












TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

-  **Technology Focus**
-  **Electronics/Computers**
-  **Software**
-  **Materials**
-  **Mechanics/Machinery**
-  **Manufacturing**
-  **Bio-Medical**
-  **Physical Sciences**
-  **Information Sciences**
-  **Books and Reports**

INTRODUCTION

Tech Briefs are short announcements of innovations originating from research and development activities of the National Aeronautics and Space Administration. They emphasize information considered likely to be transferable across industrial, regional, or disciplinary lines and are issued to encourage commercial application.

Additional Information on NASA Tech Briefs and TSPs

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TECH BRIEFS

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Fully Integrated, Miniature, High-Frequency Flow Probe Utilizing MEMS Leadless SOI Technology

The probe could be used for inlet flows, turbomachinery flows, and a variety of studies on fundamental fluid physics.

John H. Glenn Research Center, Cleveland, Ohio

This work focused on developing, fabricating, and fully calibrating a flow-angle probe for aeronautics research by utilizing the latest microelectromechanical systems (MEMS), leadless silicon on insulator (SOI) sensor technology. While the concept of angle probes is not new, traditional devices had been relatively large due to fabrication constraints; often too large to resolve flow structures necessary for modern aero-propulsion measurements such as inlet flow distortions and vortices, secondary flows, etc. Measurements of this kind demanded a new approach to probe design to achieve sizes on the order of 0.1 in. (≈ 3 mm) diameter or smaller, and capable of meeting demanding requirements for accuracy and ruggedness.

This approach invoked the use of state-of-the-art processing techniques to install SOI sensor chips directly onto the probe body, thus eliminating redundancy in sensor packaging and probe installation that have historically forced larger probe size. This also facilitated a better thermal match between the chip and its mount, improving stability and accuracy. Further, the leadless sensor technology with which the SOI sensing element is fabricated allows direct mounting and electrical interconnecting of the sensor to the probe body. This leadless technology allowed a rugged wire-out approach that is performed at the sensor length scale, thus achieving substantial sensor size reductions. The technology is inherently capable of high-frequency and high-accuracy performance in high temperatures and harsh environments.

The proposed device is capable of providing flow measurements for high-frequency, small-flow structures, and broad flow-field coverage as necessary for subsonic diffuser and exhaust nozzle flows. This design eliminates packaging redundancy by directly mounting SOI sensor components onto the flow angle probe body. The five-hole probe design achieved the following characteristics:



The all-welded five-hole **Flow Probe** design is suitable for harsh environments, allowing custom screen placement in front of the sensing elements.

- Small size: The small size allows detailed flow structure data such as flow distortions due to shock boundary interaction, crosswind effect, and inlet vortices, and better matches the characteristic frequencies associated with the probe size (due to vortex shedding, for example) with the inherent high-frequency response of the sensors (over 100 kHz). Further, the minimal frontal area will allow multiple sensor rakes to be fabricated for inlet flow field survey.
- High-frequency response above 50 kHz: This is achievable by mounting pressure-sensing elements directly onto the flow angle probe, thus avoiding plenum/cavity-related acoustic resonances.
- Measurement accuracy of $<1^\circ$ and with a $>35^\circ$ range: By utilizing computational dynamic tools as well as calibrated wind tunnel facilities, flow shape optimization and software reduction techniques shall be developed to support this objective.
- Multiple function: A single, compact probe designed to deliver two flow angles (pitch and yaw), as well as pres-

sure and Mach information, allows complete flow field characterization in both space and time.

- High-temperature capability: All-welded design utilizing all high-temperature materials in the construction.
- Harsh environment operability: Leadless sensor technology hermetically protects the entire sensing network while completely eliminating all the wire bonds. Only the silicon (backside) of the sensor is exposed to the pressure media. The addition of screens in the high-temperature version allows for protection from particle impact.

This work was done by Alex Ned, Anthony Kurtz, Tonghuo Shang, and Scott Goodman of Kulite Semiconductor Products, Inc.; and Gerald Guenette of MIT for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18938-1.

Nanoscale Surface Plasmonics Sensor With Nanofluidic Control

This sensor has applications in health centers, clinical labs, pharmaceutical firms, drug research labs, and other facilities engaged in biomarker screening.

John H. Glenn Research Center, Cleveland, Ohio

Conventional quantitative protein assays of bodily fluids typically involve multiple steps to obtain desired measurements. Such methods are not well suited for fast and accurate assay measurements in austere environments such as spaceflight and in the aftermath of disasters. Consequently, there is a need for a protein assay technology capable of routinely monitoring proteins in austere environments. For example, there is an immediate need for a urine protein assay to assess astronaut renal health during spaceflight. The disclosed nanoscale surface plasmonics sensor provides a core detection method that can be integrated to a lab-on-chip device that satisfies the unmet need for such a protein assay technology.

Assays based upon combinations of nanoholes, nanorings, and nanoslits with transmission surface plasmon resonance (SPR) are used for assays requiring extreme sensitivity, and are capable of detecting specific analytes at concentrations as low as picomole to femtomole level in well-controlled environments.

The device operates in a transmission mode configuration in which light is directed at one planar surface of the array, which functions as an optical aperture. The incident light induces surface plasmon light transmission from the opposite surface of the array. The presence of a target analyte is detected by changes in the spectrum of light transmitted by the array when a target analyte induces a change in the refractive index of the fluid within the nanochannels. This occurs, for example, when a target analyte binds to a receptor fixed to the walls of the nanochannels in the array. Independent fluid handling capability for individual nanoarrays on a nanofluidic chip containing a plurality of nanochannel arrays allows each array to be used to sense a different target analyte and/or for paired arrays to analyze control and test samples simultaneously in parallel.

The present invention incorporates transmission mode nanoplasmonics and nanofluidics into a single, microfluidically controlled device. The device com-

prises one or more arrays of aligned nanochannels that are in fluid communication with inflowing and outflowing fluid handling manifolds that control the flow of fluid through the arrays. The array acts as an aperture in a plasmonic sensor. Fluid, in the form of a liquid or a gas and comprising a sample for analysis, is moved from an inlet manifold through the nanochannel array, and out through an exit manifold. The fluid may also contain a reagent used to modify the interior surfaces of the nanochannels, and/or a reagent required for the detection of an analyte.

This work was done by Jianjun Wei and Sameer Singhal of CFD Research Corporation, and David H. Waldeck and Matthew Kofke of the University of Pittsburgh for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18967-1.

Advanced Dispersed Fringe Sensing Algorithm for Coarse Phasing Segmented Mirror Telescopes

The algorithm reduces sensitivity to calibration errors.

NASA's Jet Propulsion Laboratory, Pasadena, California

Segment mirror phasing, a critical step of segment mirror alignment, requires the ability to sense and correct the relative pistons between segments from up to a few hundred microns to a fraction of wavelength in order to bring the mirror system to its full diffraction capability. When sampling the aperture of a telescope, using auto-collimating flats (ACFs) is more economical. The performance of a telescope with a segmented primary mirror strongly depends on how well those primary mirror segments can be phased. One such process to phase primary mirror segments in the axial piston direction is dispersed fringe sensing (DFS). DFS technology can be used to co-phase the ACFs. DFS is essentially a signal fitting

and processing operation. It is an elegant method of coarse phasing segmented mirrors. DFS performance accuracy is dependent upon careful calibration of the system as well as other factors such as internal optical alignment, system wavefront errors, and detector quality. Novel improvements to the algorithm have led to substantial enhancements in DFS performance.

The Advanced Dispersed Fringe Sensing (ADFS) Algorithm is designed to reduce the sensitivity to calibration errors by determining the optimal fringe extraction line. Applying an angular extraction line dithering procedure and combining this dithering process with an error function while minimizing the phase term of the fitted signal, defines

in essence the ADFS algorithm. The error function, for the time being, is defined as the rms value of the particular signal fitting. ADFS is a unique and significant enhancement to the DFS algorithm, allowing one to reduce requirements upon calibration while obtaining significantly better and more repeatable results than using the simple DFS algorithm. In addition, this enhancement does not require any additional hardware. Moreover, ADFS can overcome hardware related alignment errors such as DFS device positional uncertainties affecting the signal dispersion direction, and still allow one to obtain precise and repeatable piston estimations.

ADFS allows dispersed fringe sensing to be less sensitive to calibration errors.

ADFS corrects for piston estimation error terms, which appear in the fitted phase term when processing a DFS signal. The results of the Monte-Carlo type simulations clearly validate the analytical work to prove a correlation exists between calibration-induced piston estimation errors and the algorithm fitted phase.

At the time of this reporting, ADFS is being integrated with the DFS algorithm

improvement called Multi-Trace. Multi-Trace is currently the baseline for the dispersed Hartman sensor (DHS) used on-flight for coarse segment alignment of the James Webb Space Telescope (JWST). Because Multi-Trace does not address many degrees of freedom for the calibration process (i.e., rotational, scaling, tangential translation), a hybrid algorithm offers a possible improvement

upon these algorithms. ADFS offers marked improvements on the DFS, DHS algorithm, and opens possibilities for broader applications of these processes.

This work was done by Joshua A. Spechler, Daniel J. Hoppe, Norbert Sigrist, Fang Shi, Byoung-Joon Seo, and Siddarayappa A. Bikkannavar of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47688

➤ Neural Network Back-Propagation Algorithm for Sensing Hypergols

A software technique working with carbon nanotube sensors provides near-real-time detection of hazardous substances.

John F. Kennedy Space Center, Florida

Fast, continuous detection of a wide range of hazardous substances simultaneously is needed to achieve improved safety for personnel working with hypergolic fuels and oxidizers, as well as other hazardous substances, with a requirement for such detection systems to warn personnel immediately upon the sudden advent of hazardous conditions, with a high probability of detection and a low false alarm rate. Current detection methods rely on dosimetry badges that are not processed instantaneously, but rather at the end of work shifts.

A software technique provides pattern recognition for monitoring large numbers of channels of carbon nanotube sensors to detect a wide range of substances, including simultaneous hypergolic fuel and oxidizer detections, in near real time. It is useful for providing continuous monitoring of potentially hazardous substance leaks, with the additional ability to add detection capabilities without requiring hardware changes. It also includes software techniques to achieve quick neural network

training with little to no human intervention, through the use of innovative adaptive training techniques.

The primary purpose of this software is to read the voltage outputs from voltage dividers containing carbon nanotube sensors as a variable resistance leg, and to recognize quickly when a leak has occurred through recognizing that a generalized pattern change in resistivity of a carbon nanotube sensor has occurred upon exposure to dangerous substances, and, further, to identify quickly just what substance is present through detailed pattern recognition of the shape of the response provided by the carbon nanotube sensor.

The software consists of input nodes, hidden nodes, and output nodes, with all input nodes connected to all hidden nodes through a set of weighted pathways, and with all hidden nodes connected to all output nodes through a set of weighted pathways. Bias terms, in addition to sums of weighted prior node layer values, are also added, for both the hidden layer nodes as well as the output

layer nodes. The number of hidden nodes must be of the order of $2n+1$, or slightly larger, where n is the dimensionality of the data space being monitored.

Modular implementation permits reusing the basic gradient-descent, simulated-annealing adaptive training algorithm for training to detect any set of patterns for any particular application, not only carbon nanotubes. This means that the pattern recognition capability using carbon nanotubes can easily be added for a wide range of detections, ranging from detecting hypergol leaks, to detecting biological agents such as anthrax, or perhaps even improvised explosive devices, provided that vapors are emitted. Carbon nanotubes may respond well to detecting biological agents due to the cilia present on biological agents likely to respond to the carbon nanotubes.

