12-bits across a 4 to 20 mA output, with linearity to ±1% at ≥ 90 degrees. Repeatability is 0.2°, and update rate is 5 kHz. Single and dual redundant versions are available. The sensors offer anodized aluminum housing with a stainless steel shaft for corrosion protection with salt and spray resistance. Axial and radial shaft loading is up to 300 N via a double-row angular ball bearing design. The 70-mm-diameter sensor has a nominal length of 35 mm, and is available with a choice of shaft styles.

For Free Info Visit http://info.hotims.com/61062-304

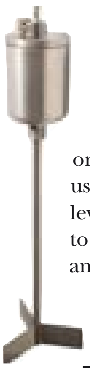
Hexapod

Aerotech (Pittsburgh, PA) offers the HEX500-350HL high-load, six-degree-of-freedom hexapod for applications in sensor testing and high-force device manipulation. It is actuated with six struts that are built with preloaded bearings, ball screws, and drive components, and is driven by AC brushless, slotless servomotors that are directly coupled to the actuator ball-screw for drive stiffness and minimum incremental motion of 20 nm in XYZ and 0.2 µrad for θxθyθz. The platform and base can be modified with user-specific features or mounting patterns.

The hexapod is designed with a 150-mm-diameter clear aperture in both the platform and base to allow for workpiece access from the bottom. The base is designed with mounting holes to adapt directly to English or metric optical tables. The hexapod is driven by A3200 motion control software that enables programming and control of the hexapod in any user-defined coordinate system.

For Free Info Visit http://info.hotims.com/61062-300

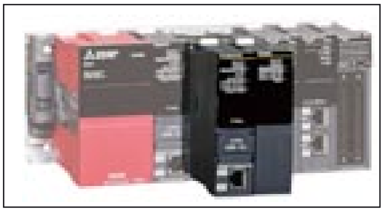
Level Indicator



The Model BM-T tilt Switch from BinMaster (Lincoln, NE) is a level indicator used for point level detection of heavy materials in bins, tanks, or silos, or over a conveyor belt or open pile. It is suspended vertically over a control point using a wire rope, chain, or flexible hanger. As the material level rises, the switch tips and causes a steel ball within the unit to shift position. When tilted to 15°, it activates a microswitch and causes an alarm condition. A stainless steel paddle is attached to the stainless steel shaft when the switch is used in rock, aggregates, or other heavy solid materials. A plastic sphere is suitable for lighter powders and solids.

For Free Info Visit http://info.hotims.com/61062-305

Machine Controller



Mitsubishi Electric Automation (Vernon Hills, IL) introduced the iQ-R Series machine control system that incorporates sequence, motion, safety, process, and C language control into one platform. The control platform is designed for applications requiring integrated motion and safety control, tight synchronization between various processes, and high production throughput. The integrated design allows machines or production lines to consolidate control in one rack. The system can have up to 4 CPUs per rack for various combinations of motion, sequence, or process control.

Features include 0.98 ns execution speed, multi-discipline control with up to 4 CPUs in a single rack, high-speed bus, GX Works3 programming software with built-in functions and configuration screens, CC-Link IE field network with deterministic performance over industrial Ethernet, and built-in SD memory card database. The control design allows communication between controllers across the backplane, eliminating the need for complex wiring. It also offers a security key feature to prevent unauthorized execution of programs.

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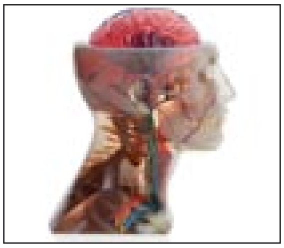
New on the MARKET

Product of the Month



Stratasys, Eden Prairie, MN, introduced the J750 3D printer that produces full-color, multi-material prototypes and parts in a single 3D print without post-processing. Users can choose from more than 360,000 different color shades plus multiple material properties ranging from rigid, to flexible and opaque, to transparent. Prototypes such as tooling, molds, jigs, and fixtures can include an array of colors, materials, and material properties in the same part. The printer is supported with PolyJet Studio™ software that allows users to choose materials, optimize the build, and manage print queues. Assignment of colors, transparencies, and rigidity is accomplished via familiar design controls. Color textures can be loaded fully intact via VRML files imported from CAD tools. Featuring a large, six-material capacity, the printer keeps the most-used resins loaded for printing.

For Free Info Visit http://info.hotims.com/61062-120

Product Focus: Test Instruments

Handheld Meters for Test Kits

OMEGA Engineering, Stamford, CT, offers the HHC200 Series portable, rugged environmental meters. Digital thermometers are offered in infrared and dual thermocouple models. Also available are light meters and optical RPM meters, a hygro-anemometer for airflow and humidity measurement, and manometers in absolute pressure and precision differential models.

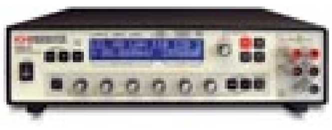
For Free Info Visit http://info.hotims.com/61062-100

Sampling Oscilloscopes

The N1092A, N1092B, and N1092D DCA-M sampling oscilloscopes from Keysight Technologies, Santa Rosa, CA, are designed for 25/100/400 Gb/s optical test. They measure low-power, high-data-rate NRZ and PAM-4 devices and feature a FlexDCA user interface. The N1092A has one optical channel, the N1092B has two optical channels, and the N1092D has four optical channels.

For Free Info Visit http://info.hotims.com/61062-101

Voltage/Current Source



The Model 526 Precision DC Voltage/Current Source/Calibrator from Krohn-Hite Corp., Brockton, MA, is a repeatable DC voltage source and DC current source that provides NIST-traceable voltages from ±100 nVdc to ±111.1110 Vdc to within 20 ppm. Up to 32 storage output settings are provided. Selecting voltages and current limits to prevent users from damaging sensitive circuitry may be set from the front panel.

For Free Info Visit http://info.hotims.com/61062-102

Power Meters

Yokogawa Corporation of America, Newnan, GA, announced the WT300E series compact power meters that consists of the WT310E single-phase, WT310EH single-phase high current, WT332E two-element, and WT333E three-element models. These units offer enhanced measurement accuracy of 0.1% of reading +0.05% of range. They provide measurement capability to 50 micro-Amps, and up to 26 Amps RMS, and use 16-bit A/D converters.

For Free Info Visit http://info.hotims.com/61062-103

Leak Detector

Pfeiffer Vacuum, Nashua, NH, offers the ASI 35 modular leak detection system for tracer gases helium and hydrogen in integral and localizing test procedures or a combination of both. An optional user interface can be controlled by PC or PLC. The system can be used in vacuum or sniffing test modes. The electronics module is suitable for universal voltage, and the detector is designed for working conditions in ambient temperatures up to 45 °C.

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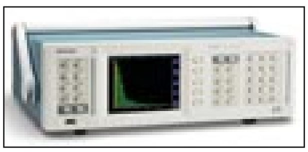
Power Analyzer



Tektronix, Beaverton, OR, introduced the PA3000 1- to 4-channel AC/DC power analyzer for testing single- and multi-phase, high-efficiency AC-DC and DC-AC power supplies. It features 10-milliwatt standby power measurement capabilities and 1-MHz bandwidth. The unit includes more than 50 standard measurement functions, including harmonics, frequency, and star-delta computation, and has multiple analog and digital inputs for sensor data.

For Free Info Visit http://info.hotims.com/61062-105

The U.S. Government does not endorse any commercial product or service identified in this section.

Mechatronics Platform

Eplan, Monheim, Germany, introduced Syngineer, a communication and information platform that interfaces MCAD, ECAD, and PLC software directly through the mechatronic structure. It synchronizes mechanical engineering, controls engineering, and software engineering, and models the mechatronic structure of a machine consisting of a user's specifications, functions, and components. The various software are linked through a browser add-in; cloud technology is required in order to network the disciplines.

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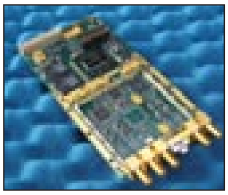
Dual-Channel Transceiver



Red Rapids, Richardson, TX, introduced the Model 372 FPGA-configurable dual-channel transceiver that features a dual-channel 16-bit analog-to-digital converter (ADC) and dual-channel 16-bit digital-to-analog converter (DAC) clocked at 310 MHz. The converters are coupled to a Xilinx Kintex-7 FPGA that is also connected to high-throughput SRAM. The transceiver is available on a single XMC, CCXMC, or PCI Express half-length form factor board. The SRAM interfaces to the FPGA through separate 18-bit read and write ports to achieve a combined 8 Gbytes/sec data transfer rate.

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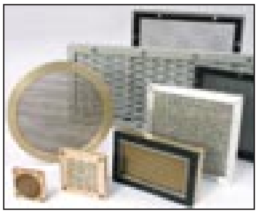
EMI-Shielded Vents and Filters



Tech-Etch, Plymouth, MA, offers EMI-shielded vents and air filters in most shapes and sizes. Nine different aluminum honeycomb vents are offered in both standard and custom configurations. Shielded fan vents are available in six sizes, and a BeCu gasket can be added to the frame. Quiet vents in 66 sizes with honeycomb media provide airflow through openings requiring shielding to 90 db attenuation levels. Shielded filters and dust shields attenuate EMI and provide a passage for cooling air while filtering dust.

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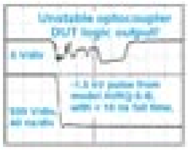
PRODUCT SPOTLIGHT



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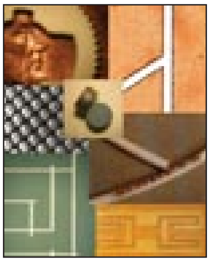

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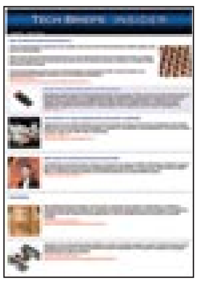

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Upcoming...

Webinars

The Role of Multi-domain Dynamic Models for Functional Verification in Model-based Systems Engineering

Thursday, June 2, 2016 at 2:00 pm U.S. EDT

Much has been made of the power of Model-based Systems Engineering (MBSE) as a formal method for capturing and managing design requirements for complex engineering systems. This Webinar seeks to demystify some of the key aspects of MBSE, and show how the methodology can bring major advantages to the engineering design process.

Speakers:

Andy Ko, Ph.D.
Manager of Engineering Services,
Phoenix Integration

Paul Goossens
Vice President,
Engineering Solutions,
Maplesoft

This 30-minute Webinar includes:

- Live Q&A session
- Application Demo
- Access to archived event on demand

Please visit www.techbriefs.com/webinar349

Chemical Machining of Titanium – A Burr Free, Stress Free and Faster Process!

Tuesday, June 14, 2016 at 2:00 pm U.S. EDT

Chemical machining of Titanium is a lower-cost alternative to producing components. Titanium is an excellent material used historically with Aerospace and Defense applications. The use of Titanium for medical applications has also grown over the past few decades as its properties are biocompatible with the human body and, of course, its mechanical strength and weight provide premium advantages as well. Recently, the use of Titanium in battery applications has also highlighted the need for alternative methods of fabricating. Chemical machining is a unique way of producing precision Titanium components and should be considered when determining how to fabricate your specific designs.

Speaker:

Robert D. Ashman
National Sales Manager,
Precision Products,
Photofabrication Engineering, Inc.