This work was done by Jose Perotti, Mark Lewis, and Pedro Medelius of Kennedy Space Center; and Gary Bastin of ASRC Aerospace Corporation. For more information, contact the KSC Technology Transfer Office at (321) 861-7158. KSC-13500

➤ Bulk Moisture and Salinity Sensor

This sensor uses electrodes on the inside of the growth container to measure capacitance and conductance over the enclosed bulk volume.

John F. Kennedy Space Center, Florida

Measurement and feedback control of nutrient solutions in plant root zones is critical to the development of healthy plants in both terrestrial and reduced-gravity environments. In addition

to the water content, the amount of fertilizer in the nutrient solution is important to plant health. This typically requires a separate set of sensors to accomplish.

A combination bulk moisture and salinity sensor has been designed, built, and tested with different nutrient solutions in several substrates. The substrates include glass beads, a clay-like substrate,

and a nutrient-enriched substrate with the presence of plant roots. By measuring two key parameters, the sensor is able to monitor both the volumetric water content and salinity of the nutrient solution in bulk media.

Many commercially available moisture sensors are point sensors, making localized measurements over a small volume at the point of insertion. Consequently, they are more prone to suffer from interferences with air bubbles, contact area of media, and root growth. This makes it difficult to get an accurate representation of true moisture content and distribution in the bulk media. Additionally, a network of point sensors is required, increasing the cabling, data acquisition, and calibration requirements.

A vessel with electrodes was devised to measure the dielectric properties of

a material in the annular space of the vessel. Because the pore water in the media often has high salinity, a method to measure the media moisture content and salinity simultaneously was devised. Characterization of the frequency response for capacitance and conductance across the electrodes was completed for 2-mm glass bead media, 1- to 2-mm Turface (a clay like media), and 1- to 2-mm fertilized Turface with the presence of root mass. These measurements were then used to find empirical relationships among capacitance (C), the dissipation factor (D), the volumetric water content, and the pore water salinity.

Conventional moisture sensors only measure moisture over a small volume. Since water will stratify in the media due to gravity, the sensors will not accurately

represent the moisture available to a plant growing in a container containing such a sensor. The sensor described here uses electrodes on the inside of the growth container to measure capacitance and conductance over the enclosed bulk volume. These measurements are then used to determine the volumetric water content and salinity of nutrient solution available to the plant. From preliminary plant growth tests, it appears that the sensor is insensitive to the presence of root mass, a problem that affects many sensors available on the market today.

This work was done by Mark Nurge of Kennedy Space Center; and Oscar Monje, Jessica Prenger, and John Catechis of Dynamac Corporation. For more information, contact the KSC Applied Physics Laboratory at (321) 861-9068. KSC-13039

Change-Based Satellite Monitoring Using Broad Coverage and Targetable Sensing

NASA's Jet Propulsion Laboratory, Pasadena, California

A generic software framework analyzes data from broad coverage sweeps or general larger areas of interest. Change detection methods are used to extract subsets of directed swath areas that intersect areas of change. These areas are prioritized and allocated to targetable assets.

This method is deployed in an automatic fashion, and has operated without human monitoring or intervention for sustained periods of time (months).

This work was done by Steve A. Chien, Daniel Q. Tran, and Joshua R. Doubleday of Caltech; and Thomas Doggett of Arizona

State University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48147.



☐ Circularly Polarized Microwave Antenna Element With Very Low Off-Axis Cross-Polarization

Goddard Space Flight Center, Greenbelt, Maryland

The goal of this work was to improve off-axis cross-polarization performance and ease of assembly of a circularly polarized microwave antenna element. To ease assembly, the initial design requirement of Hexweb support for the internal circuit part, as well as the radiating disks, was eliminated.

There is a need for different plating techniques to improve soldering. It was also desirable to change the design to eliminate soldering as well as the need to use the Hexweb support. Thus, a technique was developed to build the feed without using solder, solving the lathing and soldering issue. Internal parts were strengthened by adding curvature to eliminate Hexweb support, and in the

process, the new geometries of the internal parts opened the way for improving the off-axis cross-polarization performance as well.

The radiating disks' curvatures were increased for increased strength, but it was found that this also improved cross-polarization. Optimization of the curvatures leads to very low off-axis cross-polarization. The feed circuit was curved into a cylinder for improved strength, eliminating Hexweb support. An aperture coupling feed mechanism eliminated the need for feed pins to the disks, which would have required soldering. The aperture coupling technique also improves cross-polarization performance by effectively exciting the radiating

disks very close to the antenna's central axis of symmetry. Because of the shape of the parts, it allowed for an all-aluminum design bolted together and assembled with no solder needed.

The advantage of a solderless design is that the reliability is higher, with no single-point failure (solder), and no need for special plating techniques in order to solder the unit together. The shapes (curved or round) make for a more robust build without extra support materials, as well as improved off-axis cross-polarization.

This work was done by David Green and Cornelis Du Toit of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15727-1

☐ Ultra-Low Heat-Leak, High-Temperature Superconducting Current Leads for Space Applications

Goddard Space Flight Center, Greenbelt, Maryland

NASA Goddard Space Flight Center has a need for current leads used in an adiabatic demagnetization refrigerator (ADR) for space applications. These leads must comply with stringent requirements such as a heat leak of approximately 100 μ W or less while conducting up to 10 A of electric current, from more than 90 K down to 10 K. Additionally, a length constraint of < 300 mm length and < 50 mm diameter is to be maintained.

The need for these current leads was addressed by developing a superconducting hybrid lead. This hybrid lead comprises two different high-temperature superconducting (HTS) conductors bonded together at a thermally and electrically determined optimum point along the length of the current lead. By taking advantage of material properties of each conductor type, employing advanced fabrication tech-

niques, and taking advantage of novel insulation materials, the company was able to develop and fabricate the lightweight, low heat-leak leads currently to NASA's specs.

This work was done by Christopher M. Rey of the Tai-Yang Research Company for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16045-1

☐ Flash Cracking Reactor for Waste Plastic Processing

John H. Glenn Research Center, Cleveland, Ohio

Conversion of waste plastic to energy is a growing problem that is especially acute in space exploration applications. Moreover, utilization of heavy hydrocarbon resources (wastes, waxes, etc.) as fuels and chemicals will be a

growing need in the future. Existing technologies require a trade-off between product selectivity and feedstock conversion. The objective of this work was to maintain high plastic-to-fuel conversion without sacrificing the liq-

uid yield. The developed technology accomplishes this goal with a combined understanding of thermodynamics, reaction rates, and mass transport to achieve high feed conversion without sacrificing product selectivity.

The innovation requires a reaction vessel, hydrocarbon feed, gas feed, and pressure and temperature control equipment. Depending on the feedstock and desired product distribution, catalyst can be added. The reactor is heated to the desired temperature, pressurized to the desired pressure, and subject to a sweep flow at the optimized superficial velocity. Software developed under this project can be used to determine optimal values for these parameters. Product is vaporized, transferred to a receiver, and cooled to a liquid — a form suitable for long-term storage as a fuel or chemi-

cal. An important NASA application is the use of solar energy to convert waste plastic into a form that can be utilized during periods of low solar energy flux.

Unlike previous work in this field, this innovation uses thermodynamic, mass transport, and reaction parameters to tune product distribution of pyrolysis cracking. Previous work in this field has used some of these variables, but never all in conjunction for process optimization.

This method is useful for municipal waste incinerator operators and gas-to-liquids companies.

This work was done by Michael T. Timko, Hsi-Wu Wong, and Lino A. Gonzalez of Aerodyne Research, Inc.; and Linda Broadbelt and Vinu Ravikrishan of Northwestern University for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18843-1.



An Automated Safe-to-Mate (ASTM) Tester

This tester allows for fast, safe, and reliable checkout of connector interfaces for both critical flight hardware and companion ground support equipment (GSE).

Goddard Space Flight Center, Greenbelt, Maryland

Safe-to-mate testing is a common hardware safety practice where impedance measurements are made on unpowered hardware to verify isolation, continuity, or impedance between pins of an interface connector. Performing this on critical flight hardware under test and its associated GSE ensures minimal risk when the hardware is powered. Historically, safe-to-mate measurements are performed manually with data written into paper procedures. This laborious process potentially requires a large amount of time for connectors that could have as many as 104 pins. Risks include human error in performing the measurements on sensitive inputs or in recording the data as well as potential loss of hardcopy data.

A computer-based instrumentation solution has been developed to resolve all of these issues. The ASTM is connected to the circuit under test, and can then quickly, safely, and reliably safe-to-mate the entire connector, or even multiple connectors, at the same time. The operation is completely automated, so that personnel can devote time to other tasks. When the automated safe-to-mate is finished, data is retained as electronic

records that can be saved for later review.

The ASTM marries off-the-shelf modular components such as a computer, multiplexers, and a digital multimeter (DMM) with a custom printed circuit board all in a chassis. This approach enables multiple, identical, automated safe-to-mate units to be constructed. Test engineers will not have to worry about finding and using the same DMM as the last time, as all of the units will contain an identical model. Safety has also been designed into this system by purposely selecting a DMM that outputs a very low voltage and current to make the measurements. A resistor has also been placed in parallel with the load being measured to further limit the current output of the digital voltmeter.

The ASTM software can read in schematic netlists from common tools such as Orcad or Mentor Graphics DXDesigner and can automatically determine the type of measurements. For example, it can determine which pins should be shorted together (e.g., power connections or ground connections), and will test that they are indeed shorted. The program also has a learning function that allows it to make im-

pedance readings for those cases where a design netlist is not available (i.e., the hardware is essentially treated as a black box). Finally, the software saves all data into a file that it can use in the future to verify that the board does not change, or that identical boards that should have the same impedances actually do.

The system can handle pins with capacitive and diode loads. For example, the software senses the charge-up effect characteristic of capacitors to know that the load is capacitive. Finally, the ASTM employs a custom printed circuit board to handle the routing of signals between its front I/O connectors and its internal instrumentation multiplexers. This makes the system more reliable than other units that employ large, custom, internal harnesses. This also greatly reduces the size and the cost of assembly. Users simply develop test harnesses between the ASTM and their hardware under test.

This work was done by Phuc Nguyen, Michelle Scott, Alan Leung, and Michael Lin of Goddard Space Flight Center; and Thomas Johnson of Microtel LLC. Further information is contained in a TSP (see page 1). GSC-16098-1

Wireless Chalcogenide Nanoionic-Based Radio-Frequency Switch

The integration of a rectenna makes it possible to wirelessly control the nanoionic switch completely without onboard power.

John H. Glenn Research Center, Cleveland, Ohio

A new nonvolatile nanoionic switch is powered and controlled through wireless radio-frequency (RF) transmission. A thin layer of chalcogenide glass doped with a metal ion, such as silver, comprises the operational portion of the switch. For the switch to function, an oxidizable electrode is made positive (anode) with respect to an opposing electrode (cathode) when sufficient

bias, typically on the order of a few tenths of a volt or more, is applied. This action causes the metal ions to flow toward the cathode through a coordinated hopping mechanism. At the cathode, a reduction reaction occurs to form a metal deposit. This metal deposit creates a conductive path that bridges the gap between electrodes to turn the switch on. Once this conductive path is formed,

no further power is required to maintain it. To reverse this process, the metal deposit is made positive with respect to the original oxidizable electrode, causing the dissolution of the metal bridge thereby turning the switch off. Once the metal deposit has been completely dissolved, the process self-terminates.