This 30-minute Webinar includes:

- Live Q&A session
- Application Demo
- Access to archived event on demand

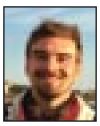
Please visit www.techbriefs.com/webinar351

Advanced Passive Thermal Management Technologies for Power Electronics: Solutions to Reduce Noise, Power Consumption, and Operating Costs

Wednesday, June 15, 2016 at 2:00 pm U.S. EDT

Components housed within power electronic devices continue to shrink in size and increase in power. Properly managing the thermal loads within these systems can be challenging, and traditional solutions of larger pumps and fans result in more noise and higher power consumption. This Webinar will present a series of advanced passive technologies used to optimize thermal performance, while reducing noise and power consumption.

Speakers:



Deniz Pamukcu
New Business Development
Specialist,
Advanced Cooling Technologies, Inc.

Darren Campo
Lead Product Development
Engineer,
Advanced Cooling Technologies, Inc.

This 30-minute Webinar includes:

- Live Q&A session
- Application Demo
- Access to archived event on demand

Please visit www.techbriefs.com/webinar352

Unlocking the Secrets of Amorphous Metals

Thursday, June 16, 2016 at 1:00 pm U.S. EDT

Bulk metallic glasses (BMGs), amorphous metals, and liquid metals are non-crystalline metal alloys that are simultaneously glasses, metals, and liquids. In this Webinar, you will learn the fundamental science of BMG formation, how to design alloys for specific properties, new manufacturing techniques to fabricate complex hardware, how structural applications are prototyped, and the results of bench-testing for various applications.

Speaker:

Dr. Douglas Hofmann
Technologist,
NASA Jet Propulsion Laboratory

This 60-minute Webinar includes:

- Live Q&A session
- Application Demo
- Access to archived event on demand

Please visit www.techbriefs.com/webinar353

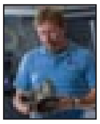
The High Frontier: In-Space Manufacturing at NASA MSFC

Wednesday, June 29, 2016 at 2:00 pm U.S. EDT

Find out about the latest additive manufacturing technologies in use at NASA MSFC, how they work, and how they are being utilized to further NASA's efforts to create a sustainable, lower-cost launch capability. This Webinar also will provide an overview of NASA's In-Space Manufacturing (ISM) project and discuss efforts underway to develop and adapt manufacturing technologies for use in space that have the potential to enhance crew safety and enable sustainable exploration.

Speakers:

Tracie Prater, Ph.D.
Aerospace Engineer,
NASA Marshall



Kenneth Cooper
Advanced Manufacturing Team Lead,
NASA Marshall

This 60-minute Webinar includes:

- Live Q&A session
- Application Demo

Please visit www.techbriefs.com/webinar359

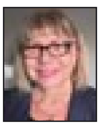
Available On Demand!

Aerogel Hybrid Composite Materials: Designs and Testing for Multifunctional Applications

Scientists at Kennedy Space Center have continued to expand the design, development, and applicability of aerogels by developing advanced composite materials and systems with multi-functional capabilities.

This Webinar introduces the broad spectrum of aerogel composites and their diverse performance properties, and expands specifically on the aerogel/fiber laminate systems and testing methodologies.

Speakers:



Dr. Martha Williams
Lead Polymer Scientist and Principal Investigator,
NASA Kennedy Space Center

James Fesmire
Senior Principal Investigator,
Cryogenics Test Laboratory,
NASA Kennedy Space Center

This 60-minute Webinar includes:

- Live Q&A session
- Application Demo
- Access to archived event on demand

Please visit www.techbriefs.com/webinar339

NASA's Technology Transfer Program

NASA's R&D efforts produce a robust supply of promising technologies with applications in many industries. A key mechanism in identifying commercial applications for this technology is NASA's national network of laboratories and business support entities. The network includes ten NASA field centers, and a full tie-in with the Federal Laboratory Consortium (FLC) for Technology Transfer. To explore technology transfer, development, and collaboration opportunities with NASA, visit **technology.nasa.gov**.

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Sensor Technology

Supplement to *NASA Tech Briefs*: 2

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Recycling Technology Converts Plastic Waste to Energy

NASA's expertise in rocket engine improvement helps optimize plastic recycling process equipment.

As good as it feels to throw plastic items into the recycling bin, the fact is most of that plastic goes unrecycled, according to Jim Garrett, a veteran of the oil and gas industry. "It's a dirty little secret in America that 90 percent of our plastic ends up [in landfills], if not in our oceans."

The reason for the low rate of recycling is that many plastics contain additives and fillers that make them incompatible with current recycling technologies, while others are contaminated with paper or ink. "Recycling companies take in the clear water bottles, but most of the other stuff is not recycled," Garrett said. But as the old adage goes, one man's trash is another man's treasure. In 2009, Garrett met petroleum geologist and geochemist Bill Ullom, who had in mind a technology that could make use of all this unwanted plastic in order to strike oil, or at least manufacture it.

Vadxx president Jim Garrett speaks with President Barack Obama about the company's plastics recycling technology at the Manufacturing Advocacy and Growth Network (MAGNET) Innovation Center in Cleveland, which helped Vadxx connect with NASA Glenn Research Center. (Credit: Vadxx Energy LLC)

In 2005, Ullom had found an expired patent for a thermal depolymerization process that could convert plastic back into its original form: light crude oil. The technology works by sending plastic feedstocks, as well as tires and car interiors, through a shredder, where rotating cutters shred the material before sending it through an extruder/kiln combination, where the feedstock is incrementally heated, producing vapor. At the exit of the process path, the vapor is released and condensed into liquid form and distilled into derivatives of light crude oil, namely fuel gas and diesel additive. The last and only solid byproduct of the process is inert char, which can serve as a strengthening agent in rubber products, among other uses.

Ullom began making improvements to the process that allowed the technology both to run nonstop and to accept contamination from materials such as wood and cardboard. After meeting Garrett, he founded Cleveland-based Vadxx Energy LLC and became its chief technology officer, with Garrett filling the role of CEO. By 2012, the company still needed help optimizing the kiln's design, which would be a complex task. While one wouldn't necessarily think NASA has much in common with a trash-recycling technology, the Agency's work on rocket propulsion makes it especially adept at analyzing such a process.

In May 2012, a team of four scientists from Glenn's chemistry kinematics group created a kinematic model where Vadxx could put in the diameter of the kiln, the feed rates, and the viscosity of the polymers, and it optimized the process, maximizing the output of the oil byproduct. The model proved to be a success, and Vadxx had the technology to manufacture its first full-scale commercial kiln.

When fully operational, the kiln will be able to process 20,000 tons of waste per year to produce 100,000 barrels of petroleum product that will be sold to distributors and marketers. While Vadxx will operate that facility, its expansion plans center around licensing the technology to other entities. The company estimates there's enough feedstock in the United States to build 1,500 Vadxx units, which would decrease the nation's oil imports by 7 percent.

All those units would be environmentally friendly, according to Garrett. No hazardous byproducts are created, and, unlike most companies that flare off excess fuel gas, which contributes to global warming, Vadxx recycles that gas to provide 80 percent of a unit's heating needs. "From both an economic and environmental standpoint, it's a winner," he said. "The EPA [Environmental Protection Agency] classifies our unit as only a minor emitter, equivalent to a hospital boiler. And the key there is we're not burning feedstock, but melting it in a vessel. It's not like we're building a new refinery where it takes 10 years to get the approval."

The technology has generated enormous interest from waste disposal companies and large manufacturing facilities, which stand to gain by paying less money to truck material to a Vadxx unit than to the landfill. What's more, each unit is projected to make $8 to $12 million per year in revenue for its operator, and provide 18 full-time jobs.

Besides the technical leg-up NASA gave the company, Garrett said there was another, more indirect benefit of having partnered with NASA: credibility. "We'd kind of brag to people that we worked with NASA, and they say, 'Really? I may be interested in investing.' The NASA name has that kind of impact."

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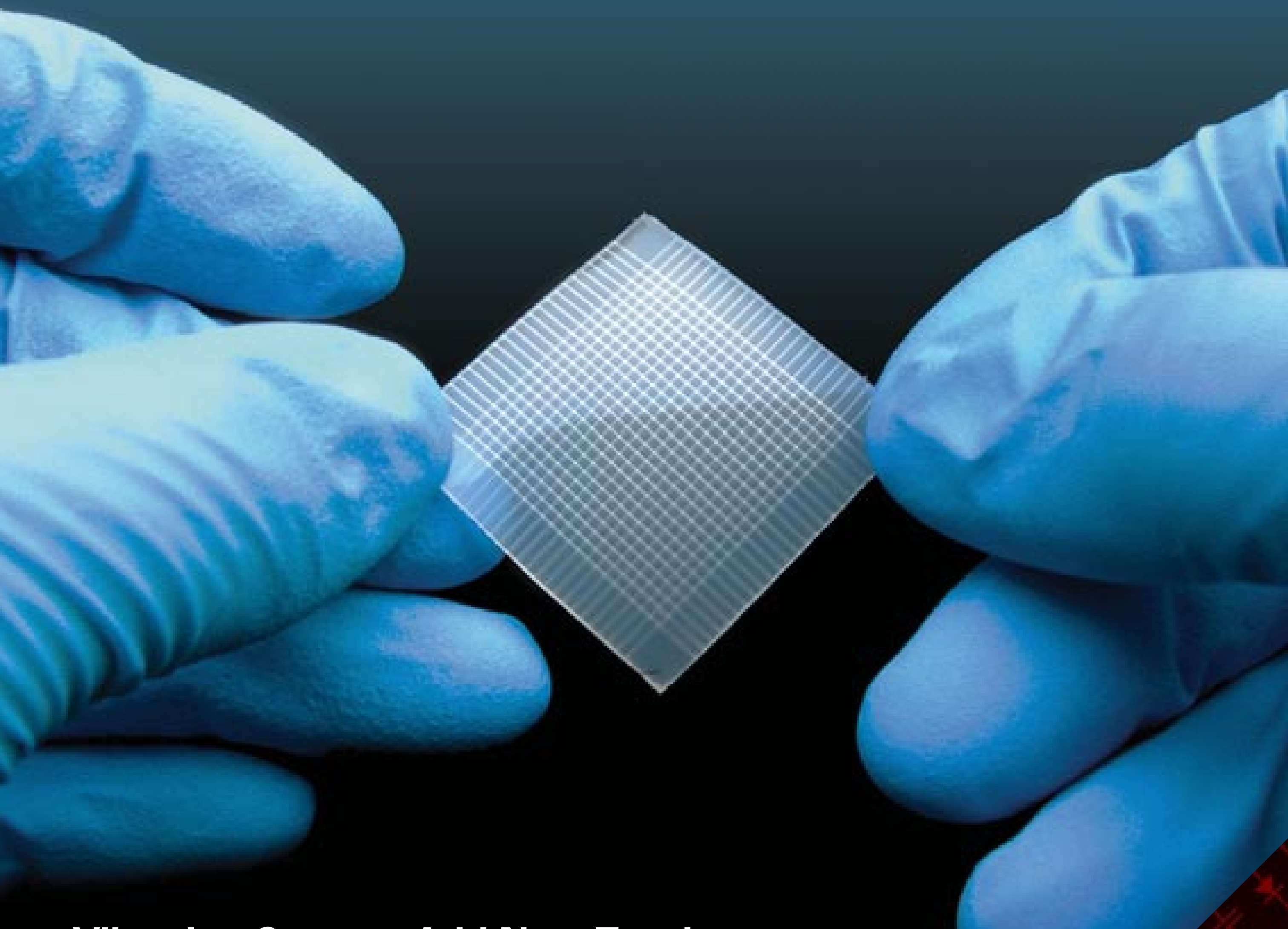
June 2016

SENSOR TECHNOLOGY



Vibration Sensors Add New Touch to Prosthetics

NASA Proxy Maps Reveal Earthquake Damage

Inertial Sensors Get in the Driver's Seat

eVADE Technology Shields Aircraft from Volcanic Ash

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ON THE COVER

Researchers at the University of California – Santa Barbara are using sensors like the one shown to design an electronic skin-like device. The "skin," worn on a human or robotic hand, provides a means for capturing what the hand feels when it touches an object. In a separate effort to determine how to electronically measure sensation of the hand, UCSB researcher Yon Visell and his students have developed a wearable sensor array that measures the mechanical signals traveling through the fingers and beyond. The findings support new tactical sensing applications, including improved prosthetics and robotics. To learn more, read the article on page 14.