This switching process features the following attributes. It requires very little

voltage/current and only needs power to change states (i.e., on and off). Furthermore, no power is required to maintain the states; hence, the state of the switch is nonvolatile. Because of these attributes the integration of a rectenna to provide the necessary power and control is unique to this embodiment. A rectenna, or rectifying antenna, generates DC power from an incident RF signal. The low voltages and power required for the nanoionic switch control are easily generated from this system and provide the switch with a novel capability to be operated and powered from

an external wireless device. In one realization, an RF signal of a specific frequency can be used to set the switch into an off state, while another frequency can be used to set the switch to an on state.

The wireless, miniaturized, and no-moving-part features of this switch make it suitable for applications such as integration into garments, RFID (radio-frequency identification) tags, and conformal structures (e.g., aircraft wings, sounding rockets contours, etc). In the case of RFID tags the innovation will provide countermeasures to attempts for identity theft and other uninvited at-

tempts for retrieval of information. It could also be applicable to the automotive industry as well as the aerospace industry for collision avoidance and phased array radar systems, respectively.

This work was done by James Nessel and Felix Miranda of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18919-1.

Compute Element and Interface Box for the Hazard Detection System

This architecture combines an FPGA and CPU to capitalize on their strengths.

NASA's Jet Propulsion Laboratory, Pasadena, California

The Autonomous Landing and Hazard Avoidance Technology (ALHAT) program is building a sensor that enables a spacecraft to evaluate autonomously a potential landing area to generate a list of hazardous and safe landing sites. It will also provide navigation inputs relative to those safe sites.

The Hazard Detection System Compute Element (HDS-CE) box combines a field-programmable gate array (FPGA) board for sensor integration and timing, with a multicore computer board for processing. The FPGA does system-level timing and data aggregation, and acts as a go-between, removing the real-time requirements from the processor and labeling events with a high resolution time. The processor manages the behavior of the system, controls the instruments connected to the HDS-CE, and services the "heavy lifting" computational requirements for analyzing the potential landing spots.

The HDS-CE is built with commercial off-the-shelf (COTS) components and one custom I/O board. The HDS consists of the compute element, a Flash LIDAR, a 2-axis gimbal, a navigation-grade inertial measurement unit (IMU), and a power distribution unit (PDU). It is designed as an independent instrument interfacing with a host vehicle.

This architecture combines the strengths of two architectures: the high-performance timing, I/O, and interface ability and processing of an FPGA, with the high-performance computing, flexi-



The ALHAT Hazard Detection System Compute Element.

bility, and programmability of a general-purpose Manycore processor. This combination of an FPGA with a Manycore processor, with both components being concurrently used for processing, has yet to be done for space applications.

This architecture is also useful for embedded robotic applications such as rovers. The FPGA/Manycore combination allows the end user to place tasks on

either the FPGA or the Manycore processor, based on the strengths and weaknesses of each component.

This work was done by Carlos Y. Villalpando, Garen Khanoyan, Ryan A. Stern, Raphael R. Some, Erik S. Bailey, John M. Carson, Geoffrey M. Vaughan, Robert A. Werner, Phil M. Salomon, Keith E. Martin, Matthew D. Spaulding, Michael E. Luna, Shui H. Motaghedi, Nikolas Trawny, An-

drew E. Johnson, Tonislav I. Ivanov, Andres Huertas, and William D. Whitaker of Caltech; and Steven B. Goldberg of Indelible Systems, Inc. for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

The software used in this innovation is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48786.

DOT Transmit Module

NASA's Jet Propulsion Laboratory, Pasadena, California

The Deep Space Optical Terminal (DOT) transmit module demonstrates the DOT downlink signaling in a flight electronics assembly that can be qualified for deep space. The assembly has the capability to generate an electronic pulse-position modulation (PPM) waveform suitable for driving a laser assembly to produce the op-

tical downlink signal. The downlink data enters the assembly through a serializer/deserializer (SERDES) interface, and is encoded using a serially concatenated PPM (SCPPM) forward error correction code. The encoded data is modulated using PPM with an inter-symbol guard time to aid in receiver synchronization. Monitor

and control of the assembly is via a low-voltage differential signal (LVDS) interface.

This work was done by Kevin J. Quirk, Jonathan W. Gin, Adit Sahasrabudhe, Ferze D. Patawaran, Danh H. Nguyen, and Huy Nguyen for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47723



Composite Aerogel Multifoil Protective Shielding

These composites are also suitable for environments containing an atmosphere.

NASA's Jet Propulsion Laboratory, Pasadena, California

New technologies are needed to survive the temperatures, radiation, and hypervelocity particles that exploration spacecraft encounter. Multilayer insulations (MLIs) have been used on many spacecraft as thermal insulation. Other materials and composites have been used as micrometeorite shielding or radiation shielding. However, no material composite has been developed and employed as a combined thermal insulation, micrometeorite, and radiation shielding.

By replacing the scrims that have been used to separate the foil layers in MLIs with various aerogels, and by using a variety of different metal foils, the overall protective performance of MLIs can be greatly expanded to act as thermal insulation, radiation shielding, and hypervelocity particle shielding. Aerogels are highly porous, low-density solids that are produced by the gelation of metal alkoxides and supercritical drying. Aerogels have been flown in NASA missions as a hypervelocity particle capture medium (Stardust) and as thermal insulation (2003 MER).

Composite aerogel multifoil protective shielding would be used to provide thermal insulation, while also shielding spacecraft or components from radiation and hypervelocity particle impacts. Multiple layers of foil separated by aerogel would act as a thermal barrier by preventing the transport of heat energy through the composite. The silica aerogel would act as a convective and conductive thermal barrier, while the titania powder and metal foils would absorb and reflect the radiative heat. It would also capture small hypervelocity particles, such as micrometeorites, since it would be a stuffed, multi-shock Whipple shield. The metal foil layers would slow and break up the impacting particles, while the aerogel layers would convert the kinetic energy of the particles to thermal and mechanical energy and stop the particles.

Thermal insulation, micrometeorite shielding, and radiation shielding on spacecraft are usually produced by using two, or even three, different materials. By using an aerogel multifoil composite, all three of these functionalities can be

achieved with a single material. The thermal insulation needed for a given application can be produced by using the number of layers required to provide a given level of thermal protection, and by using either plain silica aerogel or an aerogel composite. By varying the types of foils or aerogel used in a given composite, the effectiveness for different impactor environments can be achieved. By changing the types of foils used, the effectiveness against certain types of radiation can be increased, since the types of foils used to shield against electrons would be different from those used to shield against protons.

Since aerogels are excellent convective and conductive thermal insulators, aerogel multifoil composites can also be used in environments that include an atmosphere. Traditional MLIs are only effective in vacuum environments, since the presence of an atmosphere renders it ineffective as thermal insulation.

This work was done by Steven M. Jones of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48883

Li-Ion Electrolytes With Improved Safety and Tolerance to High-Voltage Systems

Promising electrolytes are identified.

NASA's Jet Propulsion Laboratory, Pasadena, California

Given that lithium-ion (Li-ion) technology is the most viable rechargeable energy storage device for near-term applications, effort has been devoted to improving the safety characteristics of this system. Therefore, extensive effort has been devoted to developing non-flammable electrolytes to reduce the flammability of the cells/battery. A number of promising electrolytes have been developed incorporating flame-retardant additives, and have been shown to have good performance in a number of systems. However, these electrolyte formulations did not perform well

when utilizing carbonaceous anodes with the high-voltage materials. Thus, further development was required to improve the compatibility.

A number of Li-ion battery electrolyte formulations containing a flame-retardant additive [i.e., triphenyl phosphate (TPP)] were developed and demonstrated in high-voltage systems. These electrolytes include: (1) formulations that incorporate varying concentrations of the flame-retardant additive (from 5 to 15%), (2) the use of mono-fluoroethylene carbonate (FEC) as a co-solvent, and (3) the use of LiBOB as an elec-

trolyte additive intended to improve the compatibility with high-voltage systems. One of the promising electrolytes identified of the group investigated is 1.0M LiPF₆ in EC+EMC+TPP (20:70:10 vol %) + 0.15M LiBOB, which was demonstrated to have comparable performance to that of the baseline ternary electrolyte in MPG-111/Toda (LiNiMnCoO₂) coin cells, in terms of reversible capacity and discharge rate capability at room temperature. Thus, improved safety has been provided without loss of performance in the high-voltage, high-energy system.

The use of higher concentrations of the flame-retardant additive is known to reduce the flammability of the electrolyte solution, with 15% concentration resulting in solutions of substantially reduced flammability. Thus, the desired concentration of the flame-retardant additive is the greatest amount tolerable without adversely affecting the performance in terms of reversibility, ability to operate over a wide temperature range, and the discharge rate capability. The use of FEC

was used to reduce the inherent flammability of mixtures and improve the compatibility at the interfacial regions, due to desirable surface reactions.

This work was done by Marshall C. Smart and Ratnakumar V. Bugga of Caltech, and G.K. Surya Prakash and Frederick C. Krause of the University of Southern California for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this

invention. Inquiries concerning rights for its commercial use should be addressed to:

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E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-47980, volume and number of this NASA Tech Briefs issue, and the page number.

Polymer-Reinforced, Non-Brittle, Lightweight Cryogenic Insulation

John F. Kennedy Space Center, Florida

The primary application for cryogenic insulating foams will be fuel tank applications for fueling systems. It is crucial for this insulation to be incorporated into systems that survive vacuum and terrestrial environments. It is hypothesized that by forming an open-cell silica-reinforced polymer structure, the foam structures will exhibit the necessary strength to maintain shape. This will, in turn, maintain the insulating capabilities of the foam insulation. Besides mechanical stability in the form of crush resistance, it is important for these insulating materials to exhibit water penetration resistance. Hydrocarbon-terminated foam surfaces were implemented to impart hydrophobic functionality that apparently limits moisture penetration through the foam. During the freezing process, water accumulates on the surfaces of the foams.

However, when hydrocarbon-terminated surfaces are present, water apparently beads and forms crystals, leading to less apparent accumulation.

The object of this work is to develop inexpensive structural cryogenic insulation foam that has increased impact resistance for launch and ground-based cryogenic systems. Two parallel approaches will be pursued: a silica-polymer co-foaming technique and a post foam coating technique.

Insulation characteristics, flexibility, and water uptake can be fine-tuned through the manipulation of the polyurethane foam scaffold. Silicate coatings for polyurethane foams and aerogel-impregnated polyurethane foams have been developed and tested. A highly porous aerogel-like material may be fabricated using a co-foam and

coated foam techniques, and can insulate at liquid temperatures using the composite foam.

NASA is currently involved with varying space and terrestrial projects that would greatly benefit from more efficient cryogenic insulation to reduce fuel boil-off. Hydrogen quality testing methods require terrestrial sampling lines that would benefit from this insulation by reducing line losses for more accurate representation of tank holdings. Moreover, rockets and orbital depot systems require insulation that will maintain liquid fuel during liftoff, and during the initiation of orbit.

This work was done by David M. Hess of InnoSense LLC for Kennedy Space Center. For more information, contact the Kennedy Space Center Innovative Partnerships Office at (321) 867-5033. KSC-13569

Controlled, Site-Specific Functionalization of Carbon Nanotubes With Diazonium Salts

Possible applications include molecular switches and molecular wires.

Lyndon B. Johnson Space Center, Houston, Texas

This work uses existing technologies to prepare a crossbar architecture of nanotubes, wherein one nanotube is fixed to a substrate, and a second nanotube is suspended a finite distance above. Both nanotubes can be individually addressed electrically. Application of opposite potentials to the two tubes causes the top tube to deform and to essentially come into contact with the lower tube. Contact here

refers not to actual, physical contact, but rather within an infinitesimally small distance referred to as van der Waals contact, in which the entities may influence each other on a molecular and electronic scale.