(*Image Credit: UCSB)*

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"THE BEST WAY TO PREDICT THE FUTURE ...IS TO CREATE IT."

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SENSORDRONE BLUETOOTH SENSOR

Sensordrone was one of the world's first mobile, wearable, programmable, sensing computers that dramatically extended the sensing capability of smartphones and tablets. This key fob-sized device turned smartphones into a carbon monoxide detector, non-contact thermometer, gas leak detector, lux meter, weather station, diagnostic tool, and more.

"Winning the contest generated great publicity for Sensordrone and enhanced the launch of the product in 2013. After manufacturing the product for almost 2 years, Sensorcon was acquired by Molex in 2015 and we're now replacing Sensordrone with an improved product line of wireless sensors," said Mark Wagner, GM of Sensorcon — Sensing Solutions by Molex.

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Making Sense from Sensors

How to Build a Sensor Fusion Engine

The presence of more than 1 billion sensor-rich smartphones and the intense interest surrounding the Internet of Things has drawn wide attention to all the potential and possibilities of sensor fusion engines. Availability of context data and general real-world data in digital format opens up many opportunities.

But what exactly is sensor fusion? Edge devices capture the analog world through temperature, motion, moisture, or other data. The mystery, however, is the "fusion," where all the software innovation is taking place.

Measuring the speed of an athlete, for example, requires more than just an accelerometer. Among various inputs, one needs to determine the athlete's direction of travel. Accelerometers are sensitive to many factors over short periods. To adjust for the shortcoming, gyroscope data produces reliable, short-term angle estimates, and a magnetometer's readings correct for any "sensor drift" or inaccuracies.

Performing a fusion of the data from the three sources gives a more precise estimate of the speed of the athlete. Data from each sensor corrects for the shortcomings of the others. The theory behind the operation and accuracy of each sensor type is complex, and the fusion algorithms are seen as valuable intellectual property.

The larger the number of data sources, the more complex the fusion algorithms and the closer we get to the real-life analog context. If sensor fusion is the process by which data points from multiple sensors are combined to extract the best estimate of a system context being observed, then how does one go about building such a thing?

Step 1: Get Your Analog Sensor on the Bus

You do not need to be an expert in the physics of the sensor to integrate it in a System on Chip (SoC). To create a fusion engine, the sensor requires a register set and an Advanced Peripheral Bus (APB) interface.

The Advanced Peripheral Bus is designed for low-bandwidth control accesses — for example, register interfaces on system peripherals such as sensors. The APB includes an address and data phase that have a reduced, low-complexity signal list. If the data throughput from the sensor is high, then one can consider the Advanced High-performance Bus (AHB), an industry-standard bus protocol (see Figure 1).

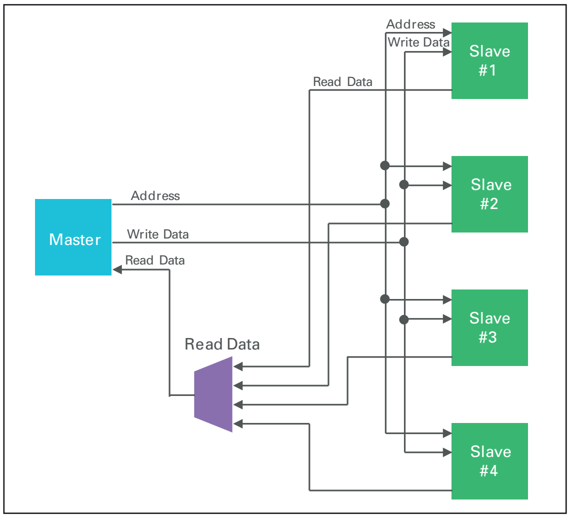


Figure 1. The Advanced Peripheral Bus (APB) is a low-complexity interface for connecting an analog slave component to a microprocessor. (Image Credit: ARM, Inc.)

When a sensor cannot be physically integrated into the SoC, one can instead integrate the peripheral interface — I2C or SPI, for example — required to communicate with the sensor. Industry-standard interface blocks are available from many sources.

Step 2: Design Tradeoffs

Once all the sensors are on the bus, the rest of the system must be built with an eye on keeping the balance between cost, power, and productivity.

For cost constraints, it is important to reduce the number of components in the device. Having only one processing unit is valuable, as opposed to multiple dedicated ones, such as a microcontroller and a DSP (digital signal processing) block. (Keep in mind that some microcontrollers also have DSP capabilities.)

A DMA (direct memory access) block optimizes power capabilities. The processor block cannot constantly handle the incoming data from all sensors, regardless of the rate. Most of the system has to be put to sleep for the maximum amount of time; otherwise the power consumption will be too high. A smart DMA block will handle the incoming data points and only "wake up" the processor when there is enough data that merits processing.

One can build a highly complex design — with distributed processing for extreme low power — but then spend years trying to build the software. Productivity is about getting the solution out the door in a reasonable amount of time. The

best setup for software development is a sufficient choice of tools and a simple debug process (see Figure 2).

Step 3: The Fusion Algorithms

To write the software that will analyze and fuse the data from the various sensors, the right processor must be selected. In order to achieve the correct amount of processing power, users need to determine the complexity of the algorithms that are needed. Could a small general-purpose processor be used, for example? Or are high-performance, DSP, or even SIMD instructions required?

Setting the data types and structures is typically a large part of the design of any algorithm. For sensor data, there is a choice between three types: fixed-point, single-precision, and double-precision floating point.

Integer is a fixed-point data type; variables use 32 bits for positive and negative whole numbers. The data type has less dynamic range than floating-point data options.

Storing real numbers as integers may also result in conversion and arithmetic round-off errors. Examples include output from sensors measuring real-world values, such as audio signals using 12-bit A/D output, or image files using 8 or 24 bits per pixel. In integer math, rules must be established for when the result of an arithmetic operation is greater than the upper bound of the integer data type (i.e., when the variable saturates as an operation result exceeds the container) and when the result is less than the lower bound.

Single-precision, a floating-point data type, has a reasonable dynamic range; variables use 32 bits to accurately represent values to approximately seven decimal places. Single-precision is ideal for storing and processing real number values where a lower level of accuracy than double precision is acceptable.

Double-precision is a floating-point data type with a larger dynamic range; variables use 64 bits to accurately represent values to approximately 15 decimal places.

With fixed-point variables, the gaps between adjacent numbers are always exactly one. In floating point notation, the gaps between adjacent numbers vary over the represented number range. If math can be done on integer and single-precision data, then one can store such data more efficiently and avoid having to convert it to doubles before processing. Fixed-point has saturation issues, while floating point has round-off errors that cause the value of the final result — after many operations — to gradually drift away from its expected value.

Variable types must be selected to match the data being processed. A processing unit needs to enable operations with maximum precision, minimum errors, and reasonable memory and power usage. An easy choice would be to use double precision for all variables, but that leads to doubling in the required amount of memory. Additionally, power consumption increases significantly since all operations take place on 64 bits.

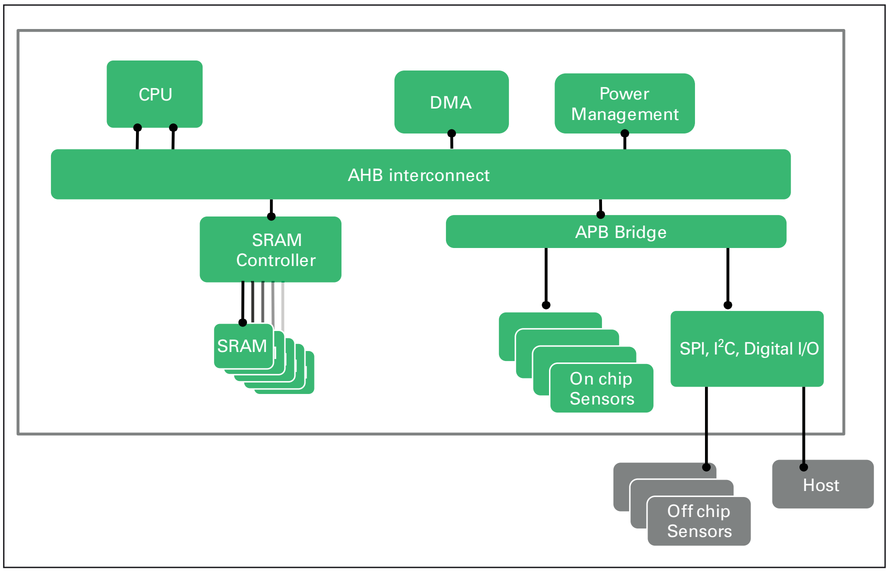


Figure 2. The components of a sensor fusion engine system. In the block diagram, power, cost, and performance are balanced for optimal operation. (Image Credit: ARM, Inc.)

Step 4: Finding the Right Instructions

There are many processors and DSP engines on the market that support these data types. In the end, there is no automatic decision process that will output the right processor choice. The decision is tightly coupled to the set of algorithms that will be used and the precision required for each. Keep in mind that all processors will run any code. There are many variations of libraries for single- and double-precision floating point operations, for example.

Power and performance must be balanced. A floating point operation using the library function may take up to ten times the processing time compared to performing the same operation on a processor that has a floating point unit. When making design choices, various criteria must be balanced. Otherwise, one would take the most advanced high-performance processor — or an array of those — to build the fusion engine.

In selecting a processor, it is important to confirm that an instructions set fits the operations to be performed on the sensor data. For example, a single-cycle multiply with a 32-bit result is a critical instruction to have for sensor processing algorithms that perform many multiplications.

There are a number of other examples. The long multiply instruction multiplies two 32-bit integers and saves the result in a 64-bit integer. The instruction is essential for implementation of the multiplication of a 32-bit fixed-point number.

The flexible Operand 2 command allows for shifting by a constant or a register. In fixed-point algorithms there are several shifts necessary, for instance when operating on or converting between fixed-point variables that have different formats.

Additionally, a hardware divide provides a measurable performance benefit over performing the same divide in software. The integer division command offers a 32-bit divide. For fixed-point math, a common case is to perform a divide of a 64-bit number by a 32-bit number, yielding a 32-bit result.

A floating point unit dramatically speeds up algorithms that cannot be easily adapted to fixed-point computation, like matrix decomposition, which otherwise would rely on a soft-float implementation. In addition, the fixed-point math can be further improved by leveraging many of the DSP extensions to the instruction set, including SIMD and instructions with saturating arithmetic.

A double-precision floating point unit, or compute block, is critical if the choice is made to use the double-precision data type; otherwise the processing time may be off by a factor of 10.

Step 5: Output the Context

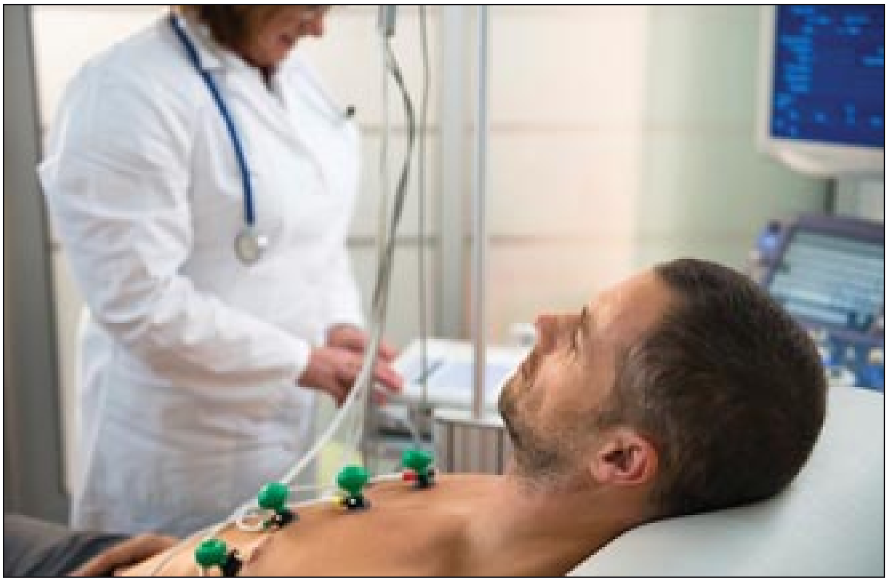
The SoC design is done, the algorithms are written and optimized, the fusion operation is tuned for the application in mind, and all that remains now is to integrate with a host. Usually, for cost considerations, the fusion engine is always a slave to a host. At system power-up, the host will download the software to the internal memory. The download removes the need to embed flash memory in the fusion engine, reducing power consumption and cost.

During the operation of the whole system, the host expects to receive indications of major context changes via the host interface — one as simple as an SPI interface. There is no industry-standard application program interface (API), however, major mobile operating systems have defined their own APIs for the exchange.

Conclusion

Building a sensor fusion engine is a straightforward exercise given the amount of technology available off the shelf in the market today. A good sequence to follow is to focus first on the desired overall context output. Then, select the algorithms that are required to extract that context. For each of those algorithms, examine the operations required for the computations used, and map those to processor instructions for optimal performance. If many iterations are expected while number crunching, then make sure to select the appropriate data types to avoid round-off and saturation errors.

Finally, keep an eye on unexpected potential optimizations. For example, some processors have what is referred to as a Multiply Accumulate Unit (MAC). Instead of using a multiply instruction followed by an addition instruction, one could use the MAC to do the multiply add operation in one single step. The upgrade dramatically speeds up all sorts of filtering operations. Selecting the most suitable processing unit will deliver the desired output with a delicate balance of cost, power, and productivity.



A patient receives an electrocardiogram, or EKG. An EKG Sensor measures the electrical voltages produced during heart contractions. The larger the number of data sources, the more complex the fusion algorithms.

This article was written by Diya Soubra, senior product marketing manager for ARM Cortex-M Processors, ARM, Inc. (San Jose, CA). For more information, visit ***http://info.hotims.com/61062-412***.

NASA Proxy Maps Reveal Earthquake Damage

On April 25, 2015, a magnitude-7.8 earthquake caused widespread building damage in central Nepal. The Italian Space Agency's COSMO-SkyMed Synthetic Aperture Radar (SAR) satellite acquired data over Kathmandu – a 50 x 50 km area – four days after the earthquake. Using the SAR information, Sang-Ho Yun and other researchers of the Advanced Rapid Imaging and Analysis (ARIA) team at NASA's Jet Propulsion Laboratory and California Institute of Technology produced a damage proxy map showing areas of potential building damage.

Sang-Ho Yun

Sensor Technology: How were you able to create the damage proxy maps?

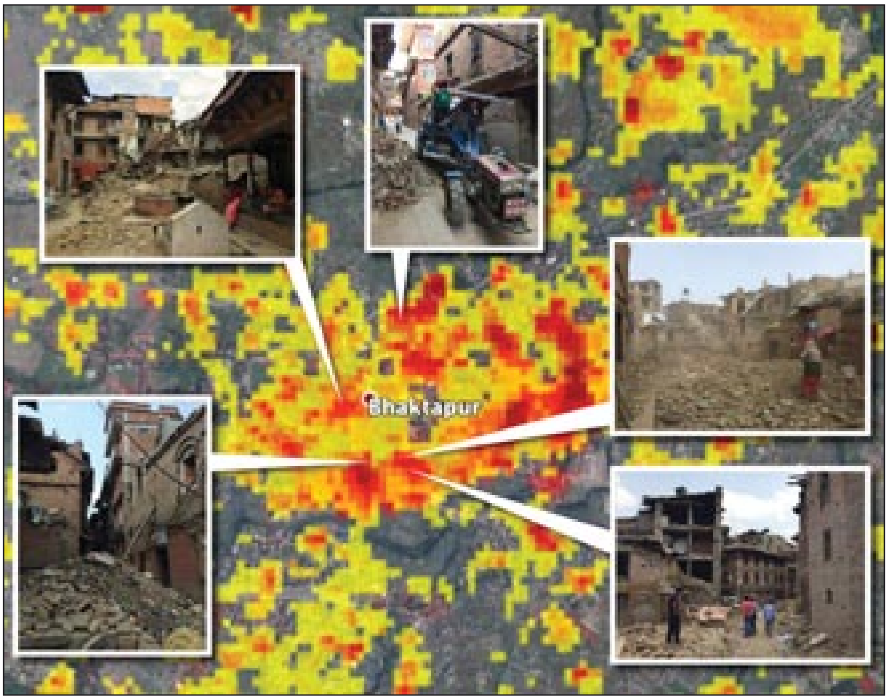
Sang-Ho Yun: We compared before and after images. It's more sophisticated than just a simple comparison. We use an image called a coherence map.

Sensor Technology: What is a coherence map?

Sang-Ho Yun: A coherence map shows similarity between two radar images, pixel by pixel. High-coherence pixel value means that the ground objects under that pixel remained the same between the two timings of the radar image acquisition, whereas low coherence means that the objects changed during that time. We take the difference of the two similarity maps; therefore we can isolate a change from other naturally occurring changes. The high pixel values in the map directly indicate high probability of damage, or high degree of change.

Sensor Technology: Who used the data?

Sang-Ho Yun: The map was used by the National Geospatial-Intelligence Agency (NGA) to determine priority areas for their analysis. Six days after the earthquake, the Office of US Foreign Disaster Assistance confirmed a strong



Photos of the damage in Bhaktapur, Nepal, are overlaid on a damage proxy map derived from COSMO-SkyMed satellite data. Colors show increasingly significant change in terrain/building properties (including surface roughness and soil moisture). Red is most severe. (Image Credit: NASA/JPL-Caltech/Google/DigitalGlobe/CNES/Astrium/Amy MacDonald/Thornton Tomasetti)

spatial correlation between the map and realities on the ground. Seven days after the earthquake, Japan Aerospace Exploration Agency's ALOS-2 [satellite] acquired SAR data over much larger areas (70 × 180 km). Nine days after the earthquake, the DigitalGlobe [an American commercial vendor of space images] decided to use the damage proxy maps to determine where to focus their collection areas for high-resolution imagery. On the following day, we produced damage proxy maps from ALOS-2 data, which revealed potential building damage as well as landslides.

Sensor Technology: Were the maps available to the public?

Sang-Ho Yun: Damage proxy maps were made available to the public and responding agencies through the ARIA team website at http://aria-share.jpl.nasa.gov/, and the US Geological Survey's Hazards Data Distribution System (HDDS) website at http://hddsexplorer.usgs.gov/. From the ARIA website alone, there were 3,198 downloads of the maps in May 2015.

Sensor Technology: What are the advantages of Synthetic Aperture Radar?

Sang-Ho Yun: The imaging radar sees through clouds and can image during day and night. So it has great potential to be used for rapid disaster response.

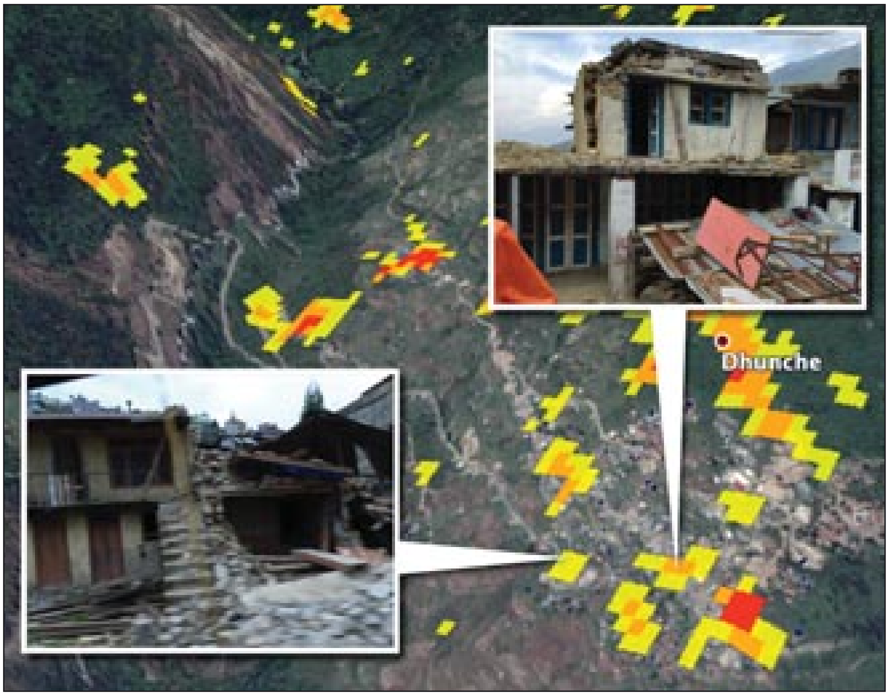
Sensor Technology: What can be seen specifically that is so valuable for recovery teams?

Sang-Ho Yun: The expanse of the imaged area is quite large: 50 × 50 kilometers and 70 × 180 km. The comprehensive map suddenly reveals the areas of potential damage. So you immediately have an idea of what areas are heavily affected. A lot of first responders and the decision-makers can look at the map and then come up with an informed decision as to where they might want to put their resources first.

Sensor Technology: How long does it take to acquire data in a damaged area?

Sang-Ho Yun: The first latency that we have is the data acquisition latency, which is the amount of time that we have

Maps Reveal Earthquake Damage



A damage proxy map, derived from ALOS-2 satellite data, shows images of Dhunche, Nepal. Unreinforced stone masonry buildings (shown) resulted in many collapses following the earthquake. (Image Credit: NASA/JPL-Caltech/Google/DigitalGlobe/Amy MacDonald/Thornton Tomasetti)

to wait until we see the first radar satellite, when you look at the sky from the affected area.

If we take into account all the existing radar satellites, the expected wait time is already within a day. That's very encouraging. In fact, we had missed the first data acquisition opportunity; there was an Italian satellite that passed over the area six hours after the earthquake. The second [satellite passed over the area] a day after the earthquake.

This is the great potential. We can better coordinate in the future with other space agencies and produce this kind of product much faster.

Sensor Technology: What were the challenges for this type of disaster sensing?

Sang-Ho Yun: We're using a radar sensor; that does not necessarily correspond with what we would see with our eyes on the ground. So we need to sort out the similarity between what the radar sees and what we would see. That's where a lot of study is warranted, and we are making progress in that direction. Radar can see very subtle changes that people cannot see, like soil moisture content change. We don't see that very well on the ground, but radar does. We want to identify it and reduce the rate of false alarm in the product.

Sensor Technology: What is the difference between what we see and what the radar sees?

Sang-Ho Yun: We see what is normal and what is damaged. Radar sees how much the object became rougher or smoother (compared to radar wavelength), and perhaps how much the ground became wetter or drier.

Sensor Technology: Where else have the maps been used?