First, the top tube is physically deformed, leading to a potentially higher chemical reactivity at the point of deformation, based on current understanding of the effects of curvature strain on reac-

tivity. This feature would allow selective functionalization at the junction via reaction with diazonium salts. Secondly, higher potential is achieved at the point of "cross" between the tubes. In a pending patent application, a method is claimed for directed self-assembly of molecular components onto the surface of metal or conductive materials by application of potential to the metal or conductive surface. In another pending

patent application, a method is claimed for attaching molecules to the surface of nanotubes via the use of reactive diazonium salts. In the present invention, the directed functionalization of the crossed-nanotube junctions by applying a potential to the ends of the nanotubes in the presence of reactive diazonium salts, or other reactive molecular species is claimed.

The diazonium salts are directed by the potential existing at the junction to react with the surface of the nanotube, thus placing functional molecular com-

ponents at the junctions. The crossed nanotubes therefore provide a method of directly addressing the functionalized molecules, which have been shown to function as molecular switches, molecular wires, and in other capacities and uses. Site-specific functionalization may enable the use of nanotubes in molecular electronic applications because device functionality is critical at the cross points.

This work was done by James M. Tour of Rice University for Johnson Space Center. For further information, contact the JSC Innovation Part-

nerships Office at (281) 483-3809.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to MSC-24050-1, volume and number of this NASA Tech Briefs issue, and the page number.

Regenerable Sorbent for CO₂ Removal

Marshall Space Flight Center, Alabama

A durable, high-capacity regenerable sorbent can remove CO₂ from the breathing loop under a Martian atmosphere. The system design allows near-ambient temperature operation, needs only a small temperature swing, and sorbent regeneration takes place at or above 8 torr, eliminating the potential for Martian atmosphere to leak into the regeneration bed and into the breathing loop. The physical adsorbent can be used in a metabolic, heat-driven TSA system to remove CO₂ from the breathing loop of the astronaut and reject it to the Martian atmosphere. Two (or more) alternating sorbent beds contin-

uously scrub and reject CO₂ from the spacesuit ventilation loop. The sorbent beds are cycled, alternately absorbing CO₂ from the vent loop and rejecting the adsorbed material into the environment at a high CO₂ partial pressure (above 8 torr). The system does not need to run the adsorber at cryogenic temperatures, and uses a much smaller temperature swing.

The sorbent removes CO₂ via a weak chemical interaction. The interaction is strong enough to enable CO₂ adsorption even at 3 to 7.6 torr. However, because the interaction between the surface adsorption sites and the CO₂ is

relatively weak, the heat input needed to regenerate the sorbent is much lower than that for chemical absorbents.

The sorbent developed in this project could potentially find use in a large commercial market in the removal of CO₂ emissions from coal-fired power plants, if regulations are put in place to curb carbon emissions from power plants.

This work was done by Gokhan Alptekin and Ambal Jayaraman of TDA Research for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32902-1

Sprayable Aerogel Bead Compositions With High Shear Flow Resistance and High Thermal Insulation Value

This aerogel insulation could be used in fuel cell systems, oil and gas pipelines, and in building and construction applications.

Marshall Space Flight Center, Alabama

A sprayable aerogel insulation has been developed that has good mechanical integrity and lower thermal conductivity than incumbent polyurethane spray-on foam insulation, at similar or lower areal densities, to prevent insulation cracking and debonding in an effort to eliminate the generation of in-flight debris.

This new, lightweight aerogel under bead form can be used as insulation in various thermal management systems that require low mass and volume, such as cryogenic storage tanks, pipelines,

space platforms, and launch vehicles. These aerogel beads, with a packing density of 0.03 to 0.05 g/cm³, can be used as pour-in, formable, or sprayable insulation, showing versatility in a variety of applications.

Silica and organically modified silica aerogel beads in a mixture with binders or foams can be formed into complex shapes, or sprayed onto panels. The aerogel composites have a fast cure, and have good mechanical strength at densities of 0.05 to 0.15 g/cm³. Compression modulus for the aerogel bead/foam composite

was 60 percent higher than the one from the foam without aerogel dopant.

Lightweight aerogel beads can be used in sprayable form together with a carrier for on-site applications. The sprayable thermal insulator has several advantages, such as a large temperature range of operation (from cryogenic temperatures to +300 °C), facile on-site installation, can be cured at room temperature, is mechanically robust and durable, and has excellent thermal performance insulation capability. This innovation is also water repellent, but does

not trap gases or cryogenic liquids and, consequently, does not pose cryopumping and cryoingestion problems.

This thermal management system can be applied in either an automated or manual spraying process with less sensitivity to process chemistry and environmental parameters than spray-on foam insulation (SOFI) products like a commercially produced polyurethane foam used on the Space Shuttle External Tank, while providing better insulation performance. The aerogel bead binder-

sprayed panel, with a thermal conductivity of 20 to 25 mW/mK, outperformed the commercial foam by 30 to 40 percent in the 10 to 100 °C temperature range.

The aerogel compositions developed for this innovation withstand repeated cycles of high enthalpy shear flows of 20 to 100 Pa at temperatures tested up to 370 °C without losing mechanical integrity. Thermal management systems with versatile installation based on aerogel beads represent a significant oppor-

tunity for improving performance of systems for long-term cryogenic propellant storage or transfer for mechanisms operating in cryogenic temperature environments, space transportation, and propulsion systems.

This work was done by Danny Ou, Roxana Trifu, and Gregory Caggiano of Aspen Aerogels, Inc. for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32810-1.



Lexan Linear Shaped Charge Holder With Magnets and Backing Plate

Lyndon B. Johnson Space Center, Houston, Texas

A method was developed for cutting a fabric structural member in an inflatable module, without damaging the internal structure of the module, using linear shaped charge. Lexan and magnets are used in a charge holder to precisely position the linear shaped charge over the desired cut area. Two types of

charge holders have been designed, each with its own backing plate. One holder cuts fabric straps in the vertical configuration, and the other charge holder cuts fabric straps in the horizontal configuration.

This work was done by Matthew W. Maples, Maureen L. Dutton, Scott C. Hacker,

and Richard J. Dean of Johnson Space Center; Nicholas Kidd and Chris Long of Jacobs Technology; and Robert C. Hicks of Barrios Technology. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-24529-1

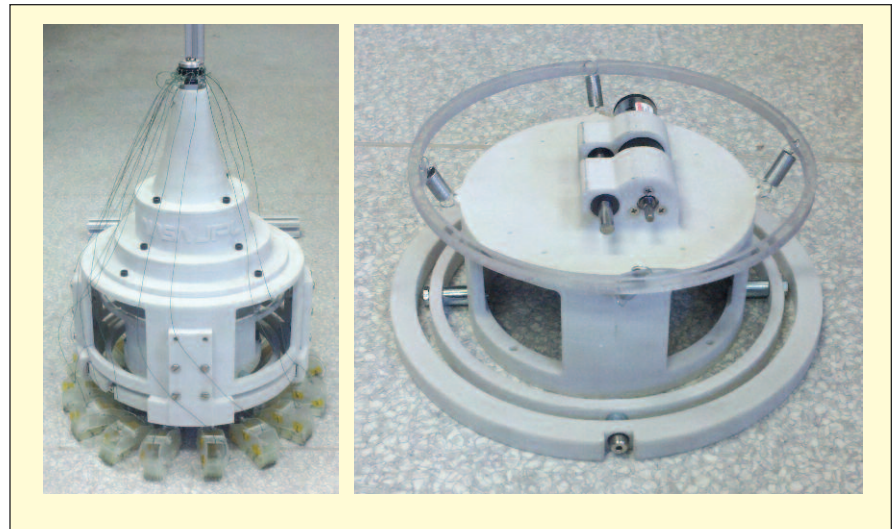
Robotic Ankle for Omnidirectional Rock Anchors

This mechanism could provide mobility for military robots on vertical cliff faces or on ceilings.

NASA's Jet Propulsion Laboratory, Pasadena, California

Future robotic exploration of near-Earth asteroids and the vertical and inverted rock walls of lava caves and cliff faces on Mars and other planetary bodies would require a method of gripping their rocky surfaces to allow mobility without gravitational assistance. In order to successfully navigate this terrain and drill for samples, the grippers must be able to produce anchoring forces in excess of 100 N. Additionally, the grippers must be able to support the inertial forces of a moving robot, as well as gravitational forces for demonstrations on Earth. One possible solution would be to use microspine arrays to anchor to rock surfaces and provide the necessary load-bearing abilities for robotic exploration of asteroids.

Microspine arrays comprise dozens of small steel hooks supported on individual suspensions. When these arrays are dragged along a rock surface, the steel hooks engage with asperities and holes on the surface. The suspensions allow for individual hooks to engage with asperities while the remaining hooks continue to drag along the surface. This ensures that the maximum possible number of hooks engage with the surface, thereby increasing the load-bearing abilities of the gripper. Using the microspine array grippers described above as the end-effectors of a robot would allow it to traverse terrain previously unreachable by traditional wheeled robots. Further-



The Ankle Mechanism (left), and the interior of the ankle (right), showing the gimbal systems, springs, and actuation device for the engagement wires.

more, microspine-gripping robots that can perch on cliffs or rocky walls could enable a new class of persistent surveillance devices for military applications.

In order to interface these microspine grippers with a legged robot, an ankle is needed that can robotically actuate the gripper, as well as allow it to conform to the large-scale irregularities in the rock. The anchor serves three main purposes: deploy and release the anchor, conform to roughness or misalignment with the surface, and cancel out any moments

about the anchor that could cause unintentional detachment.

The ankle design contains a rotary DC motor that can drag the microspine arrays across the surface to engage them with asperities, as well as a linear actuator to disengage the hooks from the surface. Additionally, the ankle allows the gripper to rotate freely about all three axes so that when the robot takes a step, the gripper may optimally orient itself with respect to the wall or ground. Finally, the ankle contains some minimal

elasticity, so that between steps, the gripper returns to a default position that is roughly parallel to the wall.

In order to give the ankle freedom to rotate about all three degrees of freedom, the gripper is mounted on a series of gimbals similar to those found on a gyroscope. The rotation of the gimbals about radial directions is limited by springs, which bring the gripper back to a default position in between steps of the robot. These springs have a relatively low spring-constant so as not to induce large torques that may upset the gripper's hold on the rock. Additionally, microspine engagement is achieved

through a motor that turns a spool and pulls on cables connected to the spine arrays. A linear actuator that pulls the microspines up and away from the rock face provides disengagement. Previous microspine robots have been limited by their feet, which only sustain forces in one direction and only work on globally smooth surfaces like brick walls and concrete. The omnidirectional anchors extend the potential of legged robots using microspines to natural rock, and would allow gripping at any orientation including inverted or in zero gravity.

This work was done by Aaron Parness, Matthew A. Frost, and Nitish Thatte of Cal-

tech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-48315 volume and number of this NASA Tech Briefs issue, and the page number.

Wind, Wave, and Tidal Energy Without Power Conditioning

NASA's Jet Propulsion Laboratory, Pasadena, California

Most present wind, wave, and tidal energy systems require expensive power conditioning systems that reduce overall efficiency. This new design eliminates power conditioning all, or nearly all, of the time.

Wind, wave, and tidal energy systems can transmit their energy to pumps that send high-pressure fluid to a central power production area. The central power production area can consist of a series of hydraulic generators. The hy-

draulic generators can be variable displacement generators such that the RPM, and thus the voltage, remains constant, eliminating the need for further power conditioning.

A series of wind blades is attached to a series of radial piston pumps, which pump fluid to a series of axial piston motors attached to generators. As the wind is reduced, the amount of energy is reduced, and the number of active hydraulic generators can be reduced to

maintain a nearly constant RPM. If the axial piston motors have variable displacement, an exact RPM can be maintained for all, or nearly all, wind speeds. Analyses have been performed that show over 20% performance improvements with this technique over conventional wind turbines.

This work was done by Jack A. Jones of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48620

An Active Heater Control Concept to Meet IXO Type Mirror Module Thermal-Structural Distortion Requirement

This innovation offers a number of advantages in terms of reduced mass, problem of routing, and the risk of x-ray attenuation.

Goddard Space Flight Center, Greenbelt, Maryland

Flight mirror assemblies (FMAs) of large telescopes, such as the International X-ray Observatory (IXO), have very stringent thermal-structural distortion requirements. The spatial temperature gradient requirement within a FMA could be as small as 0.05 °C. Conventionally, heaters and thermistors are attached to the stray light baffle (SLB), and centralized heater controllers (i.e., heater controller boards located in a large electronics box) are used. Due to the large number of heater harnesses, accommodating and routing them is extremely difficult. The total harness length/mass is

very large. This innovation uses a thermally conductive pre-collimator to accommodate heaters and a distributed heater controller approach. It minimizes the harness length and mass, and reduces the problem of routing and accommodating them.

Heaters and thermistors are attached to a short (4.67 cm) aluminum portion of the pre-collimator, which is thermally coupled to the SLB. Heaters, which have a very small heater power density, and thermistors are attached to the exterior of all the mirror module walls. The major portion (23.4 cm) of the pre-collimator for the middle and outer modules

is made of thin, non-conductive material. It minimizes the view factors from the FMA and heated portion of the pre-collimator to space. It also minimizes heat conduction from one end of the FMA to the other. Small and multi-channel heater controllers, which have adjustable set points and internal redundancy, are used. They are mounted to the mechanical support structure members adjacent to each module.

The IXO FMA, which is 3.3 m in diameter, is an example of a large telescope. If the heater controller boards are centralized, routing and accommodating heater harnesses is extremely dif-

ficult. This innovation has the following advantages. It minimizes the length/mass of the heater harness between the heater controllers and heater circuits. It reduces the problem of routing and accommodating the harness on the FMA.

It reduces the risk of X-ray attenuation caused by the heater harness. Its adjustable set point capability eliminates the need for survival heater circuits. The operating mode heater circuits can also be used as survival heater circuits.

In the non-operating mode, a lower set point is used.

This work was done by Michael Choi of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16380-1

Waterless Clothes-Cleaning Machine

This machine can be used wherever water is at a premium, or to minimize washing with water.

Lyndon B. Johnson Space Center, Houston, Texas

A waterless clothes-cleaning machine has been developed that removes loose particulates and deodorizes dirty laundry with regenerative chemical processes to make the clothes more comfortable to wear and have a fresher smell. This system was initially developed for use in zero-g, but could be altered for 1-g environments where water or other resources are scarce. Some of these processes include, but are not limited to, airflow, filtration, ozone generation, heat, ultraviolet light, and photocatalytic titanium oxide.

The machine has a chamber large enough to contain and agitate several articles of clothing, as well as a self-sealing door for insertion and removal of the clothing. The agitation and removal of particulate and volatiles in the clothes is done by airflow and some kind of agitation mechanism, possibly by rotating the chamber and/or alter-

nating airflow and/or heater panels for the zero-g environment. Agitation in 1-g could be done with tumbling. One of the main purposes of the airflow is to remove particulate from the clothing and to deposit it into a filter where the particulate can be removed from the filter at the end of the cycle. This airflow can also carry ozone into the chamber to penetrate into the clothing to kill off bacteria and break down odorizing proteins or other organics. The chamber can also contain an ultraviolet light source to expose the agitating clothes to bacteria-killing wavelengths of light. This light source could also expose a photocatalytic material such as titanium oxide, embedded coated on the interior of the chamber walls or on agitation mechanisms, to energies that would produce hydroxyl ions from the chamber humidity to aid in the removal of organic compounds from the cloth.

Heat could be introduced into the clothing chamber either by heating the airflow or by heating the clothing chamber directly using electrical heater strips on the chamber walls. The heat would aid in the killing of bacteria, breaking down proteins, and evaporating volatiles from the clothes. The airflow for this system could either be completely recycled back through the system or vented out, depending on the needs of the clothes cleaner's surrounding environment. Airflow, ozone, UV light, and the heat can be controlled independently so each can be turned on or off without affecting the others to allow for the needs of the specific type of clothing or different types of soiling on the clothes.

This work was done by Glenn Johnson and Shane Ganske of United Space Alliance for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-25280-1

Integrated Electrical Wire Insulation Repair System

John F. Kennedy Space Center, Florida

An integrated system tool will allow a technician to easily and quickly repair damaged high-performance electrical wire insulation in the field. Low-melt polyimides have been developed that can be processed into thin films that work well in the repair of damaged polyimide or fluoropolymer insulated electrical wiring. Such thin films can be used in wire insulation repairs by affixing a film of this low-melt polyimide to the damaged wire, and heating the film to

effect melting, flow, and cure of the film. The resulting repair is robust, lightweight, and small in volume. The heating of this repair film is accomplished with the use of a common electrical soldering tool that has been modified with a special head or tip that can accommodate the size of wire being repaired.

This repair method can furthermore be simplified for the repair technician by providing replaceable or disposable soldering tool heads that have repair

film already "loaded" and ready for use. The soldering tool heating device can also be equipped with a battery power supply that will allow its use in areas where plug-in current is not available.

This work was done by Martha Williams of Kennedy Space Center and Scott Jolley, Tracy Gibson, and Steven Parks of ASRC Aerospace Corporation. For more information, contact the Kennedy Space Center Innovative Partnerships Office at 321-867-5033. KSC-13193



LVGEMS Time-of-Flight Mass Spectrometry on Satellites

This technology has applications in plant contaminant monitoring, clinical and medical diagnostics, and homeland security and defense.

Goddard Space Flight Center, Greenbelt, Maryland

NASA's investigations of the upper atmosphere and ionosphere require measurements of composition of the neutral air and ions. NASA is able to undertake these observations, but the instruments currently in use have their limitations. NASA has extended the scope of its research in the atmosphere and now requires more measurements covering more of the atmosphere. Out of this need, NASA developed multipoint measurements using miniaturized satellites, also called nanosatellites (e.g., CubeSats), that require a new generation of spectrometers that can fit into a 4×4 in. (≈10×10 cm) cross-section in the upgraded satellites. Overall, the new mass spectrometer required for the new depth of atmospheric research must fulfill a new level of low-voltage/low-power requirements, smaller size, and less risk of magnetic contamination.

The Low-Voltage Gated Electrostatic Mass Spectrometer (LVGEMS) was developed to fulfill these requirements. The LVGEMS offers a new spectrometer that eliminates magnetic field issues associated with magnetic sector mass spectrometers, reduces power, and is about 1/10 the size of previous instruments. LVGEMS employs the time of flight (TOF) technique in the GEMS mass spectrometer previously developed at

Goddard Space Flight Center. However, like any TOF mass spectrometer, GEMS requires a rectangular waveform of large voltage amplitude, exceeding 100 V — that means that the voltage applied to one of the GEMS electrodes has to change from 0 to 100 V in a time of only a few nanoseconds. Such electronic speed requires more power than can be provided in a CubeSat.

In the LVGEMS, the amplitude of the rectangular waveform is reduced to about 1 V, compatible with digital electronics supplies and requiring little power. Thus, the LVGEMS concept makes possible very low power (< 0.5 W) mass spectrometers 1 to 2 in. (≈2.5 to 5 cm) in length; fitting and working well in CubeSats. With less voltage and power, there is also less risk of voltage breakdown at the spectrometer electrodes and less magnetic interference from the supporting electronics. Because of its small size, the LVGEMS can be part of an instrument suite, like the NASA/NRL WINCS (Winds-Ions-Neutral Composition Suite) that provides neutral and ion composition with other instruments providing the neutral wind, ion drift, and temperatures. Perhaps the main advantage of an instrument suite is that instruments like GEMS share electronics and power with other sensors,

thus minimizing the power consumed per spectrometer — another enabler for CubeSat missions for ionosphere-thermosphere science.

In an orbiting TOF spectrometer, measurements are difficult because all atoms and molecules species enter at the same velocity; therefore all incident atoms and molecules have the same TOF, making it impossible to differentiate between species. However, the newly developed LVGEMS mass spectrometer provides the ability to accelerate and add the same kinetic energy to all species, and this results in each species having its own unique TOF value for easy identification.

The principal feature of this invention is to enable TOF mass spectrometry in low-Earth-orbit investigations of the thermosphere at the time when new missions require multi-point measurements using large numbers of nanosatellites. LVGEMS offers a solution that requires no magnetic fields, no high-frequency voltages of high amplitudes, uses power less than 0.5 W, and has dimensions measured in a few cm (one inch or less).

This work was done by Federico Herrero of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16255-1

Surface Inspection Tool for Optical Detection of Surface Defects

The small, dual-picture tool enables both macro and micro views.

John F. Kennedy Space Center, Florida

The Space Shuttle Orbiter windows were damaged both by micrometeor impacts and by handling, and required careful inspection before they could be reused. The launch commit criteria required that no defect be deeper than a critical depth. The shuttle program used a refocus microscope to perform a quick pass/fail determination, and then followed up with mold impressions to

better quantify any defect. However, the refocus microscope is slow and tedious to use due to its limited field of view, only focusing on one small area of glass at a time. Additionally, the unit is bulky and unable to be used in areas with tight access, such as defects near the window frame or on the glass inside the Orbiter due to interference with the dashboard. Bulky camera equipment

was needed to acquire images for later processing and storage. The long depth of field of the refocus microscope provided crisp images of the defect, but didn't provide the user with a feel for depth of the defect since all parts of the image appear in focus.

The surface inspection tool is a low-profile handheld instrument that provides two digital video images on a com-

puter for monitoring surface defects. The first image is a wide-angle view to assist the user in locating defects. The second provides an enlarged view of a defect centered in the window of the first image. The focus is adjustable for each of the images. However, the enlarged view was designed to have a focal plane with a short depth. This allows the user to get a feel for the depth of different parts of the defect under inspection as the focus control is varied. A light source is also provided to illuminate the defect, precluding the need for separate lighting tools. The software provides many controls to adjust image quality, along with the ability to zoom digitally the images and to capture and store them for later processing.

Two LED light sources are included for improved illumination, allowing the user to work without an external light source. The optics enable the two cameras to be mounted in a compact manner and allow them to focus on the same image. Software provided from the camera manufacturer provides the users the capability to view the two images simultaneously to facilitate rapid defect detection. The user may use a digital zoom to enlarge smaller details, if needed. Full-resolution digital images and limited-



The **Surface Inspection Tool** (left), shown in use (right). The handle was added to accommodate smaller hands and reduce user fatigue.

resolution video can be captured and stored for later processing.

The surface inspection tool addresses many of the limitations of the existing refocus microscope. It is smaller and provides a live video output on a laptop computer that allows the user to locate defects more rapidly. The camera with the microscope objective has a depth of focus of approximately 0.00014 in. ($\approx 4 \mu\text{m}$) and a user-varied focus. This allows the user to gain a better understanding of the depth and character of the defect under inspection. Likewise, lower-resolution video capture is also an avail-

able feature not present with the refocus microscope.