Sang-Ho Yun: This is a change-detection map. We see changes on the ground; that can be a challenge when we don't know exactly what caused that change. It could be a soil moisture change on the ground; it could be building damage; it could be landslide debris; it could be a newly established group of tents for a shelter for the victims. The radar sensor sees whatever is changing on the ground; it doesn't discriminate for building damage or landslide damage.

On the flip side, it's also an advantage that we can apply this technique to many, many different applications. In fact, we did detect a landslide, which was induced by the Nepal earthquake. We also saw great potential on detecting ash fall damage from volcanic eruption. There are many applications. If there's ground surface change, there's a great potential for us to apply this technique.

Sensor Technology: What are you working on now?

Sang-Ho Yun: Most recently, I applied the Synthetic Aperture Radar technique to detect and produce a flood-extent map; there was a Midwest flood occurring over [a span of] three weeks, starting toward the end of last year along the Mississippi River.

Sensor Technology: How was the SAR used to create a flood-extent map?

Sang-Ho Yun: Flooded areas often undergo surface roughness change. This change shows up as brightness change in radar images. Thus, simple comparison of before and after radar images already gives a good idea of areas of potential floods.

Sensor Technology: What are other possibilities for damage proxy maps?

Sang-Ho Yun: Other than detecting damage of artificial structure, there have been other uses of radar images, such as mapping of liquefaction damage, landslides, forest damage, storm surge damage, tropical cyclone damage, tsunami damage, and damage from volcanic ash fall and lava flow. It is also very well known that SAR images are used to precisely measure ground deformation caused by earthquakes, volcanic activities, ground water level change, and so on. Such techniques are also useful to measure the velocity of glaciers, as well as to study spatial variation of water vapor content in the troposphere and total electron content in the ionosphere.

With more and more SAR missions in orbit, I think we're reaching the capacity of where we can and should apply the technique for more direct, societal benefits. I'm happy to see an increased level of awareness of the usefulness of the technology. We'll be continuing to improve this technique to produce a better product for better future response.

*For more information, visit **www.jpl.nasa.gov**.*

Inertial Sensors Get in the Driver's Seat

Tiny devices improve safety, comfort in ADAS

Two decades have passed since automotive manufacturers began using the first microelectromechanical systems (MEMS) accelerometer to measure strong acceleration and trigger the deployment of airbags (see Figure 1). The inaugural inertial sensor paved the way for more widespread use of accelerometers in today's advanced driver assistance systems (ADAS).

Present ADAS technologies also incorporate other types of MEMS inertial sensors, including gyroscopes, pressure sensors, and magnetometers. In fact, the much-beloved SUV would not exist if not for the rollover safety features made possible by MEMS. A MEMS gyroscope detects rotation around the x-axis of the rolling car — the primary input for the crash detection algorithm.

While inertial sensors play a prominent role in automated driving, the components enable equally important ADAS applications, which are either here today or will arrive soon. What do engineers need to know about MEMS inertial sensors when designing ADAS, and what do these technologies mean for automotive manufacturers and consumers in the next 10-20 years? Let's review the role of sensors in both present and future automotive technologies.

Rollover Sensing

Rollover sensing, a passive vehicle safety function, detects whether a car is falling over and activates the deployment of airbags. Inertial sensors provide the primary feedback (roll rate, lateral and vertical acceleration) for crash detection algorithms.

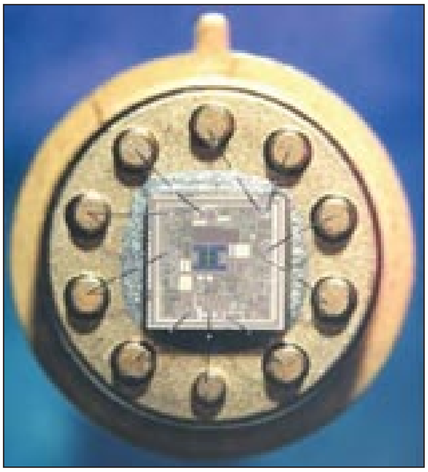


Figure 1. The first accelerometer for automotive airbags, pioneered at Analog Devices. (Image Credit: Analog Devices)

The challenge, however, is to provide reliable sensor signals in a variety of conditions: under extreme heat or cold temperatures, on motorways, or on gravel roads, for example. The requirement also applies to inertial sensors for electronic stability control (ESC), an active automotive safety feature that supports the avoidance of skidding by controlling and actuating car brakes.

One approach to the challenge is a careful design that combines the expertise of MEMS design and the understanding of automotive systems and their requirements. Products must be designed according to specifications, and samples must first be tested in lab and comply with paper-written requirements. Finally, the sensors need to undergo more real-world test drives, such as rides during winter or on gravel roads.

Navigating through Urban Canyons

Drivers have embraced in-dash navigation systems; the technologies lower the stress of self-navigation in unfamiliar cities. Relying on maps, Global Navigation Satellite System (GNSS) signals, and routing algorithms, inertial navigation systems may even provide real-time information on traffic jams via connectivity services, i.e., the traffic jam assist feature.

Automotive engineers favor adding inertial sensors to navigation systems because their system will still work in "urban canyons," or areas where GNSS signal is of poor quality, fails, or is unavailable. In such situations, inertial sensors can determine the change in position after the last trustworthy GNSS reading. If GPS signal cannot be received when a driver is inside a tunnel, for example, the inertial sensor calculates a vehicle's direction in meters. Dead reckoning algorithms then calculate the position change; one's current position can be extrapolated based on the inertial sensors' signals.

Figure 2. Bosch began testing automated driving on public roads at the beginning of 2013. The latest test vehicles are based on the Tesla Model S. (Image Credit: Robert Bosch GmbH)

Driver Assistance in Many Flavors

Driver assistance technologies are more than simply cruise control or rear backup cameras. Adaptive cruise control; lane keeping and lane changing assist; advanced emergency braking systems (AEBS); and active front steering are all variations of driver assistance — and made possible by the intelligent fusion of MEMS inertial sensors with perception systems such as cameras, radar, and/or LIDAR.

Adaptive cruise control is far more experience-specific than the familiar, traditional cruise control features. While the old cruise control technology conserves gas and may prove more relaxing on long drives, who hasn't experienced the annoying need to toggle the cruise control off and on, depending on the variable speeds of a nearby car? Rather than maintaining a single speed when on cruise, adaptive cruise control adjusts the vehicle speed as needed, in order to maintain a safe distance from other cars.

Adaptive cruise control depends primarily on measuring distances to objects by using radar, cameras, or lasers. The same kind of inertial sensor that reinforces ESC also enables adaptive cruise control. The inertial sensor helps to predict a trajectory and then relate that route to the obstacle detection.

A similar inertial device also supports hill-hold control, a feature that keeps an uphill-driving vehicle from rolling backwards. A low-g sensor determines inclination by using the downward direction of gravity.

Active steering, another driver assistance technology, reduces at higher speeds the amount of change in the steering angle for every movement of the wheel. The feature supports more precise driving on highways. Yaw rate sensors provide the relevant information about sudden changes to motion.

The good news is that some driver assistance systems are already available in mid-priced vehicles, rather than just luxury cars. While BMW was early to market with active steering, Ford offers active steering on its Ford Edge; other automakers will soon follow suit.

Much in the same way that inertial sensors support cameras, radars, and lasers for driver assistance, the detection technologies can leverage automated driving by predicting the motion of the car.

Look Ma, No Hands!

Current autopilots combine a series of ADAS functions that already exist. Fully autonomous cars need to know their environment in detail and must interpret and predict the behavior of cars and pedestrians. Using high-precision maps and vision systems, perception technology must anticipate car trajectories on highways. Highway driving predictions are easier to achieve than anticipating car and pedestrian trajectories in urban driving (see Figure 2). Such artificial intelligence by "deep learning" is imperative for achieving the cognition required for fully autonomous cars.

Localization and Navigation

In fully autonomous driving, the car becomes a robot that answers the questions: "Where am I?", "Where do I want to go?", and "How am I going to achieve that?" Inch-scale localization, which answers those questions, is essential to automated driving and autonomous

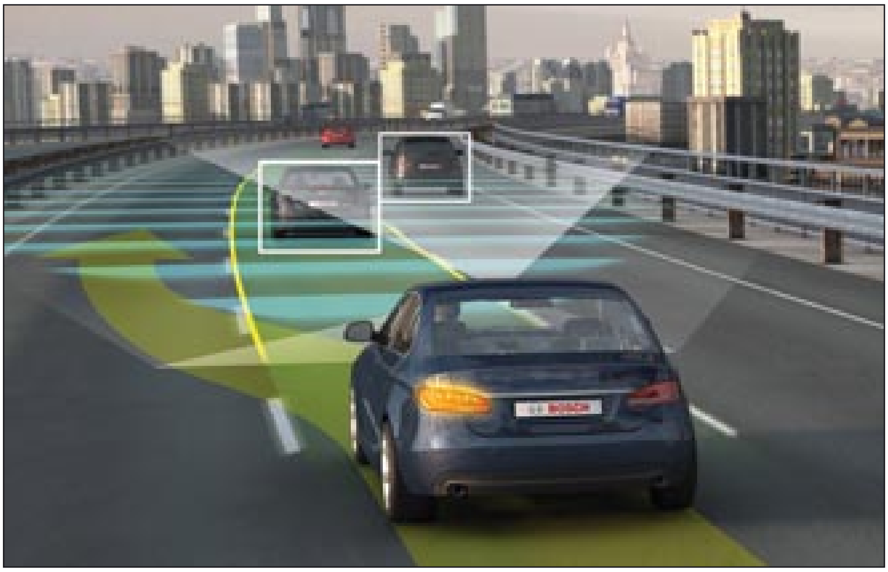


Figure 3. MEMS inertial sensors are integral to localization and navigation. (Image Credit: Robert Bosch GmbH)

vehicles. In contrast to the navigation that directs us to the nearest Starbucks, localization pinpoints one's position within the lane of a street (see Figure 3).

Inside the self-driving car, two different technological approaches converge for self-localization: robotics and transportation.

Using perception systems like cameras, LIDAR, and radar, robotics researchers have developed new methods to determine one's relative position to objects. For example, when following the approach of simultaneous localization and mapping (SLAM), the robotic car creates a map of its surrounding environment and relates its actual position to this relative outline. Using pronounced landmarks from the map, and identifying their position in a stored high-precision plot, one's absolute position can be determined.

Field-proven in the transportation industry, inertial navigation systems (INS) determine change in absolute position by measuring accelerations and rotations. Starting from an absolute position — which the system can deduce from GNSS readings, landmark navigation, or SLAM — the strapdown algorithm calculates a new position based on the readings of the inertial sensor.

Depending on the targeted accuracy, INS may require high-performance sensors, since sensor drifts and errors accumulate quickly. Highest demands are met by optical sensors, such as ring laser gyros and fiber-optical gyros. In recent years, high-performance MEMS sensors have successfully entered the market of tactical-grade sensors.

Fusing the Data of Inertial Sensors and Perception Sensors

How do vision and perception systems benefit from inertial sensors? Visual, or perception, sensors perceive moving objects — "the optical flow" — in order to reliably determine "structure from motion," and to establish an estimate of car motion and of distance to traffic partners.

Inertial sensors are completely independent of a perceiving sensor's limiting factors, such as weather conditions, suitable daylight conditions, snowy roads, or obscured landmarks. The inertial sensors do not depend on a scene's illumination because they detect kinesthetic motion and do not compute it from pictures. Additionally, the more secure inertial sensors do not rely on any connectivity and data communication external to the car. Current research discusses both a loose coupling and a tight coupling for fusing kinesthetic inertial and visual information.