The surface inspection tool consists of components that are more expensive than the refocus microscope. However, the inclusion of the wide-angle camera allows for inspection of a larger area at a time, making it quicker to scan and locate defects in large surfaces. This time savings, combined with the added features, may make it interesting enough to potential users to justify the added initial cost.

This work was done by Mark Nurge, Robert Youngquist, and Dustin Dyer of Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13580

Per-Pixel, Dual-Counter Scheme for Optical Communications

Per-pixel processing scheme for single-photon detectors would require 10 to 100 times less beacon transmit power.

NASA's Jet Propulsion Laboratory, Pasadena, California

Free space optical communications links from deep space are projected to fulfill future NASA communication requirements for 2020 and beyond. Accurate laser-beam pointing is required to achieve high data rates at low power levels. For the highest pointing accuracy, a laser beacon transmitted from near the Earth receiver location is acquired and tracked by the space transceiver to obtain accurate knowledge of the Earth receiver position in the pitch and yaw degrees of freedom. This pointing knowledge is generated by forming estimates of the beacon transmitter location by centroiding the position of a focused spot on a focal plane detector array in the space transceiver, perhaps a two-by-two pixel array (a quad detector), but often on a larger array to ease initial spatial acquisition. The accuracy of those estimates, and, therefore, the accuracy of the space transceiver point-

ing, is a function of the received optical signal power, accepted optical background power, and detector readout noise. The centroiding performance of a typical focal plane array can be 10 to 100 times poorer than the shot noise limit due to readout noise. A focal plane array of single-photon detectors can fully close this gap, and thereby require 10 to 100 times less beacon transmit power, but specialized per-pixel processing circuitry is required.

This innovation is a per-pixel processing scheme using a pair of three-state digital counters to implement acquisition and tracking of a dim laser beacon transmitted from Earth for pointing control of an interplanetary optical communications system using a focal plane array of single sensitive detectors. It shows how to implement dim beacon acquisition and tracking for an interplanetary optical transceiver with a method

that is suitable for both achieving theoretical performance, as well as supporting additional functions of high data rate forward links and precision spacecraft ranging.

Spatial acquisition and tracking on the uplink laser beacon from Earth can be achieved on the space transceiver focal plane array by connecting two counters to every array pixel. This scheme provides a low-complexity method to monitor all pixels in the detector array until a beacon signal is detected. Temporal acquisition of the uplink laser beacon square wave signal is performed using outputs from a pair of phase-offset counters. The counters alternate among three states denoted by "up," "down," and "idle." In the up state, a counter increments its value when its pixel registers a photon arrival. In the down state, the counter decrements its value when a photon arrival is

detected. The counter maintains its value in the idle state. For an outer modulation signal of 2 PPM + two intersymbol guard time slots with slot widths T_{slot} , the counters cycle through the three states with period of $4T_{\text{slot}}$. The

counters can be seen as approximations to a maximum-likelihood timing estimation with a modified pulse shape. Post-processing in software allows the outputs of the counters to be integrated in time.

This work was done by William H. Farr, Kevin M. Birnbaum, Kevin J. Quirk, Suzana E. Sburian, and Adit Sahasrabudhe of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48153



➤ Certification-Based Process Analysis

Technique analyzes a process and identifies potential areas of improvement.

NASA's Jet Propulsion Laboratory, Pasadena, California

Space mission architects are often challenged with knowing which investment in technology infusion will have the highest return. Certification-based analysis (CBA) gives architects and technologists a means to communicate the risks and advantages of infusing technologies at various points in a process. Various alternatives can be compared, and requirements based on supporting streamlining or automation can be derived and levied on candidate technologies.

CBA is a technique for analyzing a process and identifying potential areas of improvement. The process and analysis products are used to communicate between technologists and architects. Process means any of the standard representations of a production flow; in this case, any individual steps leading to products, which feed into other steps, until the final product is produced at the end. This sort of process is common

for space mission operations, where a set of goals is reduced eventually to a fully vetted command sequence to be sent to the spacecraft. Fully vetting a product is synonymous with certification. For some types of products, this is referred to as verification and validation, and for others it is referred to as checking. Fundamentally, certification is the step in the process where one insures that a product works as intended, and contains no flaws.

Candidate technologies are evaluated against a potential area of improvement using criteria such as risk, adaptation cost, adaptation time, reduction in cost, reduction in duration, reduction in risk, and maintainability. Where risk and maintainability are acceptable, and gains in either cost or duration outweigh adaptation costs, then the technology is deemed a suitable candidate. For many technologies, especially artifi-

cial intelligence technologies, certification of a technology implies the certification of the process (or process step) that the technology is used for, as compared to certifying the product (using a separate process, which, for space applications, is often manual). Certifying the process, and not the product, is the key tenet of CBA.

This work gives specific direction to architects on what operations can be allowed that are not usually allowed in modifying/designing architecture with respect to technology transfer. This work applies to any production process in general, but specifically it is being applied to spacecraft operations design, planning product production, and stowage product production.

This work was done by Russell L. Knight of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47692

➤ Surface Navigation Using Optimized Waypoints and Particle Swarm Optimization

This technique could be used in search and rescue, tracking, military scouting, navigation, and as a field resource support tool.

Lyndon B. Johnson Space Center, Houston, Texas

The design priority for manned space exploration missions is almost always placed on human safety. Proposed manned surface exploration tasks (lunar, asteroid sample returns, Mars) have the possibility of astronauts traveling several kilometers away from a home base. Deviations from pre-planned paths are expected while exploring. In a time-critical emergency situation, there is a need to develop an optimal home base return path. The return path may or may not be similar to the outbound path, and what defines optimal may change with, and even within, each mission.

A novel path planning algorithm and prototype program was developed using

biologically inspired particle swarm optimization (PSO) that generates an optimal path of traversal while avoiding obstacles. Applications include emergency path planning on lunar, Martian, and/or asteroid surfaces, generating multiple scenarios for outbound missions, Earth-based search and rescue, as well as human manual traversal and/or path integration into robotic control systems. The strategy allows for a changing environment, and can be re-tasked at will and run in real-time situations.

Given a random extraterrestrial planetary or small body surface position, the goal was to find the fastest (or shortest) path to an arbitrary position such as a safe zone or geographic objective, sub-

ject to possibly varying constraints. The problem requires a workable solution 100% of the time, though it does not require the absolute theoretical optimum. Obstacles should be avoided, but if they cannot be, then the algorithm needs to be smart enough to recognize this and deal with it. With some modifications, it works with non-stationary error topologies as well.

A novel path planning algorithm has been developed, in coordination with PSO, that generates a piece-wise linear path from a set of optimal waypoints. The path is guaranteed to be continuous, though the problem space itself may be discontinuous. The path avoids obstacles while minimizing total path distance.

The steps include setting up a region of interest, a start position, and a stop position, as well as initially random traversal waypoints. The optimization routine moves the way points around for each candidate solution and attempts to evolve the best path with regards to the reference cost function. The program calculates a path connecting all the waypoints from start to finish, and feeds this path to a cost function. The cost function determines various metrics such as length of path, collision with obstacles,

work required to traverse the path, smoothness, weight on exploration of new territory vs. tracking the original outbound path, etc. The calculation of the optimal path is iterative; several rounds of feeding candidate solutions and using their associated costs to calculate new candidate solutions are required. The practical result of the pairing of this cost function strategy with PSO is that an optimal path is evolved much faster than random search, and completely forgiving of discontinuities.

The path planning prototype can be re-tasked on the fly and uses a unique “way point” optimization strategy. Unlike other optimization strategies, this one will work in a discontinuous environment with no modification necessary and is guaranteed to provide a continuous path from start to finish.

This work was done by Brian Birge of L-3 Communications for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24864-1

Smart-Divert Powered Descent Guidance to Avoid the Backshell Landing Dispersion Ellipse

The software and methods are valid for planetary or lunar powered descent.

NASA's Jet Propulsion Laboratory, Pasadena, California

A smart-divert capability has been added into the Powered Descent Guidance (PDG) software originally developed for Mars pinpoint and precision landing. The smart-divert algorithm accounts for the landing dispersions of the entry backshell, which separates from the lander vehicle at the end of the parachute descent phase and prior to powered descent. The smart-divert PDG algorithm utilizes the onboard fuel and vehicle thrust vectoring to mitigate landing error in an intelligent way: ensuring that the lander touches down with minimum-fuel usage at the minimum distance from the desired landing location that also avoids impact by the descending backshell.

The smart-divert PDG software implements a computationally efficient, convex formulation of the powered-descent guidance problem to provide pinpoint or precision-landing guidance solutions that are fuel-optimal and satisfy physical thrust bound and pointing constraints, as well as position and speed constraints. The initial smart-divert implementation enforced a lateral-divert corridor parallel to the ground velocity vector; this was based on guidance requirements for MSL (Mars Science Laboratory) landings. This initial method was overly conservative since the divert corridor was infinite in the down-range direction despite the backshell landing inside a calculable disper-

sion ellipse. Basing the divert constraint instead on a local tangent to the backshell dispersion ellipse in the direction of the desired landing site provides a far less conservative constraint. The resulting enhanced smart-divert PDG algorithm avoids impact with the descending backshell and has reduced conservatism.

This work was done by John M. Carson and Behcet Acikmese of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

The software used in this innovation is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47884.

Estimating Foreign-Object-Debris Density From Photogrammetry Data

John F. Kennedy Space Center, Florida

Within the first few seconds after launch of STS-124, debris traveling vertically near the vehicle was captured on two 16-mm film cameras surrounding the launch pad. One particular piece of debris caught the attention of engineers investigating the release of the flame trench fire bricks. The question to be answered was if the debris was a fire brick, and if it represented the first bricks that were ejected from the flame trench wall, or was the object one of the pieces of debris normally ejected from

the vehicle during launch. If it was typical launch debris, such as SRB throat plug foam, why was it traveling vertically and parallel to the vehicle during launch, instead of following its normal trajectory, flying horizontally toward the north perimeter fence?

By utilizing the Runge-Kutta integration method for velocity and the Verlet integration method for position, a method that suppresses trajectory computational instabilities due to noisy position data was obtained. This

combination of integration methods provides a means to extract the best estimate of drag force and drag coefficient under the non-ideal conditions of limited position data. This integration strategy leads immediately to the best possible estimate of object density, within the constraints of unknown particle shape. These types of calculations do not exist in readily available off-the-shelf simulation software, especially where photogrammetry data is needed as an input.

A robust numerical method of iteratively solving for the drag force and coefficient of drag of an unknown object has been developed and implemented in Mathematica in a form readily convertible to other codes. This algorithm is based on an innovative combination of

the Verlet and Runge-Kutta integration methods. The input data is object position data as a function of time, which might, for example, be based on a previous photogrammetry analysis. This new method is not limited to object location based on photogrammetry.

This work was done by Jason Long and Philip Metzger of Kennedy Space Center, and John Lane of ASRC Aerospace Corporation. Further information is contained in a TSP (see page 1). KSC-13251

➤ Adaptive Sampling of Spatiotemporal Phenomena With Optimization Criteria

NASA's Jet Propulsion Laboratory, Pasadena, California

This work was designed to find a way to optimally (or near optimally) sample spatiotemporal phenomena based on limited sensing capability, and to create a model that can be run to estimate uncertainties, as well as to estimate covariances. The goal was to maximize (or minimize) some function of the overall uncertainty.

The uncertainties and covariances were modeled presuming a parametric distribution, and then the model was used to

approximate the overall information gain, and consequently, the objective function from each potential sense. These candidate sensings were then cross-checked against operation costs and feasibility. Consequently, an operations plan was derived that combined both operational constraints/costs and sensing gain.

Probabilistic modeling was used to perform an approximate inversion of the model, which enabled calculation of

sensing gains, and subsequent combination with operational costs. This incorporation of operations models to assess cost and feasibility for specific classes of vehicles is unique.

This work was done by Steve A. Chien and David R. Thompson of Caltech, and Kian Hsiang Low of the National University of Singapore for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48664

➤ Building a 2.5D Digital Elevation Model From 2D Imagery

High-quality DEMs are generated from a collection of 2D images.

NASA's Jet Propulsion Laboratory, Pasadena, California

When projecting imagery into a georeferenced coordinate frame, one needs to have some model of the geographical region that is being projected to. This model can sometimes be a simple geometrical curve, such as an ellipse or even a plane. However, to obtain accurate projections, one needs to have a more sophisticated model that encodes the undulations in the terrain including things like mountains, valleys, and even manmade structures. The product that is often used for this purpose is a Digital Elevation Model (DEM).

The technology presented here generates a high-quality DEM from a collection of 2D images taken from multiple viewpoints, plus pose data for each of the images and a camera model for the sensor. The technology assumes that the images are all of the same region of the environment.

The pose data for each image is used as an initial estimate of the geometric relationship between the images, but the pose data is often noisy and not of sufficient quality to build a high-quality DEM. Therefore, the source imagery is passed through a feature-tracking algorithm and multi-plane-homography algorithm, which refine the geometric transforms between images. The images and their refined poses are then passed to a stereo algorithm, which generates dense 3D data for each image in the sequence. The 3D data from each image is then placed into a consistent coordinate frame and passed to a routine that divides the coordinate frame into a number of cells. The 3D points that fall into each cell are collected, and basic statistics are applied to determine the elevation of that cell. The result of this step is a DEM that is in an arbitrary coordinate frame. This DEM is

then filtered and smoothed in order to remove small artifacts.

The final step in the algorithm is to take the initial DEM and rotate and translate it to be in the world coordinate frame [such as UTM (Universal Transverse Mercator), MGRS (Military Grid Reference System), or geodetic] such that it can be saved in a standard DEM format and used for projection.

This work was done by Curtis W. Padgett, Adnan I. Ansar, Shane Brennan, Yang Cheng, Daniel S. Clouse, and Eduardo Almeida of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

The software used in this innovation is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. NPO-47571.



Eyes on the Earth 3D

Eyes on the Earth 3D software gives scientists, and the general public, a real-time, 3D interactive means of accurately viewing the real-time locations, speed, and values of recently collected data from several of NASA's Earth Observing Satellites using a standard Web browser (climate.nasa.gov/eyes). Anyone with Web access can use this software to see where the NASA fleet of these satellites is now, or where they will be up to a year in the future. The software also displays several Earth Science Data sets that have been collected on a daily basis. This application uses a third-party, 3D, real-time, interactive game engine called Unity 3D to visualize the satellites and is accessible from a Web browser.

This work was done by Anton I. Kulikov, Paul R. Dornila, Viet T. Nguyen, Randal K. Jackson, William M. Greene, Kevin J. Hussey, Christopher M. Garcia, and Christian A. Lopez of Caltech; Justin M. Moore and Andrea Boeck of Mooreboeck, Inc.; and Kevin Lane of Bohemian Grey for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47782.

Target Trailing With Safe Navigation for Maritime Autonomous Surface Vehicles

This software implements a motion-planning module for a maritime autonomous surface vehicle (ASV). The module trails a given target while also avoiding static and dynamic surface hazards. When surface hazards are other moving boats, the motion planner must apply International Regulations for Avoiding Collisions at Sea (COLREGS). A key subset of these rules has been implemented in the software. In case contact with the target is lost, the software can receive and follow a "reacquisition route," provided by a complementary system, until the target is reacquired. The programmatic intention is that the trailed target is a submarine, although any mobile naval platform could serve as the target.

The algorithmic approach to combining motion with a (possibly moving)

goal location, while avoiding local hazards, may be applicable to robotic rovers, automated landing systems, and autonomous airships. The software operates in JPL's CARACaS (Control Architecture for Robotic Agent Command and Sensing) software architecture and relies on other modules for environmental perception data and information on the predicted detectability of the target, as well as the low-level interface to the boat controls.

This work was done by Michael Wolf, Yoshiaki Kuwata, and Dimitri V. Zarzhitsky of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-48115, volume and number of this NASA Tech Briefs issue, and the page number.

Adams-Based Rover Terramechanics and Mobility Simulator — ARTEMIS

The Mars Exploration Rovers (MERs), Spirit and Opportunity, far exceeded their original drive distance expectations and have traveled, at the time of this reporting, a combined 29 kilometers across the surface of Mars. The Rover Sequencing and Visualization Program (RSVP), the current program used to plan drives for MERs, is only a kinematic simulator of rover movement. Therefore, rover response to various terrains and soil types cannot be modeled. Although sandbox experiments attempt to model rover-terrain interaction, these experiments are time-intensive and costly, and they cannot be used within the tactical timeline of rover driving. Imaging techniques and hazard avoidance features on MER help to prevent the rover from traveling over dangerous terrains, but mobility issues have shown that these methods are not always sufficient.

ARTEMIS, a dynamic modeling tool for MER, allows planned drives to be

simulated before commands are sent to the rover. The deformable soils component of this model allows rover-terrain interactions to be simulated to determine if a particular drive path would take the rover over terrain that would induce hazardous levels of slip or sink. When used in the rover drive planning process, dynamic modeling reduces the likelihood of future mobility issues because high-risk areas could be identified before drive commands are sent to the rover, and drives planned over these areas could be rerouted.

The ARTEMIS software consists of several components. These include a preprocessor, Digital Elevation Models (DEMs), Adams rover model, wheel and soil parameter files, MSC Adams GUI (commercial), MSC Adams dynamics solver (commercial), terramechanics subroutines (FORTRAN), a contact detection engine, a soil modification engine, and output DEMs of deformed soil. The preprocessor is used to define the terrain (from a DEM) and define the soil parameters for the terrain file. The Adams rover model is placed in this terrain. Wheel and soil parameter files can be altered in the respective text files. The rover model and terrain are viewed in Adams View, the GUI for ARTEMIS. The Adams dynamics solver calls terramechanics subroutines in FORTRAN containing the Bekker-Wong equations. These subroutines use contact and soil modification engines to produce the simulation of rover movement over deformable soils, viewed in Adams View.

New drive techniques could be tested in ARTEMIS to avoid wasting limited time and energy during real-time drives. Extrication techniques can also be developed using ARTEMIS without sandbox testing. These uses of dynamic modeling are not limited to Martian vehicles, and ARTEMIS would have similar benefits for lunar vehicles. ARTEMIS could potentially be modified to dynamically simulate the movement of any vehicle over deformable soil.

This work was done by Brian P. Trease and Randel A. Lindemann of Caltech; Raymond E. Arvidson, Keith Bennett, Lauren P. Van Dyke, and Feng Zhou of the Washington University at St. Louis; and Karl Iagnemma and Carmine Senatore of MIT for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47781.

ISTP CDF Skeleton Editor

Basic Common Data Format (CDF) tools (e.g., cdfedit) provide no specific support for creating International Solar-Terrestrial Physics/Space Physics Data Facility (ISTP/SPDF) standard files. While it is possible for someone who is familiar with the ISTP/SPDF metadata guidelines to create compliant files using just the basic tools, the process is error-prone and unreasonable for someone without ISTP/SPDF expertise. The key problem is the lack of a tool with specific support for creating files that comply with the ISTP/SPDF guidelines. There are basic CDF tools such as cdfedit and skeleton-cdf for creating CDF files, but these have no specific support for creating ISTP/SPDF compliant files.

The SPDF ISTP CDF skeleton editor is a cross-platform, Java-based GUI editor program that allows someone with only a basic understanding of the ISTP/SPDF guidelines to easily create compliant files. The editor is a simple graphical user interface (GUI) application for creating and editing ISTP/SPDF guideline-compliant skeleton CDF files. The SPDF ISTP CDF skeleton editor consists of the following components: A swing-based Java GUI program, JavaHelp-based manual/tutorial, Image/Icon files, and HTML Web page for distribution. The editor is available as a traditional Java desktop application as well as a Java Network Launching Protocol (JNLP) application. Once started, it functions like a typical Java GUI file editor application for creating/editing application-unique files.

The editor provides ease of use and support for ISTP/SPDF and project-specific standards. The editor provides support for creating/editing CDF files that comply with the ISTP/SPDF guidelines.

This work was done by Reine Chimiak and Bernard Harris of Goddard Space Flight Center, and Phillip Williams of QSS Group. Further information is contained in a TSP (see page 1). GSC-16256-1

Uplink Summary Generator (ULSGEN) Version 1.0

The Uplink Summary Generator (ULSGEN) provides a convenient means of gathering together a set of uplink related files, parsing and analyzing these

files, and producing a summary of their contents, which may then be electronically signed by one or more reviewers to verify the commands. Spacecraft operations personnel view this summary as a final sanity check before actual radiation of the uplink data.

Unique features of the software are a browser-based application that can be used both inside and outside the flight operations firewall, file retrieval from the project file server or from the project DOM (Distributed Object Manager), and the ability to parse and analyze spacecraft command files (SCMF). The software also features DSN keyword file (DKF) parsing for uplink windows, and enables hosting of one or more projects in a single server. Each project can define its own uplink summary template.

Each uplink summary is generated based on the analysis results from the parsers and the selected project template. The uplink summary review and signature collection cycle supports both parallel and sequential workflows. RadList file generation enables linkage to the command system.

This work was done by Yeou-Fang Wang, Mitchell Schrock, Timothy J. Reeve, Kristine T. Fong, and Benjamin D. Smith of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48423.

Robotics On-Board Trainer (ROBoT)

ROBoT is an on-orbit version of the ground-based Dynamics Skills Trainer (DST) that astronauts use for training on a frequent basis. This software consists of two primary software groups. The first series of components is responsible for displaying the graphical scenes. The remaining components are responsible for simulating the Mobile Servicing System (MSS), the Japanese Experiment Module Remote Manipulator System (JEM-RMS), and the H-II Transfer Vehicle (HTV) Free Flyer Robotics Operations. The MSS simulation software includes: Robotic Workstation (RWS) simulation, a simulation of the Space Station Remote Manipulator System (SSRMS), a simulation of the ISS Command and Control System (CCS), and a portion of the Portable Computer System (PCS) software necessary for MSS operations.

These components all run under the CentOS4.5 Linux operating system. The JEMRMS simulation software includes real-time, HIL, dynamics, manipulator multi-body dynamics, and a moving object contact model with Tricks discrete time scheduling. The JEMRMS DST will be used as a functional proficiency and skills trainer for flight crews. The HTV Free Flyer Robotics Operations simulation software adds a functional simulation of HTV vehicle controllers, sensors, and data to the MSS simulation software. These components are intended to support HTV ISS visiting vehicle analysis and training. The scene generation software will use DOUG (Dynamic On-orbit Ubiquitous Graphics) to render the graphical scenes. DOUG runs on a laptop running the CentOS4.5 Linux operating system. DOUG is an Open GL-based 3D computer graphics rendering package. It uses pre-built three-dimensional models of on-orbit ISS and space shuttle systems elements, and provides real-time views of various station and shuttle configurations.