When employing a loose coupling, both the perception system and the INS will localize the car almost independently, and will mutually compare and correct their results afterwards. Tight coupling of inertial and visual sensor offers a second option, where direct (pixel-level) visual measurements of objects are combined with inertial measurement unit (IMU) readings.

In both approaches, the MEMS inertial sensor improves the capability of the perception system to follow objects from frame to frame, which can result in improved accuracy of localization.

Figure 4. Automated driving will be implemented in stages. (Image Credit: Robert Bosch GmbH)

	2025	2035
Partially autonomous vehicles	12.4 %	15 %
Fully autonomous vehicles	0.5 %	9.8 %

Figure 5. Autonomous Driving Market Shares. (Credit: "Revolution in the Driver's Seat: The Road to Autonomous Vehicles," The Boston Consulting Group, April 2015)

Where Do We Go from Here?

On the evolutionary pathway of automated driving functions, driver assistance systems — such as lane keeping and lane changing assist, AEBS, and active front steering — will become more commonplace. Partially automated functions, such as traffic jam assist, are already in the market. Traffic jam assist will gradually expand over the next few years, with higher levels of automated functions soon to follow (see Figure 4).

By the end of this decade, expect to see fully automated driving on highways. Fully automated driving in urban areas, however, will probably take another 10 or 15 years to achieve (see Figure 5).

With such rich technologies at their disposal, automakers will continue to satisfy consumer demand for more widespread implementation of ADAS well before fully automated, and even partially automated, driving functions reach the majority of consumers. While fully automated driving may take years to accomplish, we are already benefiting from MEMS and sensors-enabled ADAS in the family car.

*This article was written by Karen Lightman, executive director, MEMS & Sensors Industry Group, and Peter Spoden, product manager, inertial sensors, Automotive Electronics, Robert Bosch GmbH (Reutlingen, Germany). For more information, visit **http://info.hotims.com/61062-411**.*

Vibration Sensors Add New Touch to Prosthetics

The sense of touch is complex, and an instructor at the University of California – Santa Barbara (UCSB) has the technology to prove it. Yon Visell, assistant professor in the Department of Electrical and Computer Engineering, and his students designed an apparatus that captures the unique vibration patterns associated with touch-specific actions, from gripping a coffee mug to tapping on a flat surface. The findings could support new applications in prosthetics, robotics, and virtual reality.

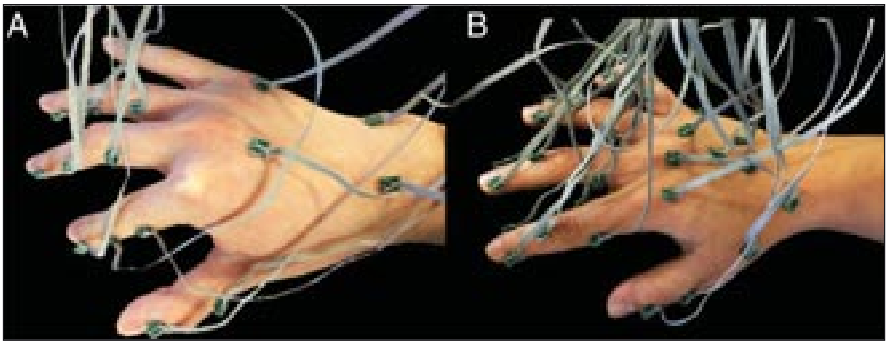


Figure A shows fifteen accelerometers with miniature PCBs and flexible wires. Figure B shows a whole-hand configuration with 30 accelerometers. (Image Credit: UCSB)

Sensing the Subtleties of Touch

To date, there are very few technological sensing approaches that have attempted to capture the submodalities within touch — the more subtle interactions between our hands and our surroundings. The UCSB researchers determined that a widespread area of the hand has access to sensory information, in the form of vibrations, that is generated at the fingertips.

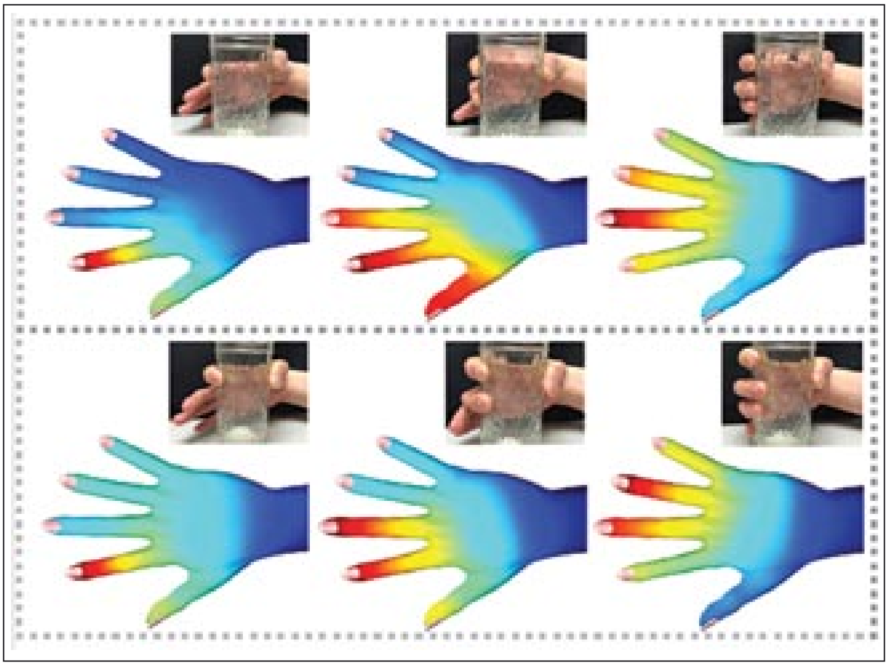
When a fingertip touches an object, the contact generates transient, wave-like mechanical signals that propagate a distance within tissues. Each action — the dragging of a finger or the picking up of an object, for example — elicits specific vibration signatures within the skin.

By bonding an array of custom accelerometers, or vibration sensors, along the sides and backs of a subject's fingers and hands, Visell captured the signals traveling beyond the fingertips and up past the arm.

By characterizing the signals and unique vibration information, the team could accurately determine the hand's action, indicate how the object was being manipulated, and even reveal the object itself. Using support vector machine (SVM) classifier algorithms, the researchers demonstrated that the spatial patterns of vibration accurately encoded the movements of the hand.

Visell suggests that the hand, much like the ear, uses vibrations produced through contact to infer what the hand is touching and how an object is being handled.

"If you tap your finger on a surface, these signals propagate pretty quickly throughout the hand and reach at least as far as the wrist, and in fact beyond the wrist," said Visell. "If you do something else with your hand, like grasp a coffee mug or tap multiple fingers, you elicit rather different patterns of vibration propagation within the skin."



The image reveals several vibration patterns as a hand grasps a glass of water. Using color, the data depicts intense transient vibrations that are generated when the fingers contact an object. Dark red demonstrates the most intense vibrations, while dark blue demonstrates the least intense vibrations. Energetic vibrations are typically transmitted beyond the fingers, and even onward to other fingers that were not in contact with the object, such as the small finger in the figure's 3rd column panels. (Image Credit: UCSB)

Vibration patterns produced by tapping a single finger, for example, were shown to be stronger than those made by grasping or gripping motions. Tapping the index and middle finger alone carried vibrations across the entire surface of the hand. The size of the object itself — a glass, for example — was also found to influence the specific vibrations and their travel path.

Although the most energetic vibrations were revealed to be at the ends of the fingers that contacted the object, Visell and the UCSB lab students determined that the vibrations typically transmit beyond the fingers, and even onward to other fingers that were not in contact with the object.

The propagation past the fingertips may help to explain intriguing touch capabilities, including how anesthetized hands still maintain the ability to feel fine surface detail and perform discriminating tasks.

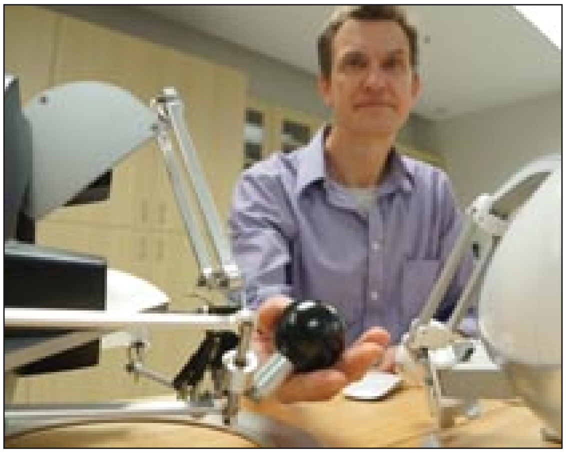
New Applications

As upper-limb motorized prosthetics become more advanced, Visell's findings could be used to provide prosthetic wearers with touch feedback. The UCSB results indicate that touch sensing can be performed using sensors distributed far away from the area of contact, yielding rich information about touch interactions with objects.

"This suggests a possible approach to tactile sensing for upper limb prosthetics in which vibration sensors, like the accelerometers used in our study, are embedded at sparse locations throughout the limb," said Visell.

Through funding from Google, the team is beginning to design interfaces that are mechanically well adapted to biological tissue. The interfaces, which consist of wearable soft actuator arrays worn on the hands and wrists, conform to the skin and can potentially reproduce the signals.

"I suspect [within a year] we'll start to be able to elicit touchlike sensations at the far ends of the fingers, the tips of the fingers, where you'd normally touch things, even using wearable interfaces that are positioned on more proximal parts of the hand, like on the wrist," said Visell.



UCSB researcher Yon Visell demonstrated the forces felt by the hand when touching an object. (Image Credit: Sonia Fernandez)

As emerging virtual reality technologies like the Oculus Rift headset hit shelves, new touch capabilities could also be used to enhance the VR experience. Visell's work demonstrates that distributed patterns of vibration could provide valuable data and reproduce feelings of touch in the virtual environments where no physical objects are present.

Ultimately, the UCSB laboratory study revealed the multifaceted nature of touch — an important concept for sensor technology-makers to grasp.

"Touch is not one thing," said Visell, "Through technologies like these, it's going to be possible to utilize touch both as input and output, both as a way to sense the world and to interact within the world in ways that people haven't thought about yet."

This article was written by Billy Hurley, Associate Editor, NASA Tech Briefs. *For questions and comments, email feedback@abpi.net. For more information, visit* ***www.news.ucsb.edu***.

Airborne Elastic Backscatter and Raman Polychromator for Ash Detection

Marshall Space Flight Center, Alabama

Volcanic ash is a significant hazard to aircraft engine and electronics. It has caused damage to unwary aircraft and disrupted air travel for thousands of travelers, costing millions of dollars. The small, jagged fragments of rocks, minerals, and volcanic glass that constitute volcanic ash are about the size of sand and silt. Volcanic ash is hard, does not dissolve in water, is extremely abrasive and corrosive, and conducts electricity when wet. The upper winds transport the particles away to eventual dispersal in an ash cloud. Ash clouds typically form above 20,000 feet, but the lower limit of the initial cloud depends on both the height of the volcanic vent and the vigor with which material is ejected from it.

eVADE (Volcanic Ash DEtection) is a compact device capable of providing information on the ash load in the atmosphere. It is designed to operate onboard an airborne platform. It uses a polychromator to measure optical depth and species to identify volcanic ash from other aerosols. The polychromator separates the spectral components of elastic backscatter and species associated with volcanic eruptions. It is designed to accept LIDAR return light whether in free space or through an optical fiber. The polychromator is compact and able to operate on a manned or unmanned airborne platform. The modular nature of the instrument allows operation as standalone with a LIDAR transmitter/receiver or in conjunction with other measurements, such as wind velocity and air density.