This work was done by Genevieve Johnson of Johnson Space Center and Greg Alexander of Harmony Lane Studios, Inc. Further information is contained in a TSP (see page 1). MSC-25005-1

Software Engineering Tools for Scientific Models

Software tools were constructed to address issues the NASA Fortran development community faces, and they were tested on real models currently in use at NASA. These proof-of-concept tools address the High-End Computing Program and the Modeling, Analysis, and Prediction Program. Two examples are the NASA Goddard Earth Observing System Model, Version 5 (GEOS-5) atmospheric model in Cell Fortran on the Cell Broadband Engine, and the Goddard Institute for Space Studies (GISS) coupled atmosphere-ocean model called ModelE, written in fixed format Fortran.

To test the tool set, the innovators first extended an annotation and conversation mechanism, known as Activities, allowing developers to provide insights into code without modifying it to include the qualification of Activities with metadata for filtering. Next, the designers created a visualization to present the relationships, or connectivity, between model variables by tracing various constructs through different components and levels of a model.

Also, a type replacement facility was tested for updating primitive types such as integers that were not qualified with a size, and thus may change as the underlying architecture is upgraded. Finally, the designers leveraged a tool, called eclim, to bridge the gap between text editors and Integrated Development Environments (IDE), by running both of them simultaneously, and set up to communicate with each other. Through this mechanism, modern IDE features were made available through text editors, minimizing the learning curve for scientists already experienced with their conventions.

This work was done by Marc Abrams, Pal-labi Saboo, and Mike Sonsini of Harmonia Holdings Group, LLC for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16475-1

Automatic Data Filter Customization Using a Genetic Algorithm

This work predicts whether a retrieval algorithm will usefully determine CO₂ concentration from an input spectrum of GOSAT (Greenhouse Gases Observing Satellite). This was done to eliminate needless runtime on atmospheric soundings that would never yield useful results. A space of 50 dimensions was examined for predictive power on the final CO₂ results.

Retrieval algorithms are frequently expensive to run, and wasted effort defeats requirements and expends needless resources. This algorithm could be used to help predict and filter unneeded runs in any computationally expensive regime.

Traditional methods such as the Fisher discriminant analysis and decision trees can attempt to predict whether a sounding will be properly processed. However, this work sought to detect a subsection of the dimensional space that can be simply filtered out to eliminate unwanted runs. LDAs (linear discriminant analyses) and other systems examine the entire data and judge a “best fit,” giving equal weight to complex and problematic regions as well as simple, clear-cut regions. In this implementation, a genetic space of “left” and “right”

thresholds outside of which all data are rejected was defined. These left/right pairs are created for each of the 50 input dimensions. A genetic algorithm then runs through countless potential filter settings using a JPL computer cluster, optimizing the tossed-out data’s yield (proper vs. improper run removal) and number of points tossed.

This solution is robust to an arbitrary decision boundary within the data and avoids the global optimization problem of whole-dataset fitting using LDA or decision trees. It filters out runs that would not have produced useful CO₂ values to save needless computation. This would be an algorithmic preprocessing improvement to any computationally expensive system.

This work was done by Lukas Mandrake of Caltech for NASA’s Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47788.

Tracker Toolkit

This software can track multiple moving objects within a video stream simultaneously, use visual features to aid in the tracking, and initiate tracks based on object detection in a subregion. A simple programmatic interface allows plugging into larger image chain modeling suites. It extracts unique visual features for aid in tracking and later analysis, and includes sub-functionality for extracting visual features about an object identified within an image frame.

Tracker Toolkit utilizes a feature extraction algorithm to tag each object with metadata features about its size, shape, color, and movement. Its functionality is independent of the scale of objects within a scene. The only assumption made on the tracked objects is that they move. There are no constraints on size within the scene, shape, or type of movement. The Tracker Toolkit is also capable of following an arbitrary number of objects in the same scene, identifying and propagating the track of each object

from frame to frame. Target objects may be specified for tracking beforehand, or may be dynamically discovered within a tripwire region. Initialization of the Tracker Toolkit algorithm includes two steps: Initializing the data structures for tracked target objects, including targets preselected for tracking; and initializing the tripwire region. If no tripwire region is desired, this step is skipped. The tripwire region is an area within the frames that is always checked for new objects, and all new objects discovered within the region will be tracked until lost (by leaving the frame, stopping, or blending in to the background).

This work was done by Steven J. Lewis and David M. Palacios of Caltech for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48253.

Towards Efficient Scientific Data Management Using Cloud Storage

A software prototype allows users to backup and restore data to/from both public and private cloud storage such as Amazon’s S3 and NASA’s Nebula. Unlike other off-the-shelf tools, this software ensures user data security in the cloud (through encryption), and minimizes users’ operating costs by using space- and bandwidth-efficient compression and incremental backup. Parallel data processing utilities have also been developed by using massively scalable cloud computing in conjunction with cloud storage.

One of the innovations in this software is using modified open source components to work with a private cloud like NASA Nebula. Another innovation is porting the complex backup-to-cloud software to embedded Linux, running on the home networking devices, in order to benefit more users.

This work was done by Qiming He of Open Research for Goddard Space Flight Center. For further information, contact the Goddard Innovative Partnerships Office at (301) 286-5810. GSC-16415-1



2 On a Formal Tool for Reasoning About Flight Software Cost Analysis

A report focuses on the development of flight software (FSW) cost estimates for 16 Discovery-class missions at JPL. The techniques and procedures developed enabled streamlining of the FSW analysis process, and provided instantaneous confirmation that the data and processes used for these estimates were consistent across all missions. The research provides direction as to how to build a prototype rule-based system for FSW cost estimation that would provide (1) FSW cost estimates, (2) explanation of how the estimates were arrived at, (3) mapping of costs, (4) mathematical trend charts with explanations of why the trends are what they are, (5) tables with ancillary FSW data of interest to analysts, (6) a facility for expert modification/enhancement of the rules, and (7) a basis for conceptually convenient expansion into more complex, useful, and general rule-based systems.

This work was done by John N. Spagnuolo, Jr. and Sherry A. Stukes of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48487.

3 A Nanostructured Composites Thermal Switch Controls Internal and External Short Circuit in Lithium Ion Batteries

A document discusses a thin layer of composite material, made from nanoscale particles of nickel and Teflon, placed within a battery cell as a layer within the anode and/or the cathode. There it conducts electrons at room temperature, then switches to an insulator at an elevated temperature to prevent thermal runaway caused by internal short circuits.

The material layer controls excess currents from metal-to-metal or metal-to-carbon shorts that might result from cell crush or a manufacturing defect.

The use of recently available nanoscale particles of nickel and Teflon permits an improved, homogenous material with the potential to be fine-tuned to a unique switch temperature, sufficiently below the onset of a catastrophic chemical reaction. The smaller particles also permit the formation of a thinner control film layer (<40 μm), which can be incorporated into commercial high-rate lithium primary and secondary cells. This innovation increases safety for high-rate batteries, thus preventing injury to nearby personnel and equipment.

This work was done by Robert C. McDonald, Shelly L. Van Blarcom, and Katherine E. Kwasnik of Giner, Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to MSC-24398-1, volume and number of this NASA Tech Briefs issue, and the page number.

4 Spacecraft Crew Cabin Condensation Control

A report discusses a new technique to prevent condensation on the cabin walls of manned spacecraft exposed to the cold environment of space, as such condensation could lead to free water in the cabin. This could facilitate the growth of mold and bacteria, and could lead to oxidation and weakening of the cabin wall.

This condensation control technique employs a passive method that uses

spacecraft waste heat as the primary wall-heating mechanism. A network of heat pipes is bonded to the crew cabin pressure vessel, as well as the pipes to each other, in order to provide for efficient heat transfer to the cabin walls and from one heat pipe to another. When properly sized, the heat-pipe network can maintain the crew cabin walls at a nearly uniform temperature. It can also accept and distribute spacecraft waste heat to maintain the pressure vessel above dew point.

The warmest portion of the spacecraft active thermal control system (ATCS) is connected to the heat-pipe network to allow the spacecraft waste heat to warm the pressure vessel walls. A backup electrical heater is attached to the ATCS loop/heat pipe interface to allow for heating in the event that the ATCS has insufficient energy to maintain the pressure-vessel walls above the dew point. A bypass control system sends ATCS fluid to the ATCS/heat pipe interface when there is sufficient energy for this purpose, and bypasses the heat-pipe network when there is not. This allows the backup electric heaters to efficiently heat the pressure vessel (without having to heat the flowing ATCS fluid). It also allows the flow to the ATCS/heat pipe interface to be modulated, thereby controlling the cabin wall temperature. The ATCS/heat pipe interface conductance is designed so that the energy input per unit length along the interface is roughly uniform. This allows the heat pipes to remain within their operational range.

A limited number of backup heaters provide a secondary source of energy to heat the cabin walls. This technique decreases control complexity, parts count, and heater power requirements. It also does not use long, massive lengths of coolant loop tubing to carry energy to the spacecraft walls.

This work was done by Laurie Y. Carrillo, Steven L. Rickman, and Eugene K. Ungar of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24526-1



Functional Near-Infrared Spectroscopy Signals Measure Neuronal Activity in the Cortex

This non-invasive monitoring method can be used to evaluate the mental state of people performing critical tasks.

John H. Glenn Research Center, Cleveland, Ohio

Functional near infrared spectroscopy (fNIRS) is an emerging optical neuroimaging technology that indirectly measures neuronal activity in the cortex via neurovascular coupling. It quantifies hemoglobin concentration ([Hb]) and thus measures the same hemodynamic response as functional magnetic resonance imaging (fMRI), but is portable, non-confining, relatively inexpensive, and is appropriate for long-duration monitoring and use at the bedside. Like fMRI, it is noninvasive and safe for repeated measurements. Patterns of [Hb] changes are used to classify cognitive state. Thus, fNIRS technology offers much potential for application in operational contexts. For instance, the use of fNIRS to detect the mental state of commercial aircraft operators in near real time could allow intelligent flight decks of the future to optimally support human performance in the interest of safety by responding to hazardous mental states of the operator. However, many

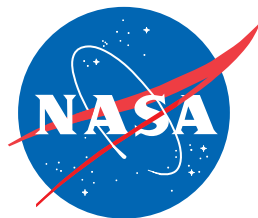
opportunities remain for improving robustness and reliability. It is desirable to reduce the impact of motion and poor optical coupling of probes to the skin. Such artifacts degrade signal quality and thus cognitive state classification accuracy. Field application calls for further development of algorithms and filters for the automation of bad channel detection and dynamic artifact removal.

This work introduces a novel adaptive filter method for automated real-time fNIRS signal quality detection and improvement. The output signal (after filtering) will have had contributions from motion and poor coupling reduced or removed, thus leaving a signal more indicative of changes due to hemodynamic brain activations of interest. Cognitive state classifications based on these signals reflect brain activity more reliably. The filter has been tested successfully with both synthetic and real human subject data, and requires no auxiliary measurement.

This method could be implemented as a real-time filtering option or bad channel rejection feature of software used with frequency domain fNIRS instruments for signal acquisition and processing. Use of this method could improve the reliability of any operational or real-world application of fNIRS in which motion is an inherent part of the functional task of interest. Other optical diagnostic techniques (e.g., for NIR medical diagnosis) also may benefit from the reduction of probe motion artifact during any use in which motion avoidance would be impractical or limit usability.

This work was done by Angela Harnivel and Tristan Hearn of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18952-1.



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