The unique features of the instrument are the compactness to operate on small aircraft, and the ability to measure multiple return signals pertaining to ash concentration.

An airborne volcanic ash detection/characterization system such as eVADE will have wide applications in the study of the threat volcanic ash poses to aircraft, and for other scientific study of volcanic plumes. Studies carried out with eVADE will allow NASA to refine their models of volcanic ash dispersion based on more data than is available at present. There is the potential to combine such a system with Michigan Aerospace Corporation's optical air data system and icing- and turbulence-detection systems to create a unified system that would sense volcanic, turbulence, and icing hazards ahead, and report airspeed along with air temperature and density.

eVADE will have similar utility for non-NASA civil organizations (NOAA, FAA, USGS, etc.) and military services (US Air Force, etc.) in conducting scientific studies of volcanic ash characteristics and dispersal. A next generation of eVADE that is more compact would be mountable aboard UAVs to "scout" the airways during major eruptions in order to confirm that commercial and military aircraft cannot fly, or give clearance for flights if the concentrations are not judged high enough to be a threat.

This work was done by Dominique Fourguette, Scott Lindemann, and Greg Ritter of Michigan Aerospace Corporation for Marshall Space Flight Center. ***NASA is seeking partners to further develop this technology through joint cooperative research and development. For more information about this technology and to explore opportunities, please contact Ronald C. Darty at Ronald.C.Darty@nasa.gov.*** *MFS-33347-1*

Intelligent Displacement Sensor Deployment Using MTConnect Protocol over Ethernet

The protocol interfaces to an intelligent sensor and provides data gathering using a PC application.

Stennis Space Center, Mississippi

Quality measurements for design validation and certification requirements sometimes require hundreds or thousands of sensors and actuators. Maintaining such a complex system is difficult, especially over an extended time period and inevitable personnel changes. Many hours are spent tracking down sensor problems related to the sensor, associated cables, mounting hardware, or some part of the data acquisition system. These are expensive, labor-intensive hours that consume valuable technical resources.

Another aspect to maintaining a complex system is the ability to gather data on critical elements that have a finite life expectancy. An example of such an element is a control valve. The two materials that provide the seal in a typical valve are copper and cast iron. During normal use, the copper will wear and the valve seal will need to be replaced. As wear occurs, the fully closed position will change. By monitoring this position change, it is possible to predict when a valve should be taken out of service and rebuilt. Predicting when a valve needs to be rebuilt before a failure will decrease the chances of a much more costly shutdown during a test.

Because of these issues, many hours can be consumed adapting data from all these data-generating devices to a format that can be used (consumed) by an application. Custom hardware interfaces and custom software drivers are often required. Therefore, a need for easier integration of industrial devices from multiple manufacturers, as well as a need for devices to become more intelligent and provide information about their own condition, in addition to the function they are performing or the process they are controlling or monitoring, was required.

To meet this need, Lion Precision developed an intelligent sensor (a sensor that can process information on its own, and is capable of two-way communication and the associated communication protocols) to monitor various components on the test stands, and a protocol with defined structure and data items using the MTConnect standard. This standard is a communication protocol that operates over Ethernet; it is not an application program. MTConnect provides information in XML format, which can be accessed and understood by multiple application programs.

The MTConnect standard was developed to accommodate many different types of devices — from intelligent sensors, to actuators, to status indicators — by providing a protocol that adheres to a pre-defined data structure and reporting scheme. In this way, sensors communicate measurement data, pre-processed measurement data, diagnostic data, and sensor/system health via existing, accepted protocols that have not yet been completely utilized in sensor interfaces. This system is the first of its type to use the MTConnect standard.

The device software is made up of several subsystems that provide the overall system functionality. The following are key system interfaces:

1. Web Services that provide a platform-independent means to communicate with the ECD device. These Web services host both ECD-specific services as well as the MTConnect interface.

2. Device Services that are responsible for hosting the various system services that include Web server, watchdog, and main board communications interface.

3. Data Access that provides general storage for both configuration and data acquisition of measurement and diagnostic data.

4. Device Framework that provides the core functionality of the ECD device software.

5. User Interface, which is a Web user interface hosted on the device for status and configuration.

By having an "open standard" that defines different types of devices without regard to the manufacturer, it is possible for third parties to write programs that consume this data. The system that was developed had both hardware and software that met the following objectives:

- Collect data from 4 displacement sensors located on 2 hardware (ECD152) devices using the MTConnect protocol.
- Collect diagnostic data from the system and provide feedback to the user as to the overall system health (valves, re: flow of LOX and LH2).
- Record and store events for analysis and history of system operation.

This type of functionality opens up the "sensor world" to a broad range of software possibilities. For example, Web developers and database developers could easily access and display or store sensor data. When measurement data, processed data, TEDS (Transducer Electronic Data Sheet), and HEDS (Health/Diagnostic Electronic Data Sheet) data types are incorporated into the MTConnect standard, the incremental cost of providing this data by the sensor manufacturer and the incremental cost of accessing the data by the end user is very low because all the data is over a single Ethernet connection, and the data is in a usable and well-established format: XML.

The overall goal was to develop sensors to communicate measurement data, pre-processed measurement data, diagnostic data, and sensor/system health using MTConnect, which has not yet been utilized in sensor interfaces. The power of data integration is evident, for example, in other fields such as the diagnostic capability of modern automobiles and other complex systems. The benefit to industry has the potential to be enormous if data integration from an "open system" consisted of devices from multiple devices from different manufacturers.

This work was done for NASA's Stennis Space Center by Don Martin, Mike Knowd, Ray Herbst, and Greg Knowd of Lion Precision. ***Please direct all inquiries to Don Martin, Lion Precision, 563 Shoreview Park Road, St. Paul, MN 55126; don@lionprecision.com; or 651-484-6544.*** *SSC-00398*

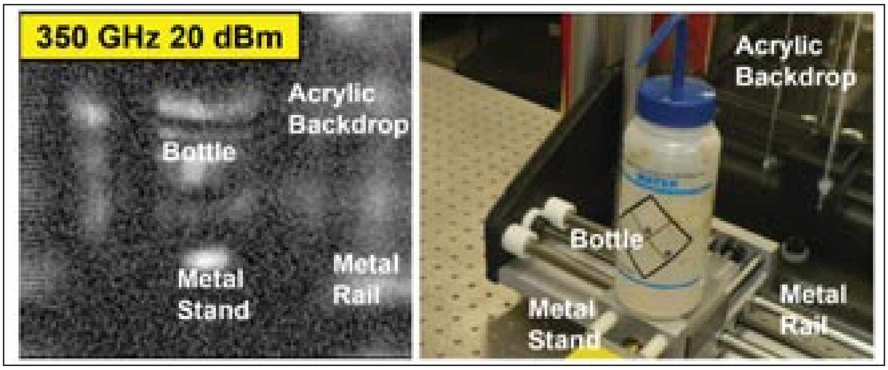
Active Remote-Sensing Radiometer

This technology can be used for security screening and security imaging, as well as automotive navigation in dust and fog conditions where machine vision performs poorly.

NASA's Jet Propulsion Laboratory, Pasadena, California

Millimeter-wave (mm-wave) imaging techniques are already a popular solution for imaging through dust and fog. While mm-wave offers excellent penetration to dust when compared with infrared or optical sensing, the longer wavelengths create many problems associated with the specular response of surfaces at mm-wave. Generally, at mm-wave, the geometry and orientation of the target object has a larger influence on captured contrast than material properties by several orders of magnitude. While these effects can be somewhat mitigated with a radar imager, there is still a large contrast dependence on beam-target angle, and images are still entirely derived from geometry instead of material compositions.

Active radiometers enable mm-wave remote imaging based on material compositions instead of geometry by deriving contrast from thermal and thermodynamic properties of the object being remotely observed. This added capability is extremely advantageous in imaging through a dust storm or heavy fog. Active radiometry is essentially a remote sensing approach where the thermal and thermodynamic properties of an object are evaluated by remotely heating the target with some form of directed energy (also a mm-wave source), while radiometry is performed to monitor spatially separated temperatures. The excitation used to raise and lower the temperature of the remote object is not continuous excitation, but instead is modulated with various waveforms so that transient (thermodynamic) properties of the object can be evaluated remotely.



A plastic water bottle illuminated by a high-power THz source shows the lack of contrast captured by a remote detector in a traditional mm-wave imaging system.

Heat capacity is one of the simplest thermal properties and describes the rise in temperature for a given quantity of energy absorbed. This is similar to "specific heat capacity," but does not factor the mass term. By simply transmitting continuous mm-wave power into the object and measuring the temperature rise with the observing radiometer, the specific heat can be estimated. The radiometer and exciter need to operate at quite different frequency bands so that interference does not occur, and the coupling between the exciter and radiometer is dominated by thermal transfer, not electromagnetic (harmonics and spurs) coupling. For this sensing approach, the exciter is located at the lower 30 to 40 GHz K_a band where high-power (>10 W) amplifiers are available to deliver useful quantities of power for heating. The radiometer will operate in the 75 to 110 GHz W-band range to provide better resolution as the setup optics will be less diffracted at shorter wavelengths.

Thermal conductance describes how quickly heat is transmitted through a material. This can be remotely measured by pulsing the exciter at a frequency comparable to the thermal constants of the object under observation (several Hz for most materials). By focusing radiometers at offset positions, the propagation rate of the exciter's energy through the object material can be directly estimated from the time difference of the heat pulses at each radiometer. Again, with further development of raster optics for this approach, the thermal conductance of the remote object can be contrasted to provide a raster image of a remote target based on its thermal conductance at each point in the image.

NASA is actively seeking licensees to commercialize this technology. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov to initiate licensing discussions. *NPO-49829*

New Products

Door Protection System

An electromechanical function from Kiekert AG (Heiligenhaus, Germany/Wixom, MI) prevents car doors from unintentionally striking nearby obstacles. The "i-protect" technology features a door-brake and sensor system for environment recognition.

The vehicle electronics evaluate the signal and send the stop command as soon as an obstacle is detected close to the door. A mechanism works at the door's arrester and stops the door electromagnetically when required. i-protect recognizes static objects of any size or shape within the door's swing range.

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Microcontrollers

Toshiba America Electronic Components (San Jose, CA) has released a group of 30 microcontrollers (MCUs) based on the ARM® Cortex®-M3 core. The M3H MCUs are fabricated with an embedded flash memory process. Target applications include motor control, consumer electronics, office automation equipment, and housing and facility equipment.

The devices operate at up to 40 Mhz, and the line-up contains low-pin-count packages (32 to 100 pins) and small flash memory sizes (32 KB to 128 KB). Features integrated into the M3H group include a 12-bit AD converter; an 8-bit DA converter; Toshiba's programmable motor control circuit (PMD), with AC motor and BLDC motor control; and general-purpose peripheral circuits, such as UART, I2C, TSPI, and timers.

For Free Info Visit http://info.hotims.com/61062-141

Multimeter

Fluke (Everett, WA) has announced the 279 FC TRMS Thermal Multimeter. The test tool integrates a digital multimeter (DMM) with a thermal camera. Using the 279 FC imager, technicians can check for hot spots in fuses, wires, insulators, connectors, splices, and switches; the DMM troubleshoots and analyzes issues.

The thermal multimeter has 15 electrical measurement functions, including ac/dc voltage, resistance, continuity, capacitance, diode test, min/max, and frequency. The optional iFlex® clamp wraps around conductors and wires in hard-to-reach spaces. The clamp additionally expands measurement capabilities to include ac current up to 2500 A. The device features a 3.5-inch full-color LCD screen. The wireless 279 FC is part of Fluke Connect® — a system of wireless test tools that communicate via the Fluke Connect app.

For Free Info Visit http://info.hotims.com/61062-142

Pyrometer

The IGA 140/23 pyrometer from LumaSense Technologies (Santa Clara, CA) offers non-contact temperature measurement on metals, ceramics, and graphite. The device, equipped with RS232 and RS485 serial interfaces, reads parameters via the provided InfraWin PC software. Parameters can also be changed via PC. Communication options include RS232, RS485, ProfiBus, ProfiNet, and Ethernet. Temperature detection ranges between 50 and 1800 °C.

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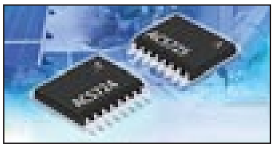
Sensor ICs

Allegro MicroSystems (Worcester, MA) offers two new current sensor ICs for AC or DC current sensing. Both the ACS724KMA (5 V) and the ACS725KMA (3.3 V) are set in a high-isolation SOIC16 wide-body surface mount package that provides reinforced isolation. The differential sensing technology protects against interfering common-mode magnetic fields from adjacent current traces or motors. Typical applications include motor control, load detection and management, switched-mode power supplies, and overcurrent fault protection.



Both devices consist of a low-offset, linear Hall sensor circuit, with a copper conduction path located near the surface of the die. Applied current flowing through the copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. The current is sensed differentially in order to reject common-mode fields, improving accuracy in magnetically noisy environments. Leadframes are plated with 100% matte tin, which is compatible with standard lead (Pb) free printed circuit board assembly processes.

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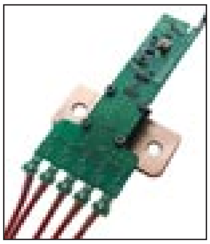
IC and Module



An IC and module from Sendyne (New York, NY) performs ground fault detection and isolation monitoring while simultaneously measuring current, voltage, and temperature. The AEC-Q100-qualified SFPGFD adheres to international standards and regulations for isolation monitoring in plug-in electric vehicles (xEVs).

Using controllable excitation voltage, the technology detects all sources of leakage, including multiple simultaneous asymmetrical and symmetrical faults, as well as resistive shorts between the chassis and battery points that have the same potential as the chassis.

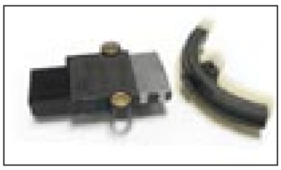
Two dedicated channels measure voltage from the battery to chassis and the total battery potential; the latter is also available for utilization by the battery management system (BMS). Sendyne's algorithm applies deep filtering and averaging on the measured data, resulting in noise rejection.

The SFPGFD module has four extra high voltage channels that monitor pre-charge status, state of fuses, and contactors. All six voltage channels on the SFPGFD module measure ±450 V continuous and ±650 V momentary overvoltage.

For Free Info Visit http://info.hotims.com/61062-147

Touchless Variable Gap Sensor

PIHER Sensors and Controls S.A. (Brighton MI), a Meggitt company, has introduced a two-piece magnetic Hall effect variable gap sensor that maintains stable electrical output and specified linearity on mobile shafts, despite radial and axial movement. A circular arc magnet is attached to rotating shafts or assemblies, such as boom loaders, skid steers, buckets, and hitch arms; the electronics module is attached to the chassis.



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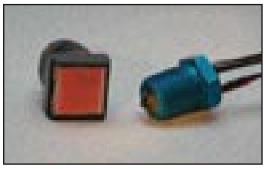
Sensor Kits



The UFS (Universal Fluid Sensor) line of sensor kits from Pillar Point Electronics (Sarasota, FL) uses an infrared (IR) emitter and microprocessor to detect the presence of air in tanks or lines containing non-particulate bearing liquids, such as fuel, water, and hydraulic fluid. The UFS-AN is a modified AN912-2D bushing. Designed for in-tank applications, a clear, cylindrical cast acrylic prism is potted into the fitting in contact with the fuel or other non-particulate bearing liquid. Custom versions of the product can be made for specific applications.

For Free Info Visit http://info.hotims.com/61062-152

Spectroradiometer

The RS-3500 field portable spectroradiometer from Spectral Evolution (Lawrence, MA) supports fast, non-destructive remote sensing applications, such as chlorophyll/moisture analysis, plant species identification, and forest canopy studies. The 7-lb RS-3500 features no moving optical parts.

A sealed unit and stainless-steel-jacketed fiber optic cable resists dust, dirt, and moisture. The new ILM-105 light source is rail-mounted to the unit. A GETAC field PDA controls the instrument, collecting and viewing scans, GPS, voice notes, and digital pictures.

The RS-3500 provides autoshutter, autoexposure, and autodark correction before each new scan. The spectroradiometer also features a full-range NIR field spectrometer (350-2500 nm). Accessories include contact probe, pistol grip, leaf clip, and FOV lenses.

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Proximity Sensor

Littelfuse (Chicago, IL) has released the 59040 Series press-fit reed sensor. No screws, brackets, or attachment accessories are needed for installation. The magnetically operated Firecracker sensor press-fits securely into a 3/8" (9.5 mm) diameter hole.

The sensor is designed for mounting on a fixed frame; the magnet actuator is positioned on a moving surface or door. The 59040 Series reed sensor offers switching capability up to 200VDC/140VAC at 10 W/VA. A range of sensitivity and cable length options are available.

The component operates through nonferrous materials such as wood, plastic, or aluminum. Hermetically sealed reed contacts last for millions of operating cycles, under microcontroller voltage and current logic-level loads.

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Current Sensors

TDK Corporation (Tokyo, Japan/Irving, TX) has added the new 600-A CCT series to its clamp AC current sensors. The CCT406393-600-36 sensor has a clamp inner diameter of 36 mm and external dimensions of 56 × 67× 96 mm. Output current is 200 mA.

Ferrite material supports the sensor's current rating. An integrated open-circuit protection element provides voltage peak suppression. The CCT series is manufactured with automated winding and soldering processes. Main applications include energy management systems (EMS) for buildings, factories, stores, and communities. Mass production will begin in July 2016.

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Three-Axis Magnetic Sensor

MEMSIC (Andover, MA) offers the MMC3630KJ magnetometer for portable devices. The magnetometer includes an integrated monolithic 3-axis AMR sensor and a signal conditioning ASIC. The BGA package measures 1.2 × 1.2 × 0.5 mm, and the MMC3630KJ reaches ±30G range. With 600Hz magnetic sensing bandwidth, the series includes a self-degaussing feature, which eliminates the output drift due to temperature change and residual magnetics. The products also include an interruption feature, used for motion detection and data acquisition notifications, to lower system-level power consumption.

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Pressure Sensors

All Sensors Corp. (Morgan Hill, CA) has announced the SPM 401 Series of stainless-steel, media-isolated pressure sensors. The pressure sensor is compatible with 316L stainless steel, a type of steel that increases corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at high temperatures. The piezoresistive sensor chip is housed in a fluid-filled cylindrical cavity and isolated from measured media. The thermally compensated device has a millivolt output of up to 180mV at a 1mA supply current. Devices are available in 1.5, 3, 5, 15, 30, 50, and 100 PSI. Other features include pressure ranges 1.5 to 100 psi; vacuum resistance; O-ring mounting; thermally compensated and passive calibrated (offset) mV output; and supply current of 1 mA.

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Night-Vision Imaging

OleaVision™ See-Through Wall Technology from Olea Sensor Networks (Reno, NV) functions optimally at a distance of 3 to 4 meters from the target surface, requiring no contact with the wall. The lightweight device, smaller than a typical smartphone, "sees" through most wall materials, regardless of whether the monitored subject is moving or motionless. Using thermal energy, OleaVision enables first responders and armed forces to identify human beings during search-and-rescue operations.

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Vision Sensors

The SBSI series of vision sensors from Festo (Hauppauge, NY) feature rugged IP67 housing, built-in lighting, and EtherNet/IP capability. SBSI sensors, which read 1D and 2D bar codes, can be ordered as components, portions of a subsystem ready for assembly, or parts of a plug-and-play module.

The SBSI-B reads Direct Part Marking (DPM) codes, including both laser-etched and dot-peened objects. The device reads up to 10 codes per image. The SBSI-Q for quality inspection can be used for completeness and presence sensing to ensure all relevant parts are mounted and/or accounted for. Optics offer a range of reading areas and working distances. Code reading models have enhanced depth of field to increase the area of focus.

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Surface Profiling Sensors

OGP® (Rochester NY), a division of Quality Vision International (QVI®), has introduced its TeleStar® Probe sensor. TeleStar Probe, a self-contained off-axis partial coherence interferometric range sensor for surface contour measurement, offers measured point resolution in the sub-micron (< 0.1 micron) space. The sensor scans up to 500 data points per second, with 1.0-micron accuracy and 0.1-micron repeatability.

TeleStar Probe features a 25-mm constant working distance, and its shallow return angle allows measurement deep inside bores and blind holes. TeleStar Probe is mounted in a mechanical deployment mechanism that retracts when not in use.

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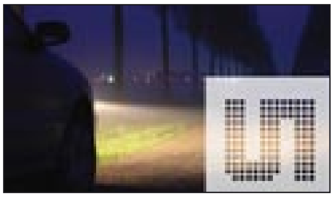
Magnetic Position Sensors

The new AS5170 and AS5171 automotive sensors from ams AG (Premstaetten, Austria) were developed as SEooC (Safety Element out of Context) devices, as defined in the ISO26262 functional safety standard. The magnetic position sensors have a System-in-Package (SiP) format. The space-saving package enables the placement of the sensor device in environments that are prohibitive to PCB-based packages.



The sensors provide full data path diagnostics, allowing automotive system OEMs to achieve a higher level of ISO26262 system-level compliance. The diagnostic system built into the AS517x series tests the entire device: from the Hall sensor front end, through the DSP engine (which converts raw measurements of magnetic field strength into sine and cosine vectors), and to the back-end interfaces and pins.

The AS517x devices, qualified to AEC-Q100 Grade 0, measure the absolute angle of rotation. The AS5171 comes in an SiP format, which integrates the sensor die and capacitors in a single, encapsulated three-pin package. The SiP eliminates the requirement to mount a position sensor IC on a PCB, reducing component count.

The AS5171A provides an analog output, and the AS5171B supplies a digital output, which may be programmed either as a PWM interface or as a SENT-compliant interface. The analog AS5170A and digital AS5170B ICs are housed in an 8-pin SOIC package.

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Surface Sensors

Sensofar Metrology (Terrassa, Spain/Scottsdale, AZ) has released two new surface metrology systems. The S *lynx*, a non-contact 3D surface profiler, integrates confocal, interferometry, and focus variation techniques into the same sensor head. The S *onix*, an ultra-compact 3D surface sensor, is purpose-designed for high-speed in-line process measurement and process control tasks. The S *onix* sensor system features a single measurement technique: interferometric – VSI.

Both systems have been designed for surface measurement applications requiring fast, non-invasive assessment of the 3D micro- and nano-geometry of technical surfaces, including surface roughness, textures and structuring, and thickness measurements.

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Wireless Switches

New wireless, batteryless limit switches from Steute Industrial Controls (Ridgefield, CT) include an internal electrodynamic energy generator. Displacement of the actuator generates power to send a uniquely coded signal to one or more compatible, easily-programmed receivers. If the limit switch does not receive the confirmation signal within 15 ms, a second signal is transmitted. The receiver accepts up to 10 discrete signals per channel.

The device, available for operation at 915 MHz, features an operating temperature range of -20 °C to + 65 °C and a maximum transmission range of 40 meters (indoors) and 450 meters (outdoors).

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steute